

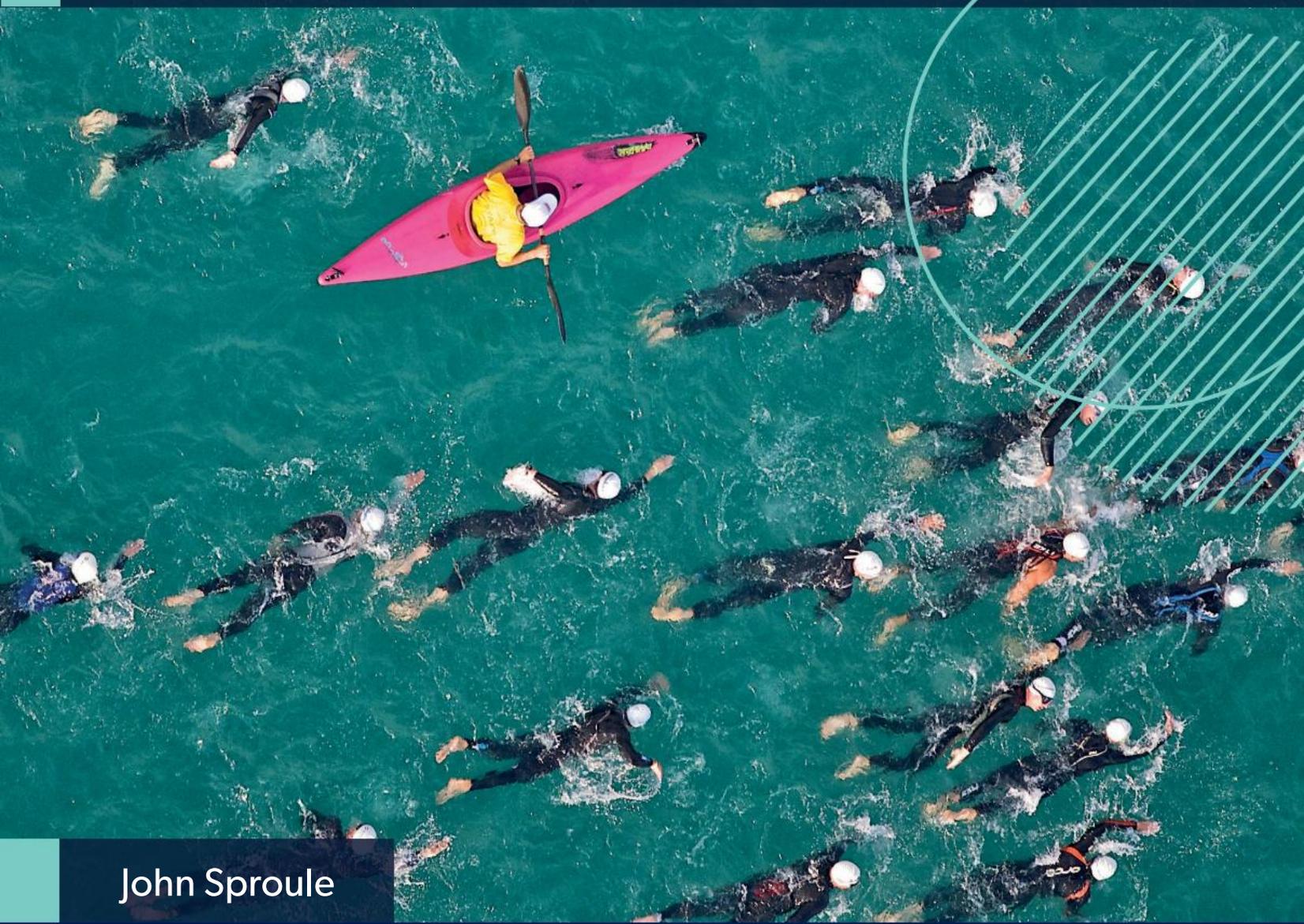
Oxford Resources for IB
Diploma Programme



2024 EDITION

SPORTS, EXERCISE AND HEALTH SCIENCE

COURSE COMPANION



John Sproule

OXFORD

Text permissions

Quote by Laurel Hubbard from *Kiwi transgender weightlifter Laurel Hubbard asks people to keep an open mind* by Marvin France, published by Stuff NZ, December 08, 2017. Reproduced by permission of Stuff NZ.

Extract from *The impact of global warming on health and mortality*; Southern medical journal, 01 Nov 2004, Vol. 97, Issue 11 by W R Keatinge, G C Donaldson, published by Southern Medical Association. Reproduced with permission of the publisher.

Extract from *Found in the Field - A Soldier With Heat Stroke, Exercise-Associated Hyponatremia, and Kidney Injury*; Current Sports Medicine Reports. 2018 Apr;17(4):123-125 by Robert C Oh, M Galer, MM. Burse; published by the American College of Sports Medicine. Reproduced with permission of Wolters Kluwer.

Extract from *IOC consensus statement: dietary supplements and the high-performance athlete*; British journal of sports medicine, 01 Apr 2018, Vol. 52, Issue 7, pages 439 - 455 by Ronald J Maughan, Louise M Burke, Jiri Dvorak, D Enette Larson-Meyer, Peter Peeling, Stuart M Phillips, Eric S Rawson, Neil P Walsh, Ina Garthe, Hans Geyer, Romain Meeusen, Lucas J C van Loon, Susan M Shirreffs, Lawrence L Spriet, Mark Stuart, Alan Vernec, Kevin Currell, Vidya M Ali, Richard GM Budgett, Arne Ljungqvist, Margo Mountjoy, Yannis P Pitsiladis, Torbjørn Soligard, Uğur Erdener, Lars Engebretsen, published by B M J Publishing Group. Reproduced with permission of the publisher.

Extract from *The anaerobic threshold: 50+ years of controversy*; The Journal of physiology, 01 Feb 2021, Vol. 599, Issue 3, pages 737 - 767 by David C. Poole, Harry B. Rossiter, George A. Brooks, Bruce L. Gladden, published by Blackwell Publishing Ltd. Reproduced with permission of John Wiley & Sons – Journals.

Extract from *Reduction of coronary atherosclerosis by moderate conditioning exercise in monkeys on an atherogenic diet*; The New England journal of medicine, 17 Dec 1981, Vol. 305, Issue 25, pages 1483 – 1489 by D M Kramsch, A J Aspen, B M Abramowitz, T Kreimendahl, W B Hood; published by Massachusetts Medical Society. Reproduced with permission of the publisher.

Extract from *Physiology: Interindividual Variation in Posture Allocation: Possible Role in Human Obesity*; Science, 01 Jan 2005, Issue 5709, pages 584 – 585 by JA Levine, published by American Association for the Advancement of Science. Reproduced with permission of the publisher.

Extract from *Racial/ethnic differences in bone mineral density among older women*; Journal of bone and mineral metabolism, 01 Mar 2013, Vol. 31, Issue 2, pages 190 – 198 by Nam Hae-Sung, Kweon Sun-Seog, Choi Jin-Su, Joseph M. Zmuda, P. C. Leung, Lui Li-Yung, Deanna D. Hill, Alan L Patrick, Jane A Cauley, published by Springer Japan. Reproduced with permission of the publisher.

Extract from *Changing perceptions of obesity—recollections of a paediatrician*; The Lancet, 27 Aug 2011, Vol. 378, Issue 9793, pages 762 – 763 by Louise A Baur, published by Lancet Publishing Group. Reproduced with permission of the publisher.

Extract from *Christian Eriksen: How tiny device led to his 'miracle' football return* by Jim Reed, published by BBC News. Reproduced with permission of BBC News at bbc.co.uk/news.

Extract from *Fatigue in Sport and Exercise* by Shaun Phillips, published by Routledge, 2015. Reproduced with permission of Taylor & Francis Group.

Extract from *IOC consensus statement on recommendations and regulations for sport events in the heat*; British journal of sports medicine, 01 Jan 2023, Vol. 57, Issue 1, pages 8 – 25 by Sebastien Racinais, Yuri Hosokawa, Takao Akama, Stephane Bermon, Xavier Bigard, Douglas J Casa, Andrew Grundstein, Ollie Jay, Andrew Massey, Sergio Migliorini, Margo Mountjoy, Nebosa Nikolic, Yannis P Pitsiladis, Wolfgang Schobersberger, Juergen Michael Steinacker, Fumihiro Yamasawa, David Anthony Zideman, Lars Engebretsen, Richard Budgett, published by B M J Publishing Group. Reproduced with permission of the publisher.

Extract from *Scaling the Equipment and Play Area in Children's Sport to improve Motor Skill Acquisition: A Systematic Review*; Sports Med. 2016 Jun;46(6):829-43 by Tim Buszard, Machar Reid, Rich Masters, and Damien Farrow, published by Springer. Reproduced under Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>).

Extract from *Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016*; British journal of sports medicine, 01 Jun 2017, Vol. 51, Issue 11, pages 838 – 847 by P McCrory, W Meeuwisse, J Dvorak, et al., published by B M J Publishing Group. Reproduced with permission of the publisher.

Extract from *Developing Mental Toughness: Lessons from Paralympians*; Frontiers in Psychology, 01 Jan 2017, Vol. 8, by Alexander J Powell and Tony D Myers, published by Frontiers Research Foundation. Reproduced with permission of the publisher.

Extract from *Are bad shots, blown leads at Australian Open 'choking'?* by Simon Cambers, Howard Fendrich, published by The Independent, 24 January 2023. Reproduced with permission of the publisher.

Extract from *The Role of Coping in the Emotions and How Coping Changes over the Life Course*; Handbook of emotion, adult development, and aging, 01 Jan 1996, Vol. 46 by Richard S. Lazarus, published by Elsevier Science & Technology Book. Reproduced with permission of the publisher.

Extract from *Routledge Companion to Sport and Exercise Psychology: Global Perspectives and Fundamental Concepts* by Joaquín Dosil, J. Gualberto Cremades, Santiago Rivera, published by Routledge, 2014. Reproduced with permission of Taylor & Francis Group.

Extract from *Foundations of Sport and Exercise Psychology* by Robert S. Weinberg, Daniel Gould, published by Human Kinetics. Reproduced with permission of the publisher.

Extract from *The what, why, and how of goal setting: A review of the goal-setting process in applied sport psychology practice*; Journal of applied sport psychology, 15 Mar 2023 by Matthew D. Bird, Christian Swann, Patricia C. Jackman, published by Taylor & Francis Ltd. Reproduced with permission of the publisher.

Extract from *The placebo effect in sports performance: a brief review*; Sports medicine, 01 Jan 2009, Vol. 39, Issue 4 by Christopher J Beedie, Abigail J Foad, published by ADIS Press. Reproduced with permission of the publisher.

Every effort has been made to contact copyright holders of material reproduced in this book. Any omissions will be rectified in subsequent printings if notice is given to the publisher. Links to third party websites are provided by Oxford in good faith and for information only. Oxford disclaims any responsibility for the materials contained in any third party website referenced in this work.

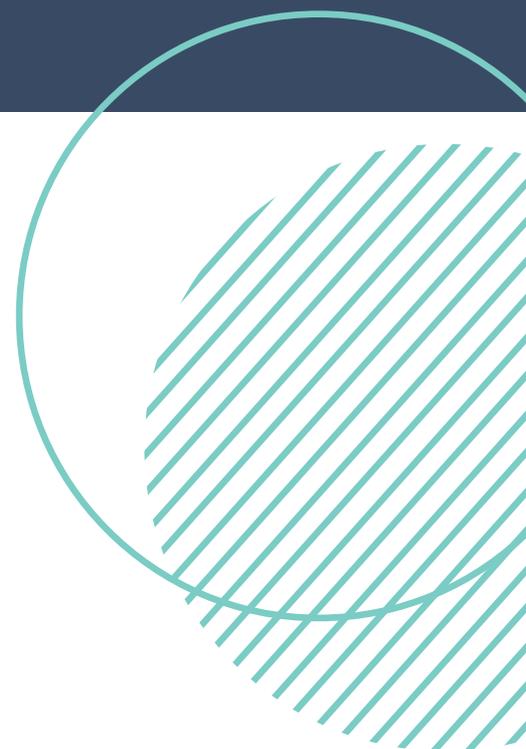
Oxford Resources for IB
Diploma Programme



2024 EDITION

SPORTS, EXERCISE AND HEALTH SCIENCE

COURSE COMPANION



John Sproule

OXFORD
UNIVERSITY PRESS

OXFORD

UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP, United Kingdom

Oxford University Press is a department of the University of Oxford. It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide. Oxford is a registered trade mark of Oxford University Press in the UK and in certain other countries.

© Oxford University Press 2024

The moral rights of the author have been asserted

First published in 2024

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior permission in writing of Oxford University Press, or as expressly permitted by law, by licence or under terms agreed with the appropriate reprographics rights organization. Enquiries concerning reproduction outside the scope of the above should be sent to the Rights Department, Oxford University Press, at the address above.

You must not circulate this work in any other form and you must impose this same condition on any acquirer

British Library Cataloguing in Publication Data
Data available

9781382042642

9781382042628 (ebook)

10 9 8 7 6 5 4 3 2 1

Paper used in the production of this book is a natural, recyclable product made from wood grown in sustainable forests. The manufacturing process conforms to the environmental regulations of the country of origin.

Printed in China by Shanghai Offset Printing Products Ltd

Acknowledgements

The "In cooperation with IB" logo signifies the content in this textbook has been reviewed by the IB to ensure it fully aligns with current IB curriculum and offers high-quality guidance and support for IB teaching and learning.

The publisher wishes to thank the International Baccalaureate Organization for permission to reproduce their intellectual property.

The publisher and authors would like to thank the following for permission to use photographs and other copyright material:

Cover: Martin Steinhilber / Moment / Getty Images; Photos: p2: David Epperson / Stockbyte / Getty Images; p9: zhukovvlad / Shutterstock; p10(t): Slawomir Kruz / Shutterstock; p10(b): MikeDotta / Shutterstock; p11: Diego Barbieri / Shutterstock; p13: A.Taoualit / Shutterstock; p19: PA Images / Alamy Stock Photo; p22(l): Goinky Production / Shutterstock; p22(r): apstockphoto / Shutterstock; p27: BearFotos / Shutterstock; p35: Bruno Ismael Silva Alves / Shutterstock; p36(ml): John Sproule; p36(mr): AP Photo / Rick Stevens / Alamy Stock Photo; p36(bl): BELGA News Agency / Alamy Stock Photo; p38(l): Ipatov / Shutterstock; p38(r): I. Noyan Yilmaz / Shutterstock; p42: Ivica Drusany / Shutterstock; p43(l): John van Hasselt - Corbis / Corbis Historical / Getty Images; p43(r): MCT / Contributor / Getty Images; p44: Dudarev Mikhail / Shutterstock; p45: Thomas Barwick / DigitalVision / Getty Images; p46: Gary Yeowell / Getty Images; p47(r): colaimages / Alamy Stock Photo; p47(l): Keystone Press / Alamy Stock Photo; p52(l): GRANGER - Historical Picture Archive / Alamy Stock Photo; p52(r): Associated Press / Alamy Stock Photo; p53: AP Photo / The Plain Dealer, John Kuntz / Alamy Stock Photo; p58: photocomedia1 / Shutterstock; p60(l): FPG / Retrofile RF / Getty Images; p60(r): wavebreakmedia / Shutterstock; p65(t): LightField Studios / Shutterstock; p65(b): I T A L O / Shutterstock; p70: Gumbariya / Shutterstock; p71(l): pics five / Shutterstock; p71(r): A3pfamily / Shutterstock; p75: Yannick Tylle / Getty Images; p78: SrdjanPav / E+ / Getty Images; p83(t): New Africa / Shutterstock; p83(m): energy1 / Shutterstock; p83(b): © Copyright ELITechGroup Inc.. All Rights Reserved; p84: David Ramos / Staff / Getty Images; p95(t): Isaieva Liudmyla / Shutterstock; p95(m): Liza888 / Shutterstock; p95(b): amenic181 / Getty Images; p97: ABCDstock / Shutterstock; p99: Edwin Remsburg / Alamy Stock Photo; p100: A7880S / Shutterstock; p104: National Health and Medical Research Council; p111: International Vegetarian Union; p118: Jule-Marigold / Shutterstock; p123: elenabsl / Shutterstock; p132(t): wavebreakmedia / Shutterstock; p134: Bochkarev Photography / Shutterstock; p136(t): Marco Iacobucci Epp / Shutterstock; p136(l): Radu Razvan / Shutterstock; p136(r): Ian MacNicol / Stringer / Getty Images Europe; p139: Associated Press Photo / The Canadian Press, Frank Gunn / Alamy Stock Photo; p143(l): hairu_nizam / Shutterstock; p143(r): hxyume / Getty Images; p143(b): leungchopan / Shutterstock; p144: Maxisport / Shutterstock; p148: Oscar Wong / Moment / Getty Images; p149(tl): Bob Daemrrich / Alamy Stock Photo; p149(tr): Yaksa Images / Shutterstock; p149(tr): Philip Date / Shutterstock; p149(bl): Istvan Csak / Shutterstock; p149(bm): Marvin Gentry / NCAA Photos / Getty Images; p149(br): Tim Clayton - Corbis / Getty Images; p151: Jacob Lund / Shutterstock; p158: Ryan McVay / Getty Images; p163: Federico Guerra Moran / Shutterstock; p164: Getty Images / Stringer; p178: Tomas Rodriguez / Getty Images; p189: OAK RIDGE NATIONAL LABORATORY / US DEPARTMENT OF ENERGY / SCIENCE PHOTO LIBRARY; p192: adike / Shutterstock; p194: John Sproule; p200(l): Jozef Polc / 500px / Getty Images; p200(r): Willowpix / Getty Images; p201: Pepermprom

/ Shutterstock; p202: Hero Images Inc / Getty Images; p206: Julia_Sadykova / Shutterstock; p211(l): The Good Brigade / Getty Images; p211(r): Lorado / Getty Images; p212(r): FG Trade / Getty Images; p219: ELIZABETH RUIZ / Stringer / Getty Images; p225: katyapulka / Shutterstock; p232: Robin Jones - AFC Bournemouth / Contributor / Getty Images; p233: Vladimir Vladimirov / Getty Images; p234: Deby Suchaeri / Getty Images; p237(l): Andrey_Popov / Shutterstock; p237(r): rock-the-stock / Shutterstock; p248: SrdjanPav / Getty Images; p252: Thomas Barwick / DigitalVision / Getty Images; p253: Anton Vierietin / Shutterstock; p264: Microgen / Shutterstock; p266: James A Boardman / Shutterstock; p269: John Sproule; p272(t): NASA; p272(b): ZUMA Press, Inc. / Alamy Stock Photo; p277: Master1305 / Shutterstock; p281: Science Photo Library - STEVE GSCHMEISSNER. / Getty Images; p287: WoodysPhotos / Shutterstock; p290: Ittitech / Shutterstock; p291: I T A L O / Shutterstock; p303: JoeSAPhotos / Shutterstock; p304: zsol_tuves / Shutterstock; p305: sirtravelalot / Shutterstock; p308: GibsonPictures / E+ / Getty Images; p315: GoodLifeStudio / Getty Images; p316(t): dwpphotos / Shutterstock; p316(b): Dean Drobot / Shutterstock; p317: Agris Krusts / Shutterstock; p318(b): Michele Morrone / Shutterstock; p318(t): JoeSAPhotos / Shutterstock; p320: vm / Getty Images; p323: Kyodo News Stills / Getty Images; p328: Emre Akkoyun / Shutterstock; p329(r): topimages / Shutterstock; p329(l): Wlad Go / Shutterstock; p330: Nattawit Khomsanit / Shutterstock; p334(l): Photo by TanMan / Getty Images; p334(r): Heide Benser / Getty Images; p337: Jamie Roach / Shutterstock; p344: Getty Images / Staff / Getty Images; p347(l): Aerovalo / 347(r): Aerovalo ; p349(t): Pier Marco Tacca / Stringer / Getty Images; p349(b): Action Plus Sports Images / Alamy Stock Photo; p350: Simon Balsom / Alamy Stock Photo; p353: FRANCK FIFE / Contributor / Getty Images; p354(t): Silverstone Sports Engineering Hub © 2022 - <https://silverstonesportshub.co.uk>; p354(b): Silverstone Sports Engineering Hub © 2022 - <https://silverstonesportshub.co.uk>; p359: astarot / Shutterstock; p362: Edwin Tan / Getty Images; p366: Mindful Media / E+ / Getty Images; p369(t): skynesher / E+ / Getty Images; p369(b): DeFodi Images / Contributor / Getty Images; p372: VisualCommunications / Getty Images; p373: Anna Om / Shutterstock; p374(t): Tyler Stableford / Getty Images; p374(m): Juan Algar / Getty Images; p374(bl): Nathan Blaney / Getty Images; p375(t): miljko / Getty Images; p375(b): Tobias Titz / Getty Images; p376(t): Monika Wisniewska / Shutterstock; p376(b): stockphotograph / Shutterstock; p378: Clive Brunskill / Staff / Getty Images; p379: Harry Murphy - Sportsfile / Contributor / Getty Images; p380: RAJAALISA / SCIENCE PHOTO LIBRARY / Getty Images; p386: PhotoStock10 / Shutterstock; p387: Boston Globe / Contributor / Getty Images; p388: miodrag ignjatovic / Getty Images; p389: Westend61 / Getty Images; p391(t): Thinkstock Images / Getty Images; p391(b): LAKRUWAN WANNIARACHCHI / Stringer / Getty Images; p398: Maki Nakamura / DigitalVision / Getty Images; p399: cristiano barni / Shutterstock; p400: MoMo Productions / Getty Images; p403(l): Hannah Bailey / Getty Images; p403(m): Westend61 / Getty Images; p403(mr): Nadia Mostrom / 500px; p403(r): Shoji Fujita / Getty Images; p411: Isogood_patrick / Shutterstock; p414(t): FG Trade Latin / Getty Images; p414(b): JEAN-PIERRE MULLER / Contributor / Getty Images; p421: LOIC VENANCE / Contributor / Getty Images; p422: David McNew / Stringer / Getty Images; p430: Neale Cousland / Shutterstock; p431: Todd Easterbrook / Ascent Xmedia; p437: ballyscanlon / Getty Images; p438: Evan Davies / Alamy Stock Photo; p444: vgajic / E+ / Getty Images; p446(t): Zadorozhnyi Viktor / Shutterstock; p446(m): Dmitry Kalinovsky / Shutterstock; p446(b): Igor Sirbu / Shutterstock; p460: Visage / Getty Images; p462(t): IvanRiver / Shutterstock; p462(b): ANGELA WEISS / Contributor / Getty Images; p463(tl): JoeSAPhotos / Shutterstock; p463(tr): bbernard / Shutterstock; p463(bl): muzsy / Shutterstock; p463(br): Dziurek / Shutterstock; p464(tl): Alberto Gardin / Shutterstock; p464(tr): Richard Paul Kane / Shutterstock; p464(b): Don Mason / Getty Images; p465(t): TORWAISTUDIO / Shutterstock; p465(b): Alexander Gunawan / Shutterstock; p467: Rapt.TV / Shutterstock; p468: The Washington Post / Getty Images; p471: Andrew Wilson / Alamy Stock Photo; p477: Shaun Botterill / Staff / Getty Images; p478(t): Joe Murphy / Getty Images; p478(b): VicVic Liu / Shutterstock; p479: roibu / Shutterstock; p480: PAUL ELLIS / Contributor / Getty Images; p481: KAZUHIRO NOGI / Staff / Getty Images; p482(tl): Eurasia Sport Images / Contributor / Getty Images; p482(bl): Power Sport Images / Contributor / Getty Images; p482(tr): Anadolu Agency / Contributor / Getty Images; p482(br): Tim Clayton - Corbis / Contributor / Getty Images; p483: SolStock / Getty Images; p484: John Sproule; p486: Associated Press / Alamy Stock Photo; p487: anton5146 / Getty Images; p492: 10'000 Hours / DigitalVision / Getty Images; p494(tl): Take A Pix Media / Shutterstock; p494(tr): Ground Picture / Shutterstock; p494(bl): John Sproule; p495: John Sproule; p500: Lighthouse Films / Getty Images; p501: Douglas Sacha / Getty Images; p504: ProfessionalStudiomages / Getty Images; p507(l): Comstock / Getty Images; p507(r): Maskot / Getty Images; p511(l): Thomas Barwick / Getty Images; p511(r): John Giustina / Getty Images; p516: Anchly / Getty Images; p520(l): PeopleImages.com - Yuri A / Shutterstock; p520(r): BigPixel Photo / Shutterstock; p524: Elena Popova / Moment / Getty Images; p543: Vitalii Nesterchuk / Shutterstock; p548: LordHenriVoton / Getty Images; p559: Hiramam / Getty Images; p564: Steve Baccon / Getty Images; p565: STEVE PARSONS / Contributor / Getty Images; p572: Clerkenwell / DigitalVision / Getty Images; p583: kali9 / Getty Images; p584: Rena Schild / Shutterstock; p586: Kmatia / Getty Images; p590: vm / Getty Images; p591(tl): Salty View / Shutterstock; p591(tr): Mike Schirf / Getty Images; p591(bl): John Dowland / Getty Images; p591(br): A.RICARDO / Shutterstock; p593: Rudolf Vlcek / Getty Images; p594: Jack Guez / Staff / AFP / Getty Images; p598: beeboys / Shutterstock; p613(tl): Mariam88 / Shutterstock; p613(tm): Jacob Lund / Shutterstock; p613(tr): Victor Velter / Shutterstock; p613(bl): imagedb.com / Shutterstock; p613(br): luri Osadchi / Shutterstock.

Artwork by Aptara Inc., Q2A Media, Steve Evans, Peters & Zabransky, and Angela Knowles.

Contents

Exercise physiology and nutrition of the human body

A.1 Communication	2	Tony Turner, Olivia Murray, Laura Sproule & John Sproule
A.1.1 Inter-system communication	3	
A.1.2 Maintaining homeostasis	22	
A.1.3 Transport	58	
A.2 Hydration and nutrition	78	Dave Saunders, Jody Phillips, Dan Tao, Julien Baker & John Sproule
A.2.1 Water and electrolyte balance	79	
A.2.2 Fuelling for health and performance	92	
A.2.3 Energy systems	126	
A.3 Response	148	Shaun Phillips, Sean Sproule, David Stensel & John Sproule
A.3.1 Qualities of training	149	
A.3.2 Benefits to health of being active	176	
A.3.3 Fatigue and recovery	206	

Biomechanics

B.1 Generating movement in the body	252	Georgios Machtsiras, Olivia Murray & John Sproule
B.1.1 Anatomical position, planes and movement	253	
B.1.2 Structure and function of connective tissues and joints	269	
B.1.3 Muscular function	281	
B.1.4 Levers in movement and sport	300	
B.2 Forces, motion and movement	308	Georgios Machtsiras, Murray Craig & John Sproule
B.2.1 Newton's laws of motion	309	
B.2.2 Fluid mechanics	334	
B.2.3 Movement analysis and its applications	359	
B.3 Injury	366	Mark Sanderson, Linda Linton & John Sproule
B.3.1 Causes of injury	367	
B.3.2 Interventions related to injury	386	

Sports psychology and motor learning

C.1 Individual differences	398	Alan MacPherson, Amanda Martindale, Anne MacDonald & John Sproule
C.1.1 Personality	399	
C.1.2 Mental toughness	421	
C.2 Motor learning	444	Howie Carson, Ray Bobrownicki, Terry McMorris, Shirley Gray, Russell Martindale & John Sproule
C.2.1 Motor learning processes	445	
C.2.2 Attentional control	476	
C.3 Motivation	492	Neil Buchanan, Kevin Morgan, John Wang & John Sproule
C.3.1 Achievement motivation	493	
C.3.2 Self-determination	504	
C.3.3 Motivational climate	516	
C.4 Stress and coping	524	Hugh Richards & John Sproule
C.4.1 Arousal and anxiety	525	
C.4.2 Coping	548	
C.5 Psychological skills	572	Amanda Martindale, Russell Martindale & John Sproule
C.5.1 Goal setting	573	
C.5.2 Imagery	590	
Mathematical tools	598	Terry McMorris, Tony Turner & John Sproule
Inquiry process	605	Trevor Hayes, Pat Lacasse & John Sproule
Internal assessment (IA) and practical work	620	
Preparing for your exams	628	
Glossary	639	
Index	644	

Answers: www.oxfordsecondary.com/ib-sport-support

Introduction

The aim of the International Baccalaureate Sports, exercise and health science (SEHS) syllabus is to integrate concepts, topic content and the nature of science (NOS), through inquiry. The course is divided into three themes, each explored through the dual lenses of health and performance, with the syllabus content organized into topics and subtopics. Students and teachers are encouraged to personalize their approach to the syllabus according to their circumstances and interests.

Nature of science

The effective pursuit of modern scientific work and its theories depends on the nature of science. Scientists act as observers, looking for patterns and trends. Patterns lead to a possible explanation, formulated as a hypothesis, which may be tested through experiments. Measurements can be qualitative or quantitative, but it is always important to know the limitations of data. Sometimes the observations in experiments are unexpected and lead to serendipitous results or new models. Scientists learn to be sceptical and require claims to be tested and theories to be supported by evidence. Peer review is an essential tool to verify the research methods of knowledge claims. The global scientific community is responsible to society for the consequences of its work and must communicate findings to the public honestly and clearly.

From the author

Writing this course companion would not have been possible without a team approach. I gratefully acknowledge my dedicated and talented co-authors and colleagues at the University of Edinburgh who gave graciously of their time for one purpose: to try to provide an excellent resource to our next generation of IB DP SEHS students. I would like to thank the staff at Oxford University Press, and a special thanks to Alice for her patience and insightful feedback. Also, I am extremely grateful to the expert reviewers who offered insightful suggestions for improvement. They have contributed generously and with enormous goodwill in supporting my enthusiasm and interest in the education of IB students globally.

Historically, the value of SEHS in schools has received less recognition than other curricular areas. Fortunately, this has changed and, backed by research, SEHS now has the same recognition as other subjects. SEHS is situated in meaningful contexts for teaching and learning to address the needs and challenges of young people today. The study of SEHS has traditionally been approached from a mono-disciplinary point of view, but improving performance for those who participate in sports, exercise and health-related activity is complex. This can comprise many interacting variables, such as physiological fitness, psychological preparedness, functional anatomy and physical development, and perceptual-cognitive-motor skill. This is one reason why shifting SEHS to an interdisciplinary approach that involves the integration and application of knowledge from different sub-disciplines within SEHS is of great importance pedagogically, and for the study of SEHS to be relevant in the lives of IB DP students. An interdisciplinary study of SEHS will enable students to achieve a range of knowledge, skills, and competencies that is much broader than that afforded by approaches centred only on physical performance and sports.

I dedicate this book to those who have had the greatest impact in my life: my parents, my wife Bee Leng (Maggie), and our two children of whom we are immensely proud: Sean (a doctor specialising in anaesthetics) and Laura-Beth (a Geography teacher at Gordonstoun School). Their patience and support are sincerely appreciated. Hopefully, we continue to take forward Alec Peterson's vision for the IBO. A message to our IB DP SEHS students:

The greatest glory in living lies not in never falling, but in rising every time we fall.

Nelson Mandela

This book, like any course book, isn't perfect, and I would be most grateful to have feedback (good or bad) from the people who matter most: you.

John Sproule, Professor of Physical Education, University of Edinburgh.

Course book definition

The IB Diploma Programme course books are resource materials designed to support students throughout their two-year Diploma Programme course of study in a particular subject. They will help students gain an understanding of what is expected from the study of an IB Diploma Programme subject while presenting content in a way that illustrates the purpose and aims of the IB. They reflect the philosophy and approach of the IB and encourage a deep understanding of each subject by making connections to wider issues and providing opportunities for critical thinking.

The books mirror the IB philosophy of viewing the curriculum in terms of a whole-course approach; the use of a wide range of resources, international mindedness, the IB learner profile and the IB Diploma Programme core requirements, theory of knowledge, the extended essay, and creativity, activity, service (CAS).

Each book can be used in conjunction with other materials and, indeed, students of the IB are required and encouraged to draw conclusions from a variety of resources. Suggestions for additional and further reading are given in each book and suggestions for how to extend research are provided.

In addition, the course companions provide advice and guidance on the specific course assessment requirements and on academic honesty protocol. They are distinctive and authoritative without being prescriptive.

IB mission statement

The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end, the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

The IB learner profile

The aim of all IB programmes is to develop internationally minded people who work to create a better and more peaceful world. The aim of the programme is to develop this person through ten learner attributes, as described below.

Inquirers: They develop their natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They actively enjoy learning and this love of learning will be sustained throughout their lives.

Knowledgeable: They explore concepts, ideas and issues that have local and global significance. In so doing, they acquire in-depth knowledge and develop understanding across a broad and balanced range of disciplines.

Thinkers: They exercise initiative in applying thinking skills critically and creatively to recognize and approach complex problems, and to make reasoned, ethical decisions.

Communicators: They understand and express ideas and information confidently and creatively in more than one language and in a variety of modes of communication. They work effectively and willingly in collaboration with others.

Principled: They act with integrity and honesty, with a strong sense of fairness, justice and respect for the dignity of the individual, groups and communities. They take responsibility for their own actions and the consequences that accompany them.

Open-minded: They understand and appreciate their own cultures and personal histories, and are open to the perspectives, values and traditions of other individuals and communities. They are accustomed to seeking and evaluating a range of points of view, and are willing to grow from the experience.

Caring: They show empathy, compassion and respect towards the needs and feelings of others. They have a personal commitment to service, and to act to make a positive difference to the lives of others and to the environment.

Risk-takers: They approach unfamiliar situations and uncertainty with courage and forethought, and have the

independence of spirit to explore new roles, ideas and strategies. They are brave and articulate in defending their beliefs.

Balanced: They understand the importance of intellectual, physical and emotional balance to achieve personal well-being for themselves and others.

Reflective: They give thoughtful consideration to their own learning and experience. They are able to assess and understand their strengths and limitations in order to support their learning and personal development.

A note on academic integrity

It is of vital importance to acknowledge and appropriately credit the owners of information when that information is used in your work. After all, owners of ideas (intellectual property) have property rights.

For a piece of work to be authentic, it must be based on your individual and original ideas with the work of others fully acknowledged. Therefore, all assignments, written or oral, completed for assessment must use your own language and expression. Where sources are used or referred to, whether in the form of direct quotation or paraphrase, such sources must be appropriately acknowledged.

How do I acknowledge the work of others?

The way that you acknowledge that you have used the ideas of other people is through the use of footnotes and bibliographies.

Footnotes (placed at the bottom of a page) or endnotes (placed at the end of a document) are to be provided when you quote or paraphrase from another document or closely summarize the information provided in another document. You do not need to provide a footnote for information that is part of a 'body of knowledge'. That is, definitions do not need to be footnoted as they are part of the assumed knowledge.

Bibliographies should include a formal list of the resources that you used in your work. 'Formal' means that you should use one of the several accepted forms of presentation. This usually involves separating the resources that you use into different categories (e.g. books, magazines, newspaper articles, internet-

based resources, CDs and works of art) and providing full information as to how a reader or viewer of your work can find the same information. A bibliography is compulsory in the Extended Essay.

What constitutes malpractice?

Malpractice is behaviour that results in, or may result in, you or any student gaining an unfair advantage in one or more assessment components. Malpractice includes plagiarism and collusion.

Plagiarism is defined as the representation of the ideas or work of another person as your own. The following are some of the ways to avoid plagiarism:

- words and ideas of another person to support one's arguments must be acknowledged
- passages that are quoted verbatim must be enclosed within quotation marks and acknowledged
- email messages, websites on the internet and any other electronic media must be treated in the same way as books and journals
- the sources of all photographs, maps, illustrations, computer programs, data, graphs, audio-visual and similar material must be acknowledged if they are not your own work
- when referring to works of art, whether music, film, dance, theatre arts or visual arts and where the creative use of a part of a work takes place, the original artist must be acknowledged.

Collusion is defined as supporting malpractice by another student. This includes:

- allowing your work to be copied or submitted for assessment by another student
- duplicating work for different assessment components and/or diploma requirements.

Other forms of malpractice include any action that gives you an unfair advantage or affects the results of another student. Examples include taking unauthorized material into an examination room, misconduct during an examination and falsifying a CAS record.



Take learning online with Kerboodle

What is Kerboodle?

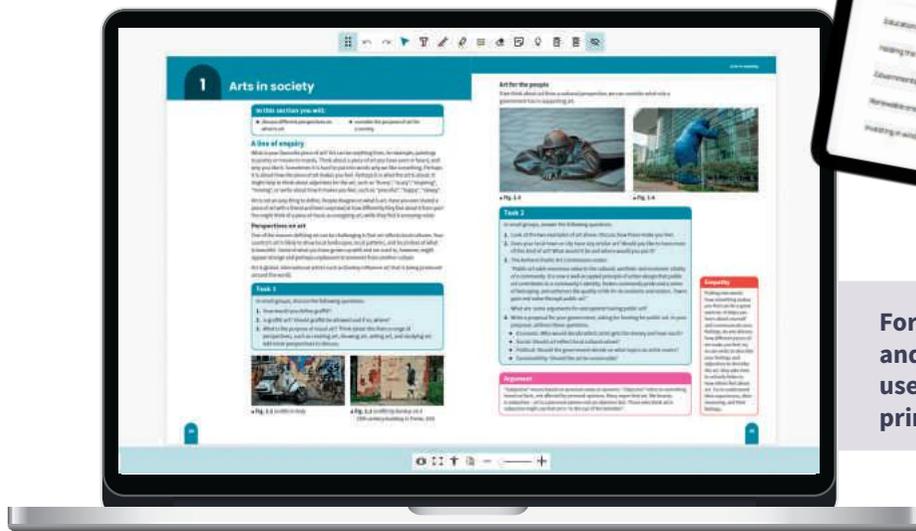
Kerboodle is a digital learning platform that works alongside your print textbooks to create a supportive learning environment. Available for UK and international curricula, Kerboodle helps you save time and reinforces student learning with a range of supportive resources.

Find out more and sign up for a free trial!



Use Kerboodle to:

- Enable learning anywhere with online and offline access to digital books
- Enhance student engagement with activities and auto-marked quizzes
- Boost performance and exam confidence with assessment materials
- Support independent learning with easy access across devices
- Deliver responsive teaching underpinned by in-depth reports
- Save time with tools to help you plan, teach, and monitor student progress
- Improve the classroom experience by highlighting specific content
- Get fast access with single sign-on via school Microsoft or Google accounts



For the best teaching and learning experience use Kerboodle with your print resources!

For more information, visit:

www.oxfordsecondary.com/kerboodle

Need help?

Contact your local Educational Consultant: www.oxfordsecondary.com/contact-us

How to use this book

The aim of this book is to develop conceptual understanding, aid in skills development, provide opportunities to reflect upon your learning and cement knowledge and understanding through practice.

Feature boxes and sections throughout the book are designed to support these aims, by signposting content relating to particular ideas and concepts, as well as opportunities for practice. This is an overview of these features:

Developing conceptual understanding

Guiding questions

At the start of every topic, a guiding question gives a sense of what is covered in the topic and acts as a prompt for inquiry.



Linking questions

Within each chapter, you will find examples of linking questions followed by prompts for consideration. The linking questions help you view the course content through a different lens.



Nature of Science

These illustrate NOS using issues from both modern science and science history, and show how the ways of doing science have evolved over the centuries. There is a detailed description of what is meant by NOS and the different aspects of NOS on page iv of this book and in the subject course guide.

TOK

This is an important part of the IB Diploma course. It focuses on critical thinking and understanding how we arrive at our knowledge of the world. The TOK features in this book pose questions for you that highlight these issues.

AHL

Content marked as additional higher level is required for HL students only.

Developing skills

Approaches to learning

The approaches to learning (ATL) framework seeks to promote skills that will support your learning processes in a way that is useful to all of your IB subjects and in your academic career following your study of the IB. The framework consists of five general skill categories: thinking skills, communication skills, social skills, research skills and self-management skills. Throughout the text, there are examples of how the SEHS course can support ATL skill development.

Reflecting

Summary

Summary sections provide a recap of the key learning at the end of each chapter.

Check your understanding

Use this feature to reflect upon the understanding you have developed throughout the chapter.

Practising

Activity

Throughout each chapter, activities provide opportunities to apply your learning and deepen your understanding.

Self-study questions

At the end of each chapter, these questions allow you to check your understanding and reflect upon your learning.

Data-based questions

Data-based questions have been included at the end of each chapter. These allow you to practise the skills of data presentation, processing and analysis.

Practice questions

Use these questions to practise answering exam-style questions. Many of these are past SEHS exam questions.

A.1

Communication

How does the body send and receive information about its internal environment to maintain optimal functioning conditions?

The endocrine and nervous systems work together to control all of the physiological processes that support exercise. This topic begins with a focus on how the nervous system controls and generates movement, before progressing to consider the endocrine system, which helps to control the body's activities by releasing hormones. Homeostasis is the interplay of the body's regulatory processes to maintain equilibrium in the body's internal environment, for example, during exercise or when adapting to stressful environments (such as heat, humidity, cold or altitude). The topic concludes with the cardiovascular and respiratory systems and their important functions in the body, such as the transport of oxygen to and the removal of carbon dioxide from all tissues of the body.

A.1.1 Inter-system communication

Syllabus understandings

A.1.1.1 The nervous system senses both internal and external conditions to coordinate the responses of the body's physiological systems effectively.

A.1.1.2 The endocrine system, made up of the body's glands and hormones, regulates all biological processes in the body.

Introduction

The **nervous system** is a complex, highly organized network of billions of neurons. It influences all functions within the human body in some way. The nervous system carries out a range of tasks, such as producing speech, regulating internal organs and providing signals that control body movements. Nerves are the wiring through which electrical impulses are sent to—and received from—tissues of the body.

The brain acts as a central computer. It integrates incoming information, selects an appropriate response, and signals for organs and tissues to take action.

Activities of the nervous system can be grouped into three basic functions.

- **Sensory function**—detecting internal stimuli, such as an increase in blood acidity.
- **Integrative function**—analysing (and storing some) sensory information and making decisions for responses.
- **Motor function**—responding to integration decisions; in other words, motor (or efferent) neurons carry information from the brain towards the spinal cord (or from the brain and spinal cord to, for example, muscle fibres).

The nervous system allows communication, coordination and interaction of the tissues and systems in the body, as well as between the body and the external environment.

During exercise and exposure to extreme environments, the body must make physiological adjustments. For example, cardiovascular and respiratory function adjust to match the demands placed on body systems as the body transitions from resting to an active state. For example, the rate of metabolism increases to provide energy during exercise.

Although the nervous and endocrine systems act together to coordinate functions of all body systems, their means of control are different. The nervous system acts through nerve impulses to control body activities, whereas the endocrine system controls body activities by releasing hormones. A hormone (ancient Greek *hormon* = to excite or get moving) is a molecule that is released in one part of the body but regulates the activity of cells in other parts of the body. The circulating blood delivers hormones to cells throughout the body. Responses of the endocrine system are often slower than responses of the nervous system—some hormones act within seconds, but most take several minutes to cause a response. The endocrine and nervous systems work together to control all

physiological processes that support exercise. The effects achieved by activating the nervous system are generally quicker but briefer (that is, short-lived, local effects), whereas the endocrine system responds more slowly but has broader, longer-lasting effects.

Structure and functions of the nervous system

The nervous system:

- influences all functions in the human body
- senses internal and external conditions
- allows communication, coordination and interaction:
 - of tissues within the body (such as muscle and tendon tissue to move limbs)
 - of systems within the body (such as cardiovascular and respiratory systems to supply the muscle tissue with oxygen)
 - between the body and the external environment
- is divided into two main divisions:
 - the **central nervous system (CNS)**
 - the **peripheral nervous system (PNS)**.

The CNS

The CNS consists of the brain and the spinal cord.

The brain acts as a central computer for both conscious and unconscious nervous activity. It is responsible for processing and interpreting sensory information, initiating and coordinating movements, and regulating the body's physiological functions.

The spinal cord enables information to travel between the brain and the rest of the body.

The CNS is key in maintaining a relatively stable and constant internal environment through the processes of homeostasis by responding to changes in the environment and regulating body functions, such as respiration and heart rate.

You will study homeostasis in more detail in chapter A.1.2.

The PNS

The PNS consists of all the nerves outside of the CNS.

It is divided into **sensory** (or **afferent**) **nerves** and **motor** (or **efferent**) **nerves**.

Sensory nerves inform the CNS about what is going on within the body and outside the body (for example, "it is hot"). In response to signals coming in from the sensory division, motor nerves send information from the CNS to tissues, organs and systems of the body.

The motor nerves of the PNS are further divided into:

- the **somatic nervous system**, which controls voluntary movements of the skeletal muscles
- the **autonomic nervous system**, which regulates involuntary bodily functions, such as heart rate, digestion and breathing.

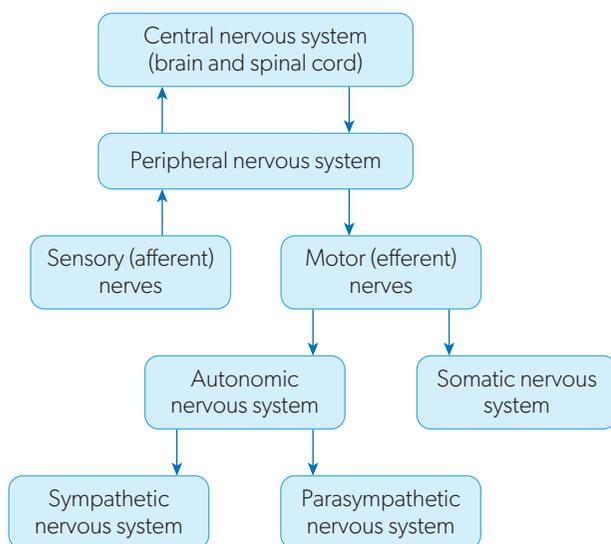
The autonomic nervous system is further divided into:

- the **sympathetic nervous system**, which activates the “fight-or-flight” response
- the **parasympathetic nervous system**, which has a major role in carrying out processes such as digestion, urination, glandular secretion and conservation of energy—it is the body’s “housekeeping system”.

Two examples of the effects of sympathetic stimulation are:

- peripheral vasodilation of blood vessels to increase blood flow to active skeletal muscles during exercise
- vasoconstriction in most other tissues (such as liver and kidneys) to divert blood to the active muscles, where it is needed most.

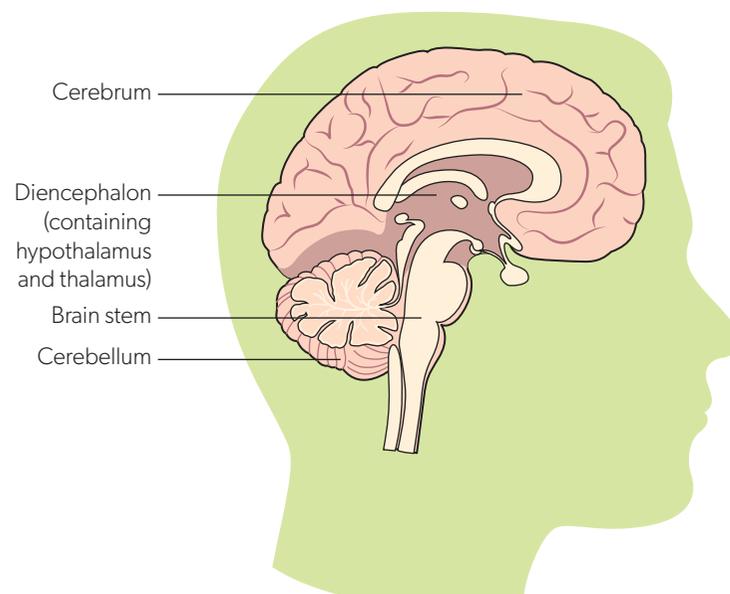
The organization of the nervous system is shown in Figure 1.



▲ Figure 1 The organization of the nervous system

The brain and the spinal cord

The brain consists of four major parts: the **brain stem**, **cerebellum**, **cerebrum** and **diencephalon** (Figure 2).



◀ Figure 2 The four main regions of the brain: brain stem, cerebellum, cerebrum and diencephalon

Key terms

Vasodilation The widening of blood vessels (caused by relaxation of the smooth muscle in the wall of the blood vessel).

Vasoconstriction The narrowing of blood vessels (caused by contraction of the smooth muscle in the wall of the blood vessel).

The brain stem connects the brain and the spinal cord. Nerve messages (sensory and motor) pass through the brain stem and relay information in both directions between the brain and the spinal cord.

The cerebellum governs balance and coordinates skilled movements.

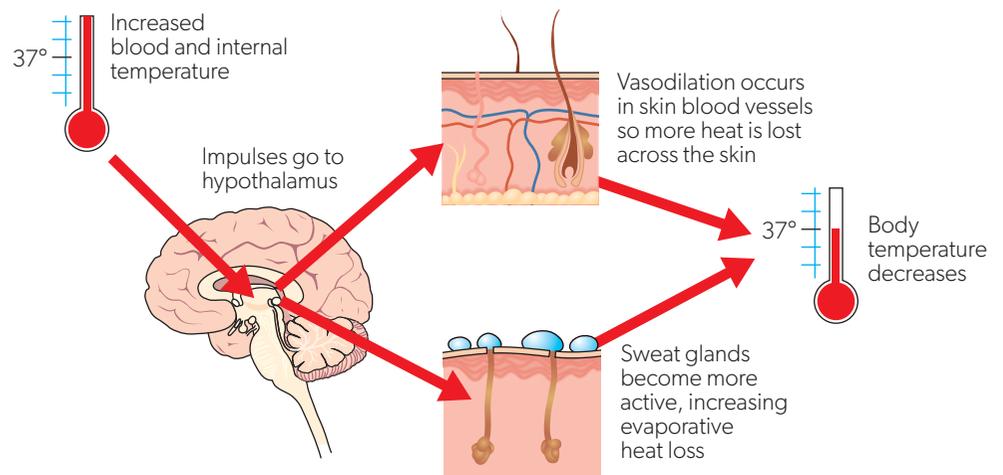
The cerebrum is composed of two connected hemispheres that communicate with each other. The cerebral cortex is the outermost layer of the cerebrum (about 2–4 mm thick). The cerebral cortex is the conscious brain, allowing athletes to think, be aware of sensory stimuli and voluntarily control their movements.

The diencephalon contains the **thalamus** (very important for motor control) and the **hypothalamus** (control centre for homeostasis).

The hypothalamus is responsible for maintaining homeostasis. This is done by regulating processes that affect the body's internal environment, including:

- blood pressure
- heart rate and stroke volume
- respiration
- digestion, thirst and fluid balance
- appetite control and food intake
- sleep-wake cycles
- body temperature.

Figure 3 shows the role of the hypothalamus in controlling body temperature.



▲ Figure 3 The role of the hypothalamus in controlling body temperature

The autonomic nervous system

The autonomic nervous system consists of the sympathetic and parasympathetic nervous systems. It controls the body's involuntary internal functions. Functions key to sport, exercise and physical activity include heart rate, blood pressure, blood distribution and lung function.

Sympathetic nervous system

Stimulation of the sympathetic nervous system with its “fight-or-flight” response is important during sport and exercise. Some of the effects of sympathetic nervous system stimulation are shown in Table 1.

▼ **Table 1** Some of the effects of sympathetic nervous system stimulation and their importance during sport and exercise

Target	Effect of sympathetic stimulation	Importance during sport and exercise
heart	↑ increased heart rate and strength of contraction	↑ increased cardiac output
	↑ dilation of coronary blood vessels	↑ increased blood supply to the heart muscle
blood vessels	↑ dilation of peripheral blood vessels	↑ increased blood flow to active skeletal muscles
	↑ vasoconstriction in tissue not essential for activity	↑ increased blood flow to active muscle ↓ reduced blood flow to, for example, kidneys
circulatory system	↑ increased blood pressure	↑ increased blood flow through muscle capillaries ↑ increased flow of venous blood returning to the heart
lungs	↑ dilation of bronchi and bronchioles in lungs	↑ increased ventilation ↑ increased exchange of O ₂ and CO ₂ gas
metabolism	↑ increased metabolic rate	↑ increased ability to meet demands of physical activity
brain	↑ increased mental activity	↑ increased concentration on performance
liver	↑ increased glucose from liver to blood	↑ increased availability of energy source
skin	↑ increased sweat gland activity	↑ sweating helps thermoregulation

Parasympathetic nervous system

The parasympathetic nervous system is responsible for regulating the body's involuntary functions. This plays an important role in processes such as digestion, urination and glandular secretion. It contributes to maintaining homeostasis by promoting rest, relaxation and the conservation of energy. Some of the effects of the parasympathetic nervous system are shown in Table 2.

▼ **Table 2** Some effects of the parasympathetic nervous system on various body targets

Target	Parasympathetic effects	Importance during rest and conservation of energy
heart	↓ decreased rate of contraction of heart muscle	↓ decreased heart rate
	↑ increased vasoconstriction of coronary blood vessels	↓ decreased blood pressure
lungs	↑ constriction of bronchi and bronchioles in lungs	↓ decreased ventilation
digestive system	↑ peristalsis ↑ glandular secretion relaxes sphincters	↑ increased digestion and absorption of nutrients
pupils	↑ increased constriction of pupils	↓ decreased light entering eye
bladder	↑ contraction of bladder	↑ urine removed from the body

The role of the nervous system in controlling heart rate

The heart is the main pump for circulating blood through the cardiovascular system. The heart has two atria that act as receiving chambers, and two pumping chambers (the right and left ventricles). The right atrium contracts and blood flows to the right ventricle. The right ventricle contracts and pumps the blood into the lungs for reoxygenation. After the blood is oxygenated in the lungs, the blood flows to the left atrium, which contracts to move the blood into the left ventricle. The left ventricle contracts and blood is distributed to the systemic circulation. Cardiac muscle has the unique ability to generate its own electrical signal, which allows it to contract without any external stimulation. This is known as **intrinsic excitation**. The impulse for heart contraction is initiated in the **sinoatrial (SA) node** located in the wall of the right atrium. The electrical impulse generated by the SA node spreads through both atria and reaches the **atrioventricular (AV) node** located in the right atrial wall near the centre of the heart. The atria contract, and the AV node conducts the electrical impulse from the atria into the ventricles. From the AV node, the electrical impulse enters the **bundle of His**. This is the only site where electrical impulses can conduct from the atria to the ventricles. After moving along the bundle of His, the electrical impulse is conducted by **Purkinje fibres** from the apex of the heart upwards to the ventricles. The ventricles contract, pushing the blood to the systemic circulation. Refer to chapter A.1.2 for a diagram of the heart.

The heart initiates its own electrical impulse, but both the heart rate and the force of contraction can be altered by three **extrinsic factors**:

- the parasympathetic nervous system
- the sympathetic nervous system
- the endocrine system (hormones).

Within the parasympathetic nervous system, stimulation of the vagus nerve leads to slower electrical conduction, which causes a decrease both in heart rate and in the force of heart muscle contraction.

Stimulation of the sympathetic nervous system, which has the opposite effect of faster electrical conduction, leads to increases in both heart rate and force of contraction.

As we will see later in this chapter, hormones released by the endocrine system also stimulate the heart, increasing both heart rate and force of contraction—similar to the action of the sympathetic nervous system.

How does a sensory stimulus bring about a motor response?

To be able to participate in sport, exercise and physical activity, the body's sensory and motor systems need to be coordinated. For example, when someone is taking part in a cross-country running event, how do the muscles in the legs coordinate to move the weight of the whole body upwards (flight phase of running) and forwards?

To coordinate a response, the sensory and motor systems must communicate with each other.

Consider the runner in Figure 4:

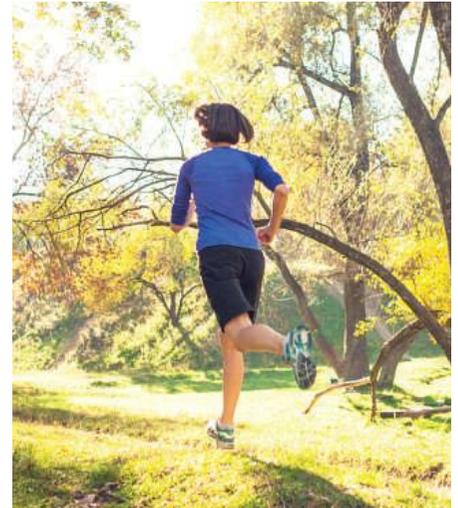
- a sensory stimulus is received (their foot contacts the ground)
- this information travels along sensory nerves to the CNS
- the CNS selects an appropriate response
- the CNS sends a message along the motor nerves to the skeletal muscles
- a motor response occurs (for example, eccentric contraction in the quadriceps muscles to control the runner's body on impact with the ground, followed by concentric contraction in the quadriceps muscles to propel the runner upwards and forwards).

Sensory stimulation travels along sensory nerves to the spinal cord. This can then terminate at the spinal cord or travel on up via sensory pathways to different parts of the brain (brain stem, cerebellum, thalamus or the cerebral cortex). Table 3 outlines some examples of how this sensory input is interpreted and linked to motor response(s).

▼ Table 3 Parts of the CNS and linked motor responses

Part of CNS where the sensory signal terminates	Type of motor response	Example of motor response
spinal cord	reflex	pulling a finger away from a hot surface
brain stem	subconscious	postural control (sitting, standing, moving)
cerebellum	coordination	contracting muscle groups to perform the desired movement
thalamus	consciousness	distinguishing between various sensations
cerebral cortex	location of sensory input from skin, muscles, tendons and joints	knowing where parts of the body are, relative both to each other and to our surroundings

As shown in Table 3, a sensory stimulus can be received and lead to a motor response that starts at different levels of the CNS. Simple reflex movements (for example, mistakenly touching and immediately pulling a finger away from boiling water) have their level of control at the spinal cord. However, motor responses for more complicated movements—ones that require you to think and make decisions about complex movement patterns—come from the cerebral cortex and the cerebellum in the brain.



▲ Figure 4



▲ Figure 5

For example, the mountain biker in Figure 5 is attempting to quickly (but safely) navigate their way down a tree-lined, constantly changing route. They must make appropriate decisions and coordinate postural adjustments to maintain balance, keep control of their bicycle and avoid crashing into a tree!

Proprioceptors, chemoreceptors and baroreceptors

Information about sensory stimuli is provided by specialized receptor cells.

Proprioceptors are specialized cells located in muscles, tendons, joints and the inner ear. They provide information about body position, muscle length and tension, position and movement of joints, and help maintain balance (and equilibrium). For example, proprioceptors allow us to monitor:

- where our head and limbs are located and how they are moving without looking at them
- the degree to which muscles are contracted
- the amount of tension on tendons
- the positions of joints
- the orientation of the head relative to the ground and head position during movement.

The brain is continually receiving nerve impulses related to the position of different body parts and makes adjustments to ensure coordination. Additionally, proprioceptors communicate the rate of movement of one body part relative to other body parts—this allows us to do things without using our eyes, such as walk or put on socks. Proprioceptive sensations help us decide the correct amount of muscular effort needed to perform a task, whether it is lifting a spoon to eat, performing a “clean and jerk” Olympic weightlifting movement or changing direction while skiing (Figure 6).



▲ Figure 6

Proprioceptors also provide an important stimulus for the quick rise in heart rate when starting physical activity. For example, as exercise begins, proprioceptors monitor the position of limbs, and muscles send an increased frequency of nerve messages to the cardiovascular centre in the brain (the part of the nervous system responsible for regulation of heart rate).

Additionally, chemoreceptors and baroreceptors provide input to the cardiovascular centre in the brain. Chemoreceptors monitor chemical changes in the blood. Baroreceptors monitor stretching caused by blood in major arteries and veins. These factors work together with the intrinsic mechanisms controlling heart rate (chapter A.1.2).

Chemoreceptors detect chemicals in the mouth (taste), nose (smell) and body fluids. For sports science, the chemoreceptors that monitor the chemical composition of blood are especially interesting. These are located in different parts of the body including the neck (carotid bodies) and the aorta (aortic bodies).

Chemoreceptors detect changes in levels of oxygen (O_2), carbon dioxide (CO_2) and hydrogen ions (H^+) in the blood. Hypoxia (lowered O_2 availability), acidosis (an increase in H^+ concentration) or excess CO_2 stimulate the chemoreceptors to send messages to the brain to do something about this disturbance to homeostasis. For example, these chemoreceptors provide input to the respiratory centre in the brainstem, which can respond by adjusting how quickly and how deeply we breathe.

Baroreceptors are pressure-sensitive nerve cells. They can detect higher or lower pressure. They are located in the aorta and carotid arteries (and other large arteries in the neck and chest). They are sensitive to changes in arterial pressure and send messages to the cardiovascular centre in the brain to help regulate blood pressure.

When blood pressure falls, the baroreceptors are stretched less, and they send messages at a slower rate to the brain. Parasympathetic stimulation of the heart decreases and sympathetic stimulation of the heart increases. Conversely, when heart rate increases, blood pressure is elevated. The baroreceptors send messages to the brain, which responds by sending messages to the heart (increased parasympathetic stimulation and less sympathetic stimulation). Heart rate lowers, which causes blood pressure to decrease back to normal—and homeostasis is restored.



Linking question

How does coordination between the nervous system and the muscular system result in the ability to produce various types of movement? (B.1.3)

Consider:

- how the specific muscle (or group of muscles) knows when to contract
- the role of the neuromuscular junction
- motor unit recruitment.

Look at the cyclist in Figure 7. Consider:

- what ensures the appropriate muscle group is contracting to provide the main force through the pedals to move the bicycle forward
- whether this muscle group contracts in both limbs at the same time (left and right simultaneously) or alternates
- how the muscle group “knows” to do this.



▲ Figure 7

ATL Research skills

Baroreceptors are also located in the walls of bronchi and bronchioles. When you inhale, the baroreceptors are stretched, a message is sent to the inspiratory centre in the brain, inspiration is inhibited and exhalation begins. As air leaves the lungs during exhalation, the lungs deflate and the baroreceptors are no longer stimulated. The inspiratory centre in the brain is no longer inhibited, and a new inhalation begins.

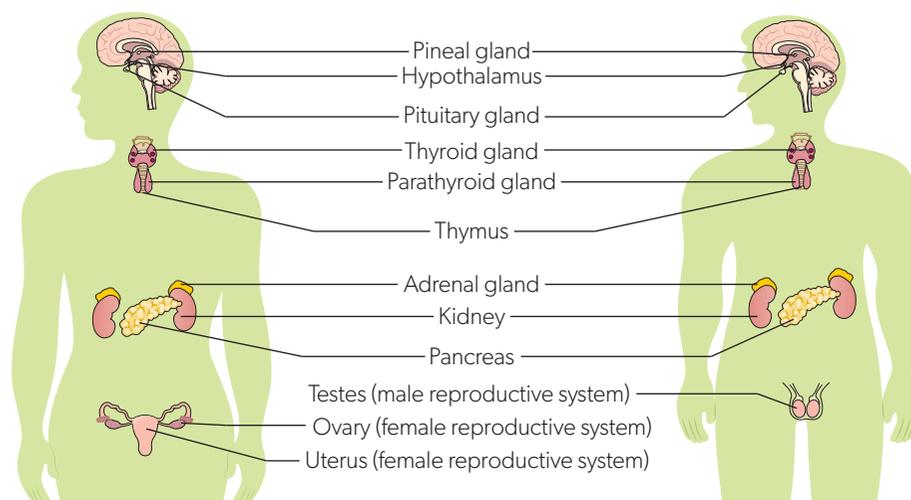
What is the Hering-Breuer reflex, and what is its purpose?

The endocrine system

Structure and function of the endocrine system

The **endocrine system** is the partner of the nervous system in regulating the human body and controlling the responses to physiological challenges. Many of the nervous system responses are fast (within seconds) and acute in nature. The endocrine system responses tend to be a little slower (they can take minutes, or longer), but the effects last longer. Almost all cells of the body are influenced by the endocrine system, through the release of mediators, called hormones. The endocrine system consists of all tissues or glands that secrete hormones.

Hormones are chemicals released by glands or tissues to control and regulate the activity of other cells around the body. The majority of endocrine glands secrete these hormones directly into the blood for transport to target cells. However, each hormone can only interact with specific receptors on some cells to cause a specific response. So, the human body has lots of different endocrine glands, which each secrete numerous different hormones with widely varying effects. The major endocrine organs of the body are shown in Figure 8.



▲ Figure 8 The major endocrine glands

Table 4 shows some of the hormones that are particularly important for sports.

▼ Table 4 Hormones important for sports

Hormone(s)	Information
Epinephrine and norepinephrine	<ul style="list-style-type: none"> released from the adrenal medulla increase heart rate and force of contraction increase the pumping output of the heart (which increases blood pressure), preparing the body for a fight-or-flight response increase blood flow to the heart, liver, skeletal muscles and adipose tissue dilate airways to the lungs increase blood levels of glucose and fatty acids norepinephrine also plays a role in arousal (awakening from deep sleep), dreaming and regulating mood

Insulin and glucagon	<ul style="list-style-type: none"> produced by the pancreas help regulate blood sugar concentration insulin assists glucose entry into cells glucagon promotes increased breakdown of liver glycogen to glucose
Antidiuretic hormone	<ul style="list-style-type: none"> secreted by the pituitary gland regulates fluid and electrolyte balance in the blood by reducing urine production
Oestrogen	<ul style="list-style-type: none"> female sex hormone secreted by the ovaries promotes body growth by broadening the pelvis, stimulating breast development and increasing fat deposition, particularly in the thighs and hips promotes secondary sex characteristics (voice pitch and hair growth on the body) increases protein anabolism, including building strong bones lowers blood cholesterol and helps our bodies store glycogen insufficient oestrogen causes joints to feel stiff and not move as easily
Progesterone	<ul style="list-style-type: none"> female sex hormone secreted by the ovaries plays a key role in the menstrual cycle and pregnancy
Testosterone	<ul style="list-style-type: none"> predominant male sex hormone secreted by the testes needed for the development of sperm helps control the development of male reproductive hormones promotes the development and maintenance of male secondary sex characteristics (such as body hair) helps with bone formation (to make them stronger) aids in muscle growth and repair through protein synthesis helps in the production of erythropoietin, which ensures the body has enough oxygen-carrying red blood cells

Activity 1



▲ Figure 9 Lionel Messi

Footballer Lionel Messi (Figure 9) is widely regarded as one of the greatest players of all time. However, he was born with an endocrine hormone disorder and received important treatment to enable him to realize his potential.

1. What was the disorder and what hormone was affected?
2. How was he medically treated and what physiological effects does this have?
3. Does such treatment give an unfair advantage through use of drugs in sport?

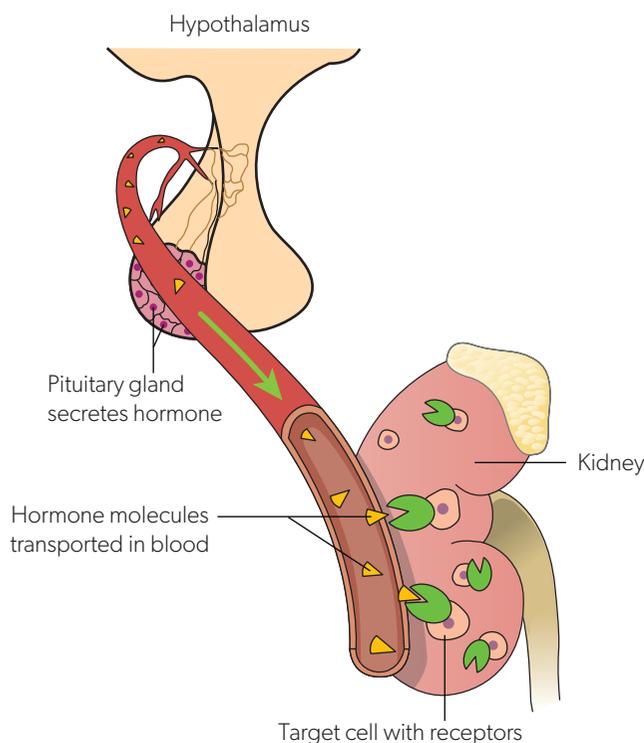
Types of hormones

Hormones can be grouped into two categories—steroid, or non-steroid—dependent on their chemical make-up.

- Steroid hormones are fat-soluble and can easily pass through cell membranes to interact with the receptors and elicit a response. Examples of steroid hormones include testosterone, oestrogen and progesterone.
- Non-steroid hormones, which are not fat-soluble, must interact with receptors on the cell surface to trigger messenger chemicals inside the cell that then elicit the response. Examples of non-steroid hormones include epinephrine (also known as adrenaline and secreted by the adrenal glands) or glucagon (secreted by the pancreas).

Another type of hormone—prostaglandins, which fall into the non-steroid group—are produced in the membranes of most cells. Prostaglandins are secreted very near the site of action, although some can be transported short distances before they are quickly broken down. An example of prostaglandin action is part of the inflammation response following an injury, where prostaglandins are secreted at the injury site and stimulate a local swelling response.

Hormones are typically released in waves or pulses in response to direct stimuli, whereas others are more regular or sustained. For example, the menstrual cycle in a menstruating female will see a repeating cyclical release of hormones (refer to Figure 10 in chapter A.3.1). In contrast, Table 5 provides some examples of hormone involvement in the integrated physiological systems' responses to the immediate challenge of exercise, aligned with the major endocrine organs (Figure 9). Hormones must bind to specific target cells to exert an effect (Figure 10).



▲ Figure 10 Hormones are transported to specific target cells

▼ Table 5

Endocrine organ	Example hormone	Example target	Example action
hypothalamus	growth hormone stimulating hormone	pituitary gland	increased secretion stimulates the pituitary gland to secrete growth hormone
pineal	melatonin	unknown	decreased secretion with evening exercise may cause disrupted sleep
pituitary	growth hormone	muscle	increased secretion promotes muscle growth
thyroid	thyroxine	muscle	increased secretion contributes to increased metabolic rate
adrenal	epinephrine	cardiac tissue	increased secretion increases heart rate, cardiac output and blood pressure
pancreas	insulin	muscle	decreased secretion slows glucose storage to increase availability
ovaries	oestrogen	muscle	small increase may contribute to muscle growth
testes	testosterone	muscle	small increase may contribute to muscle growth

ATL Thinking skills

What does the research evidence tell us regarding testosterone as the one essential muscle growth hormone?

It has long been argued that testosterone is the key anabolic (building) hormone required for muscle growth (hypertrophy). That is why some bodybuilders use drugs to boost testosterone levels and enhance muscle growth. But contemporary research shows that a much wider range of training loads can elicit the muscle hypertrophy response, provided the level of effort is sufficient.

Furthermore, it is not as simple as merely increasing testosterone to increase muscle mass; research has highlighted the importance of having sufficient target receptor activity in skeletal muscle. Otherwise, any testosterone increase is wasted. A suitable goal with resistance training can, therefore, be to up-regulate these testosterone receptors to take advantage of training-induced increases in testosterone. Nevertheless, we recognize that genetics also plays a significant role in determining this, and hence the magnitude of training-induced hypertrophy. Testosterone is still a piece of the complex muscle-building puzzle, in concert with other coordinated signalling and hormonal pathways. It is certainly not a case of "one size fits all".

Hormone regulation

The endocrine system responds to a wide range of stimuli from around the body to increase or decrease hormone secretion in response to the changing internal environment. Almost all endocrine glands operate using a negative feedback system. In a negative feedback system, an increase in a monitored variable is detected, invoking a coordinated physiological response (such as hormone secretion) to reduce the elevated variable. This was illustrated in Figure 3 showing the response when body temperature becomes too high.

There are three main sources of information that increase or decrease hormone secretion: neural, humoral and hormonal.

Neural

Neural sources of information are signals from the nervous system. For example, when exercising intensely, the sympathetic branch of the autonomic nervous system stimulates the adrenal gland to secrete epinephrine into the blood. This will increase the cardiovascular response to the exercise in proportion to the intensity of the exercise, to improve delivery of oxygen and nutrients to active muscles, yet preserve other physiological functions.

Humoral

Humoral sources of information are due to changes in the chemistry of the blood. For example, when blood glucose levels increase after eating, the pancreas is stimulated to release more insulin. The insulin interacts with cell receptors to increase the uptake of glucose into cells and increase the conversion of glucose to glycogen for storage. This reduces blood glucose levels and the pancreas reduces insulin release again. In contrast, glucagon, which is also secreted by the pancreas, has the opposite effect and is increased when blood glucose is too low.

Hormonal

Hormones relay information by responding to changes in other hormone levels. For example, when the stomach is empty of food, it secretes more ghrelin into the bloodstream, which signals the hypothalamus in the brain to increase appetite. After eating, the stomach reduces ghrelin release, and the hypothalamus detects this change, leading to decreased appetite. This process is part of the complex mechanisms that control appetite and satiety.

The master gland

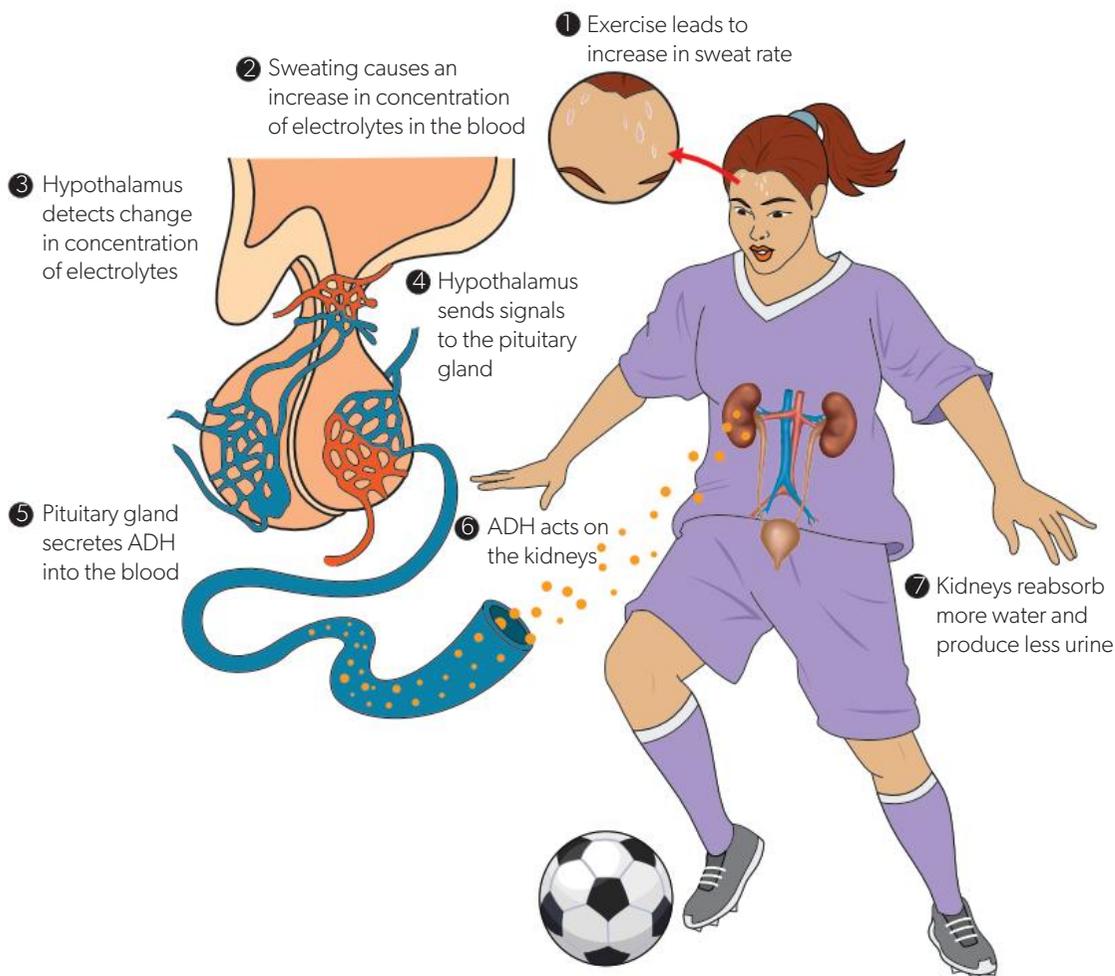
The pituitary gland in the brain is the most important endocrine gland involved in maintaining homeostasis. The pituitary gland secretes many different hormones to stimulate or inhibit organs in a highly coordinated way. It is often considered the “master gland” governing homeostasis.

However, with improvements in scientific techniques, it is now apparent that the pituitary gland itself is controlled primarily by the hypothalamus. So, the hypothalamus is the real master.

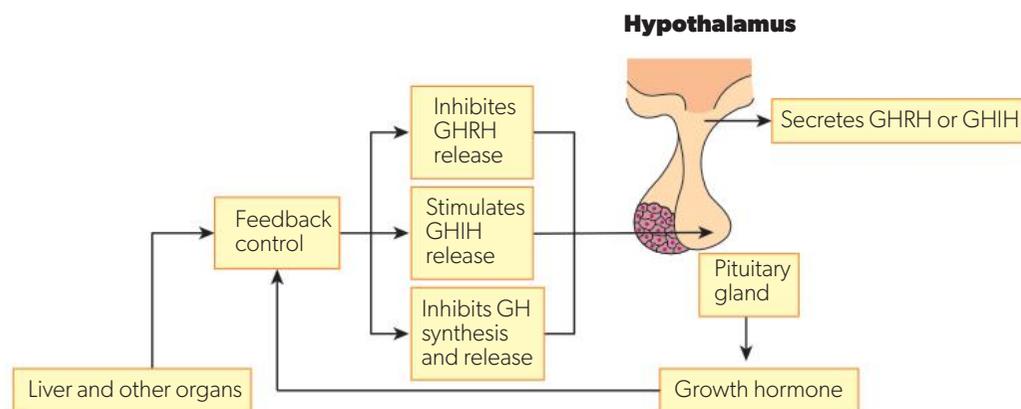
Although the hypothalamus is located only slightly above the pituitary gland in the brain, the hypothalamus can regulate the release of hormones from the pituitary gland through both neural mechanisms (for example, antidiuretic hormone, ADH) and hormonal mechanisms (for example, growth hormone secretion), as shown in Figures 11 and 12.

Key point

The regulation of blood glucose by insulin and glucagon is an example of a **feedback mechanism**. Refer to chapter A.1.2 for more detail.



▲ Figure 11 The hypothalamus stimulates the pituitary to release ADH and trigger fluid conservation



▲ Figure 12 The hypothalamus secretes either growth-hormone-releasing hormone (GHRH) or growth-hormone-inhibiting hormone (GHIH) to regulate growth hormone secretion by the pituitary gland

The impact of female reproductive hormones on health and performance

The menstrual cycle involves large fluctuations in female reproductive hormones, including oestrogen and progesterone. For example, during the **luteal phase** (the second half of the menstrual cycle), progesterone levels increase.

We will study the menstrual cycle in more detail in chapter A.3.1, including considerations for training programmes. Some impacts of these hormones on health and performance are discussed below.

Oestrogen and joint stiffness

Oestrogen is thought to influence joint stiffness through its effects on various tissues, including bones, cartilage and the synovium (the tissue lining the joint capsule). When oestrogen levels decrease, such as during the menopause, bone density loss can occur, leading to conditions like osteoporosis. Weakened bones can contribute to joint stiffness and discomfort. Also, oestrogen is believed to play a role in maintaining cartilage health, and reduced oestrogen levels could potentially lead to decreased cartilage quality and contribute to joint stiffness. Additionally, oestrogen may influence the production of synovial fluid (helps reduce friction in the joints). Changes in oestrogen levels might affect the composition and production of synovial fluid, potentially leading to joint stiffness. Finally, oestrogen can help reduce inflammation in the joints; that is, reduced oestrogen levels might cause inflammation, which can lead to joint stiffness and discomfort. However, note that the relationship between oestrogen and joint stiffness is complex and can vary from person to person. This is because factors such as age and genetics can also influence joint stiffness.

Oestrogen and glycogen sparing

Oestrogen and progesterone influence metabolism, muscular fitness and body composition. There is consensus among researchers that biological females rely more on fat as a source of fuel and spare more glucose compared with biological males both at rest and during exercise. It seems there is a link between sex, intensity of exercise, and the differences found in use of carbohydrates and fats, and more specifically muscle glycogen (Fernandez del Valle, 2023).

Progesterone and fuel availability

Some research indicates that during the luteal phase of the menstrual cycle, when progesterone levels are higher, there might be a shift in fuel utilization. This shift could involve a relatively greater reliance on fat as a fuel source compared with carbohydrates. This impact of progesterone on fuel availability might be more noticeable during low-to-moderate-intensity exercise. At higher exercise intensities, the body tends to rely more on carbohydrates for quick energy production (Isacco, Boisseau, 2023).

Progesterone and thermoregulation

Thermoregulation is the process by which the body keeps a relatively constant temperature over a wide range of environments and activity levels. Progesterone tends to promote higher body temperatures during the luteal phase of the menstrual cycle when progesterone levels are elevated (refer to chapter A.3.1 for a diagram showing a theoretical pattern of hormone levels during the menstrual cycle). The mechanism for increased temperature during the luteal phase of the menstrual cycle is thought to be a progesterone-related shift to a higher “thermoregulatory set-point” (Charkoudian, Stachenfeld, 2016). Imagine a thermostat in a room that can be adjusted to make the room warmer or cooler. Your body has something similar. The body’s thermoregulatory set-point is like a temperature goal that your body wants to keep. When it is too hot outside, your body tries to cool down to reach this goal. And when it is too cold, your body tries to warm up to get there. Refer to chapter A.1.2 for more on sex differences and thermoregulation.

Progesterone and sleep quality

Progesterone has a calming and sedative effect on the CNS. Increased progesterone levels during the second half of the menstrual cycle (the luteal phase) can contribute to feelings of relaxation and drowsiness. This sedative effect can help promote falling asleep and staying asleep. Progesterone can slightly increase body temperature, and this rise in temperature is thought to facilitate the transition from wakefulness to sleepiness. As we will study in chapter A.3.3, the quality of sleep can affect both recovery and performance.

ATL Research skills

How might progesterone impact breathing, sleep regulation and mood regulation?

Case study

How much athletic advantage is due to reproductive hormones?

Naturally produced reproductive hormones see large increases in production during puberty, and these may confer physiological benefits for athletic performance. For biological males, testosterone is involved in increasing protein synthesis, promoting bone size and strength, and increasing haemoglobin levels for oxygen transport. For biological females, elevated oestrogen and progesterone have been associated with sparing muscle glycogen, for example, but also with some increases in ligament injury risk associated with reduced stiffness, altered thermoregulation and sleep quality. Estimated athletic benefits for biological males have ranged from 0% to 30% dependent on the sport (Heather, 2022). This raises the question of what advantages an athlete assigned male at birth may gain in female competition.

At Tokyo 2020, weightlifter Laurel Hubbard (Figure 13) became the first athlete assigned male at birth to compete in female competition at an Olympic Games. In an interview, she said, "I'm mindful I won't be supported by everyone but I hope that people can keep an open mind and perhaps look at my performance in a broader context."

Hormone therapy is used to reduce testosterone concentration and increase female sex hormones in some individuals. Some argue that there should be a fixed below-threshold blood testosterone concentration that competitors must have before competing in female sport. Others suggest that eligibility criteria focusing only on testosterone levels are too narrow. This issue has presented an inclusive debate that has divided athletes, sports and governing bodies across the world.

1. Research how biological sex is determined.
2. In what sports would this issue most likely present a challenge?
3. What are the ethical and moral challenges that exist for both sides of the debate?



▲ Figure 13 Laurel Hubbard

Practice questions

1. Outline the nervous control and mechanics of inspiration during exercise. (6 marks)
2. Explain how the hypothalamus regulates the pituitary gland. (4 marks)

Summary

- The nervous system is divided into two main divisions: the central nervous system (CNS) and the peripheral nervous system (PNS).
- The CNS consists of the brain and the spinal cord. The PNS is all the nerves outside of the CNS.
- Sensory (afferent) nerves inform the CNS about what is going on within the body and outside the body. Motor (efferent) nerves send information from the CNS to tissues, organs and systems of the body.
- The somatic nervous system controls voluntary movements of the skeletal muscles. The autonomic nervous system, which consists of the sympathetic nervous system and the parasympathetic nervous system, regulates involuntary bodily functions.
- The cerebral cortex is the centre of conscious motor control.
- The diencephalon is a major control centre for maintaining the body's internal environment.
- The cerebellum is critical for coordinating movement.
- The brain stem connects the brain and the spinal cord.
- Proprioceptors provide information about body position and movements.
- Baroreceptors sense changes in blood pressure.
- Chemoreceptors detect the presence of and react to a chemical stimulus.
- The endocrine system includes all tissues or glands that secrete hormones.
- Hormones are chemicals that are released by glands or tissues to control and regulate the activity of other cells around the body.
- Hormone actions take longer than neural actions but effects often last longer.
- Only tissues with very specific receptors can be controlled by a specific hormone.
- The main endocrine organs are the hypothalamus, pineal gland, pituitary gland, thyroid gland, adrenal gland, pancreas, ovaries and testes.
- Hormones are classed as steroid or non-steroid, with a third category of hormone-like prostaglandins.
- Epinephrine and norepinephrine increase heart rate, force of contraction and the pumping output of the heart.
- Insulin and glucagon help regulate blood sugar concentration.
- Antidiuretic hormone, secreted by the pituitary gland, regulates the fluid and electrolyte balance in the blood by reducing urine production.
- Oestrogen and progesterone are female sex hormones secreted by the ovaries.
- Oestrogen helps our bodies store glycogen. When we do not have enough oestrogen, our joints can feel stiff and not move as easily.
- Progesterone plays a key role in the menstrual cycle and pregnancy. It influences fuel availability and can affect thermoregulation and sleep quality.
- Testosterone is the predominant male sex hormone. It helps with bone formation, aids in muscle growth and repair through protein synthesis, and also helps in the production of erythropoietin, which ensures our body has enough oxygen-carrying red blood cells.
- Hormones can be secreted into the blood or produced locally to the target action.
- Endocrine glands use negative feedback loops.
- Three main sources of information increase or decrease hormone secretion: neural, humoral or hormonal.
- The hypothalamus and pituitary gland are the main endocrine glands maintaining homeostasis in the body.
- The hypothalamus regulates pituitary action using hormones and nervous system signals.

Check your understanding

After reading this chapter, you should be able to:

- describe the structure and function of the nervous system and its divisions
- outline how the sensory and motor systems communicate to coordinate responses to internal and external conditions
- explain the roles of proprioceptors, baroreceptors and chemoreceptors
- label the location of the major endocrine organs in the human body
- outline the functions of key hormones
- describe the role of circulating (blood) and local hormones
- explain how circulating hormone levels are regulated
- explain the relationship between the hypothalamus and the pituitary gland.

Self-study questions

- List **three** functions of the nervous system.
- Describe the importance of sympathetic nervous system stimulation during sport and exercise.
- Explain how proprioceptive sensations help us decide the correct amount of muscular effort needed to perform an exercise task.
- List **three** sources of information that regulate hormone release.
- Explain how interaction between the hypothalamus and pituitary gland successfully maintains homeostasis of a chosen variable during exercise.

Data-based question

Cortisol is an endocrine hormone secreted by the adrenal gland. It is often described as a stress hormone because increased cortisol can be detected in the blood and saliva during and following stress—including intense exercise. Cortisol plays an important role in regulating metabolism. However, too much cortisol may be associated with negative consequences.

A research study on 48 young people at school investigated whether education delivered outside the classroom (including physical education) for

one day each week would help to reduce stress and have positive effects on brain activity, compared with all education in the classroom. Cortisol levels were measured from saliva samples taken at the start of term, mid-term and the end of term. On each of those three days the samples were taken at 08.30am, 10:30am and 12:30pm.

Table 6 shows the mean (SD) for the salivary cortisol concentrations ($\mu\text{g l}^{-1}$) for the outdoor and indoor groups.

▼ Table 6

Time	Salivary cortisol concentrations ($\mu\text{g l}^{-1}$)					
	Term start		Mid-term		Term end	
	Outside of classroom	Inside of classroom	Outside of classroom	Inside of classroom	Outside of classroom	Inside of classroom
08.30	0.45 (0.27)	0.39 (0.16)	0.36 (0.24)	0.40 (0.24)	0.42 (0.19)	0.41 (0.13)
10.30	0.30 (0.20)	0.30 (0.19)	0.35 (0.21)	0.43 (0.20)	0.21 (0.21)	0.34 (0.15)
12.30	0.29 (0.24)	0.32 (0.13)	0.24 (0.19)	0.39 (0.12)	0.25 (0.20)	0.40 (0.17)

- Identify:
 - which group had the lowest cortisol value at any point (1 mark)
 - what time of day elicited the highest cortisol value. (1 mark)
- Distinguish the effect of time of day on cortisol responses between the outdoor and indoor groups. (3 marks)
- Explain why reduced cortisol levels may be beneficial for the participants. (4 marks)

A.1.2 Maintaining homeostasis

Syllabus understandings

A.1.2.1 Homeostasis is any self-regulating biological process aiming to produce a relatively stable, constant internal environment for optimal functioning of the body. In response to changing internal and external conditions, various mechanisms work constantly towards homeostasis.

AHL

A.1.2.2 The body has acute and possible long-term responses to the environment in which it functions.

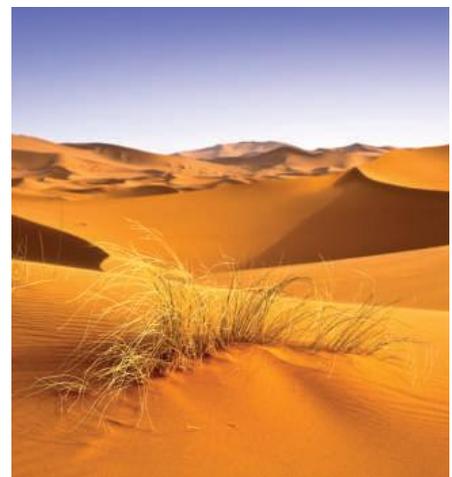
Introduction

The French physiologist Claude Bernard (1813–1878) suggested that the cells of the human body flourish because they live in the relative constancy of “*le milieu interieur*”—the internal environment of the body. How the body’s organ systems, tissues and cells work and how their functions are integrated to regulate the body’s internal environment is a process called **homeostasis**.

Homeostasis is the condition in which the body’s internal environment remains relatively constant, within physiological limits. It occurs due to the body’s continuous balancing act of various regulatory processes. It is a dynamic state. Challenging environments such as hot and humid, cold, and high altitudes can affect the body during sports, exercise and physical activity. Extreme temperatures can harm performance, increase the risk of heat illness or cold injury and even pose life-threatening situations. This chapter will enhance your understanding of homeostasis, environmental physiology and their impact on sports, exercise and health.



▲ Figure 1



▲ Figure 2

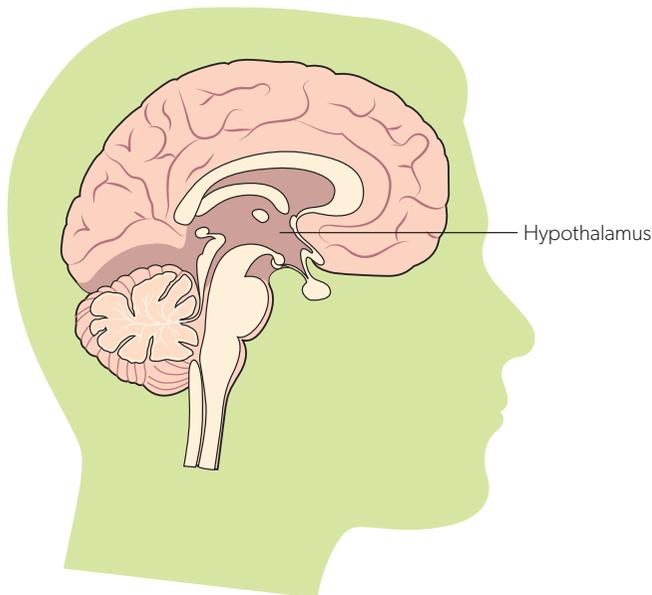
Homeostasis

To understand homeostasis, we need to study how the body functions and adapts to stressors, including physical activity, and cold, hot and humid environments.

Stressors may be internal (within the body, such as a low blood glucose level) or external (outside the body, such as intense heat or lack of oxygen). A relatively stable, constant internal environment is essential to maintain optimal conditions for performance and safe functioning of the body.

The hypothalamus is a part of the brain located within the diencephalon (Figure 3). It is responsible for maintaining homeostasis by regulating most processes that affect the body's internal environment, including:

- blood pressure
- heart rate
- strength of contraction of the cardiac muscle tissue
- respiration
- digestion
- body temperature
- thirst and fluid balance
- interaction of the nervous system and endocrine system
- appetite and food intake
- sleep-wake cycles.



▲ Figure 3 The hypothalamus

Control of homeostasis by feedback mechanisms

During physical activity and exposure to extreme environments (for example, participating in the heat of a desert marathon, or cold water swimming) the body must make many rapid and well-coordinated physiological adjustments. The body may need to:

- increase metabolism to meet energy demands
- adjust cardiovascular and respiratory responses to ensure a supply of oxygen (O_2)
- clear metabolic by-products (such as carbon dioxide [CO_2])
- regulate body temperature to prevent hyperthermia/hypothermia.

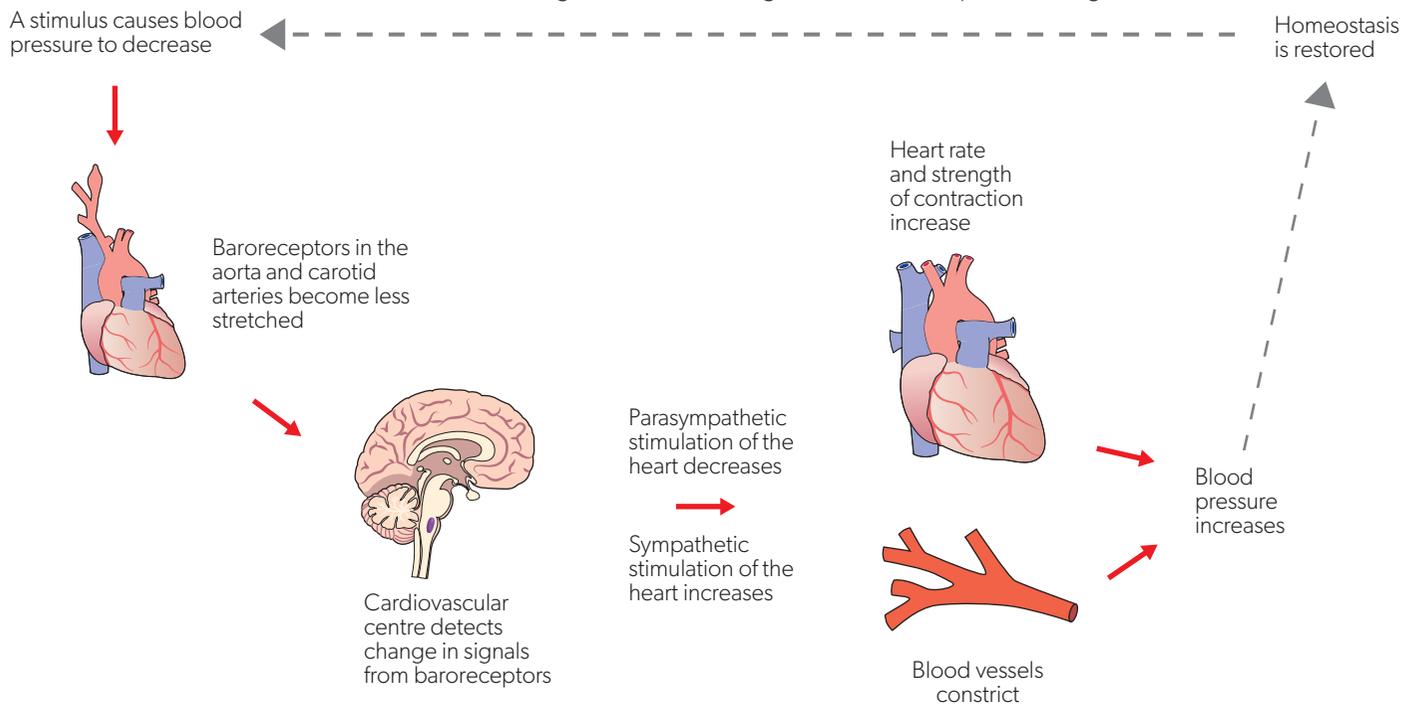
This physiological regulation and integration is done by the nervous system and the endocrine system. The nervous system regulates homeostasis by sending nerve messages to organs. The endocrine system has glands that secrete hormones (chemical messages) into the blood. Nerve messages usually cause rapid changes, whereas hormones usually work more slowly.

The body regulates its internal environment using feedback mechanisms to monitor variables such as body temperature or blood glucose level.

The three basic components that make up a feedback mechanism are:

- a receptor (such as nerve endings in the skin that sense temperature)
- a control centre (such as the hypothalamus)
- an effector (such as shivering if your body temperature drops sharply).

There can be negative feedback mechanisms to *reverse* the effects of the stimulus, and positive feedback mechanisms to *enhance* or *intensify* the stimulus. Homeostasis is generally maintained by negative feedback mechanisms, such as the negative feedback regulation of blood pressure (Figure 4).



▲ Figure 4 Negative feedback regulation of blood pressure via baroreceptors

Regulation of blood pH

The pH of blood is an important component of homeostasis. The normal pH range of arterial blood is 7.35–7.45 (slightly alkaline). CO_2 produced by cellular metabolism is transported in the blood to the lungs and expelled. An increase in CO_2 concentration in the blood can lead to an increase in hydrogen ion (H^+) concentration. This can lower the blood pH and make it more acidic, which can have harmful effects on the body's tissues and organs.

To maintain homeostasis, the respiratory control centre in the brain and chemoreceptors throughout the body monitor the blood pH and CO_2 concentration. If the blood pH drops below the normal range (becomes more acidic), the respiratory control centre increases the rate and depth of breathing. This increases the removal of CO_2 from the lungs and helps to restore the normal blood pH. This is an example of a negative feedback mechanism.

Regulation of the heart

Unlike other muscular contractions in the body, the cardiac cycle does not require a nerve stimulation to make the heart muscle contract. The regulation of the heart involves both intrinsic excitation and extrinsic excitation. Intrinsic

excitation refers to the electrical activity that originates within the heart itself, while extrinsic excitation refers to the signals that come from outside the heart, such as from the nervous and hormonal systems.

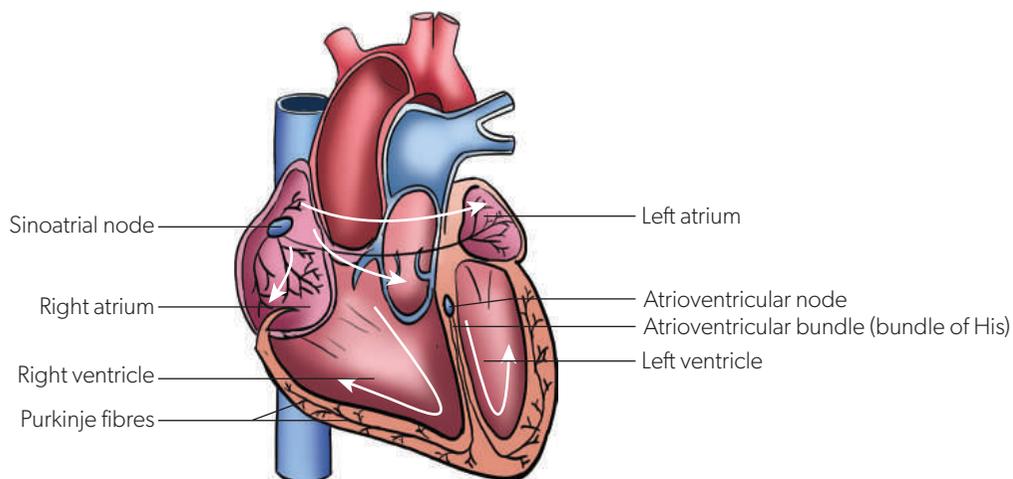
Intrinsic excitation of the heart

Intrinsic excitation of the heart is controlled by the sinoatrial (SA) node (sometimes referred to as the heart's natural pacemaker). The SA node is a specialist group of cells found in the wall of the right atrium. The SA node generates electrical impulses that cause it to contract and pump blood. The rate at which the SA node fires electrical impulses is influenced by several factors, including the level of O_2 and CO_2 in the blood, and hormones (such as epinephrine and norepinephrine from the adrenal gland).

The SA node sends an impulse through the walls of the atria (left and right sides) to a second group of specialist cells called the atrioventricular (AV) node (Figure 5). This rapid conduction of the impulse causes the muscles in the walls of the atria to contract simultaneously, increasing the pressure in the atria and forcing blood from the atria, through the AV valves, into the ventricles. The AV valves then close.

Following a very brief delay, the impulse is conducted rapidly via a bundle of specialist cells called the bundle of His. These cells rapidly conduct the impulse along the very fast conducting Purkinje fibres that spread the impulse along the ventricle walls. This impulse causes the fibres in the ventricle walls to contract simultaneously, increasing ventricular pressure and pushing blood up and out through the main arteries leaving the heart.

The semi-lunar valves at the openings into the aorta and pulmonary artery now close and, as the ventricles relax, the cycle begins again with the atria filling with blood returning to the heart, triggered by the firing of the SA node.



▲ Figure 5 Excitation of the heart

Extrinsic excitation of the heart

Extrinsic excitation of the heart is controlled by the autonomic nervous system, which can speed up or slow down the natural pacemaker firing rate by adjusting the relative contributions from the sympathetic and parasympathetic branches, respectively. The sympathetic nervous system is responsible for increasing the heart rate and force of contraction, while the parasympathetic nervous system is responsible for slowing down the heart rate and decreasing the force of contraction. For example, the sympathetic nervous system releases the hormone epinephrine, which causes heart cells to contract more forcefully and more frequently, increasing both heart rate and

This work must not be reproduced, stored, transmitted or circulated in any other form.

Key term

Glycogen The storage form of glucose.

cardiac output. In contrast, the stimulation of the parasympathetic nervous system can lead to the release of acetylcholine (a hormone), which slows down the firing rate of the SA node, reducing the force of contraction, and results in a decrease in both heart rate and cardiac output. Refer to chapter A.1.1 for more about the role of the nervous system in controlling the heart rate.

This involuntary control is an example of systems responding to a range of stimuli to try to maintain homeostasis, by increasing or decreasing the release of specific chemicals called neurotransmitters. For example, when exercise begins, parasympathetic stimulation is reduced (this normally keeps the heart rate low), and sympathetic stimulation is increased, resulting in an increased heart rate.

ATL Thinking skills

The cardiovascular centre, located in the brain stem, receives input from the cerebral cortex. The cerebral cortex processes sensory, motor and integrative signals. Sensory receptors receive messages via:

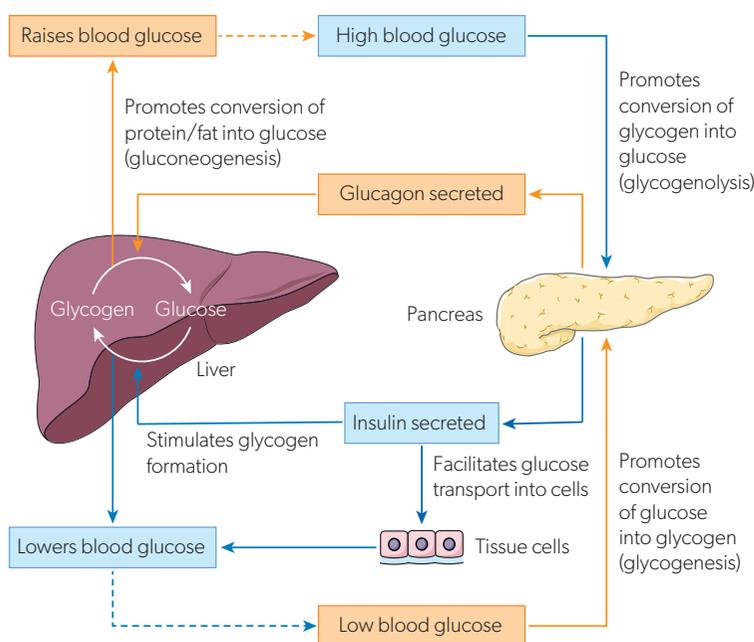
- proprioceptors (monitoring movements)
- chemoreceptors (monitoring blood chemistry)
- baroreceptors (monitoring blood pressure).

The motor areas of the cerebral cortex initiate movements, and integrative functions include memory, emotions and personality traits.

The cardiovascular centre then directs what happens by increasing or decreasing the frequency of messages

(nerve impulses) in the sympathetic and parasympathetic divisions of the autonomic nervous system. It is not unusual for there to be an anticipatory rise in heart rate before exercise begins—this happens because the limbic system (part of the brain concerned with aspects of emotion and behaviour) sends messages to the cardiovascular centre.

Then, as physical activity begins, proprioceptors (monitoring the position of limbs and muscles) send an increased frequency of messages to the cardiovascular centre to increase heart rate. Stimulation of the sympathetic division leads to an increase in heart rate and **stroke volume**.



▲ Figure 6 Regulation of blood glucose by glucagon and insulin

Regulation of blood glucose

The pancreas secretes the hormones insulin and glucagon to control blood glucose concentration. When blood glucose is elevated, the pancreas secretes insulin into the blood. Insulin facilitates glucose transport into the cells, especially muscle fibres, and this reduces the amount of glucose in the blood. When blood glucose falls below normal concentrations, the pancreas secretes glucagon. Glucagon promotes glycogenolysis (breakdown of liver glycogen to glucose) and gluconeogenesis (conversion of protein or fat into glucose).

During exercise (lasting ≥ 30 minutes), the body tries to maintain plasma glucose concentrations, but insulin concentrations tend to decline. The ability of insulin to bind to its receptors on muscle cells increases during exercise—increasing the body's sensitivity to insulin (as well as reducing the need to maintain high plasma insulin concentrations for transporting glucose into the muscle cells).

Regular exercise improves insulin sensitivity, which means that the body needs less insulin to transport glucose into cells (and lower blood glucose levels). This is because exercise promotes the uptake of glucose by muscle cells, which reduces the amount of glucose circulating in the bloodstream and lowers insulin resistance. Insulin resistance is a condition in which the body's cells (including muscle cells) become less sensitive to insulin, and this can lead to high blood sugar levels, which can cause serious health problems (such as type 2 diabetes). Insulin resistance results in the pancreas producing more insulin to regulate blood sugar levels, and over time the body becomes less sensitive to insulin. Factors that can contribute to insulin resistance include a sedentary lifestyle and a diet high in processed foods. Therefore, it is important to be physically active, exercise regularly and eat a healthy diet because this can improve insulin sensitivity, whereas a sedentary lifestyle and a diet high in processed and sugary foods can decrease insulin sensitivity.



▲ Figure 7 Exercise limits the release of insulin and improves insulin sensitivity



Linking question

How does the endocrine system interact with the energy systems to maintain appropriate blood glucose levels? (A.2.2 and A.2.3)

Consider:

- insulin helps to lower blood glucose levels by stimulating the uptake of glucose from the blood into the body's cells, where it can be used for energy
- when blood glucose levels are high (for example, after a meal) the pancreas releases insulin into the bloodstream
- insulin signals the liver and muscle cells to take up glucose and convert it into glycogen for storage, and stimulates adipose tissue to take up glucose and store it as fat
- when blood glucose levels are low (for example, during exercise) the pancreas releases glucagon
- glucagon signals the liver to break down glycogen and release glucose into the bloodstream, raising blood glucose levels
- the endocrine system and energy systems work together to maintain appropriate blood glucose levels by using hormones to regulate glucose metabolism in the body.

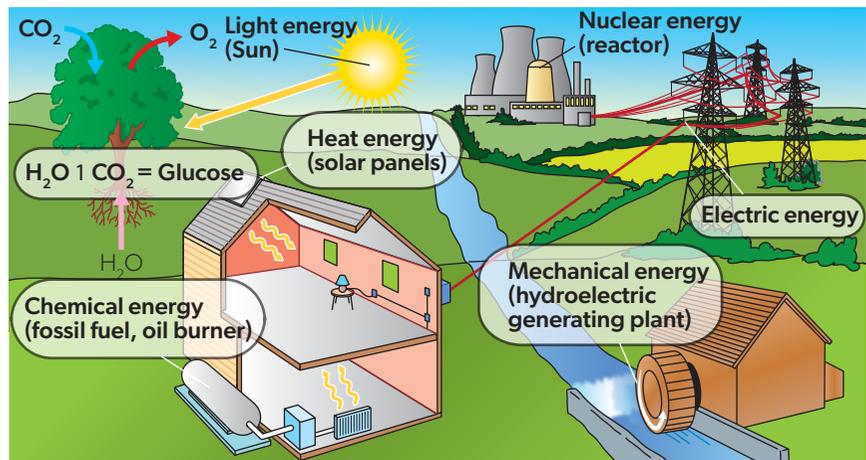
Regulation of body temperature

Thermoregulation (regulation of body temperature) relies on the cardiovascular, muscular, nervous and integumentary systems working together to maintain a core body temperature of $37 \pm 1^\circ\text{C}$.

The production of heat in the human body

All energy originates from the Sun as light energy (Figure 8). Chemical reactions in plants convert light into stored chemical energy. In turn, we obtain energy by eating plants or eating animals that feed on plants. Energy is stored in food in the form of carbohydrates, fats and proteins, and we use this energy for muscle contraction. Foods are primarily composed of carbon, hydrogen, oxygen and nitrogen. The energy in food molecule bonds is chemically released within our cells. This energy is then stored in the form of adenosine triphosphate (ATP)—a high-energy compound for storing and conserving energy for muscles to contract

and provide movement. Muscle contraction is about 20% efficient, with around 80% of this energy released as heat that must be removed from the body to avoid heat storage and too much of an increase in body temperature. For heat loss to occur, excess heat must be transported from the core of the body to the skin where the heat can be lost to the environment.



Interconversions of forms of energy

ATL Thinking skills

Key term

Adenosine triphosphate (ATP)

A molecule that provides energy for muscle contraction when it is split.

Energy from food is stored in **ATP**. The splitting of ATP provides energy for muscle contraction. Energy can be measured in kilocalories (kcal). One kcal is the amount of heat energy needed to raise 1 kg of water 1°C at 15°C.

Carbohydrate and protein each provide about 4.1 kcal of energy per gram. Fat provides about 9 kcal per gram. When energy is transferred to heat during exercise, this heat production can be measured in watts (W), where 1 W = 1 joule per second. In adults, this can range from around 70 W when resting, to more than 1,000 W during heavy exercise.

There are limited stores of ATP in muscle tissue. The average person will only have about 40–50 g in total. This is enough to enable high-intensity activity for around 2–4 seconds. Hence the importance of resynthesis of ATP—refer to chapter A.3.3.

Normal physiological range for core temperature

Humans are able to maintain a reasonably constant core body temperature (T_c) throughout their lives despite a wide range of ambient temperatures.

Common methods used for measuring T_c during exercise testing include:

- a basic mercury thermometer (held in the mouth to measure oral temperature)
- an ear thermistor (measures tympanic membrane temperature)
- the use of a rectal probe (considered one of the most accurate methods)
- a gastrointestinal radio pill (expensive; a small single-use pill is swallowed and gives off a radio signal).

T_c is the temperature deep within the body. Shell temperature is the temperature near the body surface (around the skin). Depending on the environmental

temperature, shell temperature is 1–6°C lower than T_c . We detect that our bodies are under thermal stress with the help of temperature sensors located throughout the body, such as the skin. The hypothalamus, in the brain, is the control centre that functions as the body's thermostat.

Activity 1

Why is there no one true core body temperature?

When thinking about this, consider:

- heat production in muscles in different parts of the body
- blood flow
- temperature difference between inside the body and near the body's surface
- the temperature of inactive skeletal muscle is between 33°C and 35°C.

Metabolic rate and body heat

The production of body heat is proportional to metabolic rate. There are several factors that can affect this, such as:

- exercise (increases metabolic rate)
- hormones (for example, thyroid hormones increase basal metabolic rate)
- nervous system (for example, during exercise, sympathetic nervous system activity increases metabolic rate)
- body temperature (a higher body temperature increases metabolic rate)
- ingestion of food (energy is used to digest, absorb and store nutrients, which increases metabolic rate)
- age (children have a higher metabolic rate compared with adults)
- sex differences (metabolic rate is lower in biological females, except during pregnancy).

Heat transfer

To maintain normal body temperature there needs to be a balance between heat production and heat loss to the environment. Heat can be transferred away from the body via **conduction**, **convection**, **radiation** and **evaporation**.

Body temperature reflects a careful balance between heat production and heat loss. When we start to exercise there is an increase in heat production within the skeletal muscles. In other words, skeletal muscle temperature rises. Sometimes there is an imbalance—such as too much heat production and too little heat loss—which leads to a medical condition called **hyperthermia**.

Environmental heat stress increases the need for sweating and circulatory responses to remove body heat. The heat from deep in your body (the core) is moved by the blood to your skin and transferred to the environment by any of four mechanisms.

Conduction

Heat generated deep in your body can be conducted through tissue to the body's surface and to the clothing or air (or water) that is in direct contact with

This work must not be reproduced, stored, transmitted or circulated in any other form.

Activity 2

1. State normal core body temperature.
2. At rest, how does the difference between core body temperature and skeletal muscle temperature help transfer heat?
3. When does the heat transfer gradient flow from the body?

Key point

Under normal resting conditions in a temperate environment, body temperature is usually within $\pm 1.0^\circ\text{C}$ of average core body temperature (37.0°C).

Key term

Hyperthermia An elevated body temperature, usually above 39°C (102°F).

your skin. The rate of conductive heat loss depends on the temperature gradient between the skin and surrounding surfaces. However, in most hot and humid situations, conduction accounts for less than 2% of heat loss.

Convection

Convection involves moving heat from one place to another by the motion of air (or water). For example, blood transfers heat by convection from the deep body tissues to the skin. If air movement is minimal, the air next to the skin warms and heat loss slows down. Conversely, if cooler air continually replaces warmer air around the body, such as on a windy day, heat loss increases.

Radiation

Radiation is the transfer of energy waves that are sent out from one object and absorbed by another. For example, solar energy from direct sunlight can be reflected from snow, sand or water to help warm a person. The body absorbs radiant heat energy when the temperature of the environment is higher than skin temperature.

Evaporation

As the environmental (ambient) temperature increases, conduction, convection and radiation decrease their effectiveness for helping body heat loss. When this happens, evaporative cooling (conversion of sweat from liquid to water vapour) is the main way for the body to lose heat during exercise.

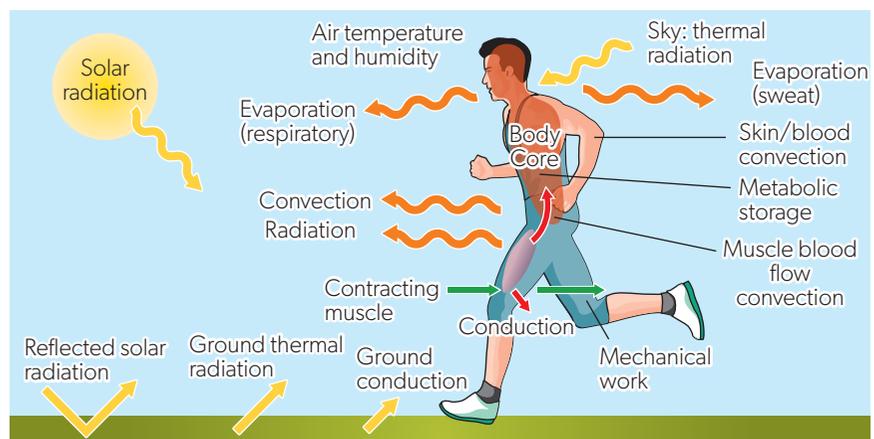
Key point

Evaporation of sweat is potentially the most important mechanism of heat dissipation, dependent upon the relative humidity of the environment.

Key point

When the environmental temperature is above skin temperature, evaporative heat exchange will account for almost all heat loss.

There are several thermoregulatory mechanisms by which humans strive to maintain a relatively constant core body temperature. For example, **non-shivering thermogenesis** is a process by which the body generates heat in response to cold temperature exposure without shivering. In non-shivering thermogenesis, the sympathetic nervous system stimulates increased metabolism—and increasing the metabolic rate increases heat production. Additionally, when muscle tissue contracts it produces heat. In cold environments involuntary contractions of skeletal muscle, known as **shivering**, can greatly increase the rate of heat production. For example, during maximal shivering, body heat production can rise to about four times the basal rate.



▲ **Figure 9** The potential avenues for heat exchange during exercise

Water vaporizing from the respiratory passages and skin surface (referred to as insensible water loss) continually transfers heat from the body to the environment (580 kcal of heat for each litre of water vaporized). This accounts for about 80% of total heat loss when you are physically active, but only about 20% of body heat loss at rest.

ATL Thinking skills

A thought-provoking 2012 paper suggested that fit individuals are the ones most at risk of developing hyperthermia during intense exercise. This is because, during self-paced exercise, unfit individuals do not reach higher core temperatures than fit individuals. A 2013 article disagreed, arguing that aerobic fitness enhances the ability to tolerate high body temperatures.

What do you think, and why?

The body's surface contains between two and four million sweat glands. Sweat production over an area of the skin depends on:

- the density (the number of sweat glands per cm² of skin surface)
- the amount of sweat per gland.

In most people, the back and chest have the greatest sweating rates. The limbs have relatively high sweating rates only after a substantial elevation in core temperature.

Heat production increases almost immediately at the onset of exercise, causing the core temperature to rise. The increase in sweating during exercise reflects this increase in body temperature. However, sweating is not 100% efficient because some sweat can drip from the body and not be evaporated.

Maximal evaporative heat loss from the body occurs when sweat is vaporized from the skin. Sweat that either drips off the skin, or is towelled off, does not provide any evaporative cooling. Sweat evaporation is also influenced by the amount of moisture in the air. For example, dry air receives vaporized sweat readily, whereas wet air receives little evaporated sweat because it is already heavily laden with moisture. The relative humidity provides an index of the amount of water in the air, and represents the most important factor in determining the effectiveness of evaporative heat loss.

Sex differences and thermoregulation

Sex differences affect thermoregulatory responses. Biological males typically have a higher sweat rate than biological females, which can help to dissipate heat more efficiently.

Biological females typically have a smaller body mass and a larger surface-area-to-mass ratio compared with biological males. Therefore, when athletes with similar aerobic ability and running performance are compared, the sex difference in surface-area-to-mass ratio may be a thermoregulatory advantage for female athletes in endurance events. However, having a higher surface-area-to-mass ratio is not a thermoregulatory advantage in all environments. For example, when performing exercise under hot, dry conditions with air temperature higher than skin temperature, athletes with a larger body surface-area-to-mass ratio will gain heat faster (all else being equal).

Additionally, as discussed in chapter A.1.1, the hormonal fluctuations of the menstrual cycle in a menstruating female may affect thermoregulation. Levels of the hormone progesterone peak during the luteal phase following ovulation (refer to chapter A.3.1 for a diagram showing a theoretical pattern of hormone levels during the menstrual cycle). The elevated levels of progesterone during

Key point

The respiratory system plays a significant role in conductive, convective and evaporative heat exchange. As air is inhaled, the respiratory tract warms and humidifies it. Even air below 0°C approaches body temperature when it reaches the alveoli.

Key point

Dehydration is a significant concern when losing body fluid through increased sweating in the heat.

Activity 3

Biological females tend to produce less sweat per gland. Would this be an advantage or disadvantage when exercising in:

- hot, dry environments, or
- hot, humid environments?

the luteal phase are associated with a delayed onset of sweating and decreased skin blood flow. There is a small increase in internal body temperatures following aerobic exercise in the heat in the luteal phase of the menstrual cycle compared with the follicular phase—but this should not affect performance until core temperature approaches around 40°C. However, it is accepted that more research is needed to explain thermoregulatory differences based on sex hormone fluctuation throughout the menstrual cycle.



Experiments

Most research conducted examining human thermoregulation and responses to exercise in the heat has been carried out with biological males. Among the small proportion of research that included biological females, menstrual cycle phase was often restricted to the early follicular phase. Why?

ATL Research skills

The Marathon des Sables is an ultramarathon around 250 km long. It is held annually in the Sahara Desert in Morocco. The organizers of the event are committed to respecting the environment in which the event takes place, promoting the message, “The Earth doesn’t belong to us, it’s the heritage we leave our children.”

The organizers’ initiatives to protect the environment, called Operation Desert Clean, include:

- numbering water bottles, with a penalty incurred for anyone who abandons a bottle during the race
- setting up toilets every day and maintaining them using biodegradable products
- providing pocket ashtrays to avoid disposal of cigarette butts
- using an incinerator to remove waste.

Identify a sporting event that is taking place outdoors in your own country. Try to find out how the participants and organizers protect the environment and “the heritage we leave our children”.

Key point

With globalization of sporting events, adventure tourism, oil exploration in the Arctic, space travel and so on, environmental stressors are more than simply the daily variation in local weather.

Yanovich et al. (2020) evaluated whether menstrual cycle phase in young females was an important contributor to being classified as heat-tolerant or heat-intolerant during a heat-tolerance test. They found no difference between the follicular and luteal phases in terms of whether individuals fell into the heat-tolerant or heat-intolerant categories. The strongest predictor for successful completion of the heat-tolerance test was maximal oxygen uptake, i.e. fitter individuals (with higher maximal oxygen uptake values) have improved physiological heat dissipation (sweating and skin blood flow) compared with less fit individuals. Importantly, there is no evidence that females are at greater risk of heat illness when the usual risk management techniques are in place. The roles of sex and reproductive hormones in thermoregulation and performance are complex and depend on the specifics of a given situation, including exercise intensity and environmental conditions.

Responses and adaptations to environment

Temperature regulation

Globalization and the popularity of adventure tourism have led to increased participation in activities in extreme environments, with more people participating in extreme sports and ultra-endurance events worldwide. Although performance is the main interest for athletes, safety is important when planning training programmes, events such as the Marathon des Sables, and policies for sport and exercise. It is therefore important to understand how the body regulates its temperature in response to its environment.

Adaptations are the body's attempts to counteract stressors—such as heat, humidity and cold—and maintain homeostasis. There are at least 31 climatic zones around the world, ranging from year-round freezing conditions to daily hot temperatures of around 45°C. Each zone is inhabited by people who have acclimatized to accommodate the environmental conditions. **Acclimatization** is a natural adaptation, for example, to improve exercise performance and heat tolerance in a hot climate. **Acclimation** is acclimatization in an artificial environment (e.g. an environmental chamber).

Hot environments

Heat acclimatization

Heat acclimatization requires exercise in a hot environment, not merely exposure to heat, and usually requires 10–14 days. It results in better matching of thirst to the body's water needs and increased total body water (by as much as 5%).

Your total exercise–heat exposure time each day should work towards 90–100 minutes. However, you should reach this gradually by increasing duration and intensity. Important signs of heat acclimatization during submaximal exercise in the heat are a lower heart rate and core temperature and a higher sweat rate.

Submaximal exercise refers to the intensity of an exercise session and means exercising below maximum effort. With acclimatization you are able to maintain submaximal exercise for longer periods of time.

For example, classification of exercise intensity could be based on a percentage of maximal heart rate (HR_{max}), such as:

- 35–59% of HR_{max} = light exercise intensity (submaximal light)
- 60–79% of HR_{max} = moderate exercise intensity (submaximal moderate)
- 80–89% of HR_{max} = heavy exercise intensity (submaximal heavy).

Chronic adaptations to exercise that can improve exercise performance in the heat include:

- increased plasma volume
- earlier onset of sweating (and at a lower core temperature)
- a more dilute sweat composition (electrolyte loss reduced)
- reduced rate of muscle glycogen use
- decreased psychological perception of effort.

Key point

Heat stress depends upon the environmental conditions (ambient temperature and humidity), clothing, exercise intensity and acclimatization.

Heat stress during a single exercise bout increases the metabolic rate (including increased muscle glycogen use) needed for the body to perform submaximal exercise. With acclimatization there is a reduced rate of muscle glycogen use when performing at the same relative submaximal exercise intensity. This may help improve endurance performance.

Higher levels of aerobic fitness decrease the intensity and duration needed to maintain acclimatization (or to re-acclimate) to heat. The major benefits of heat acclimatization gradually disappear if not maintained by continued heat exposure. The benefits of heat acclimatization are retained for about a week after returning to a cooler environment, but approximately 75% of the benefits will be lost after about three weeks away from the heat exposure.

Key point

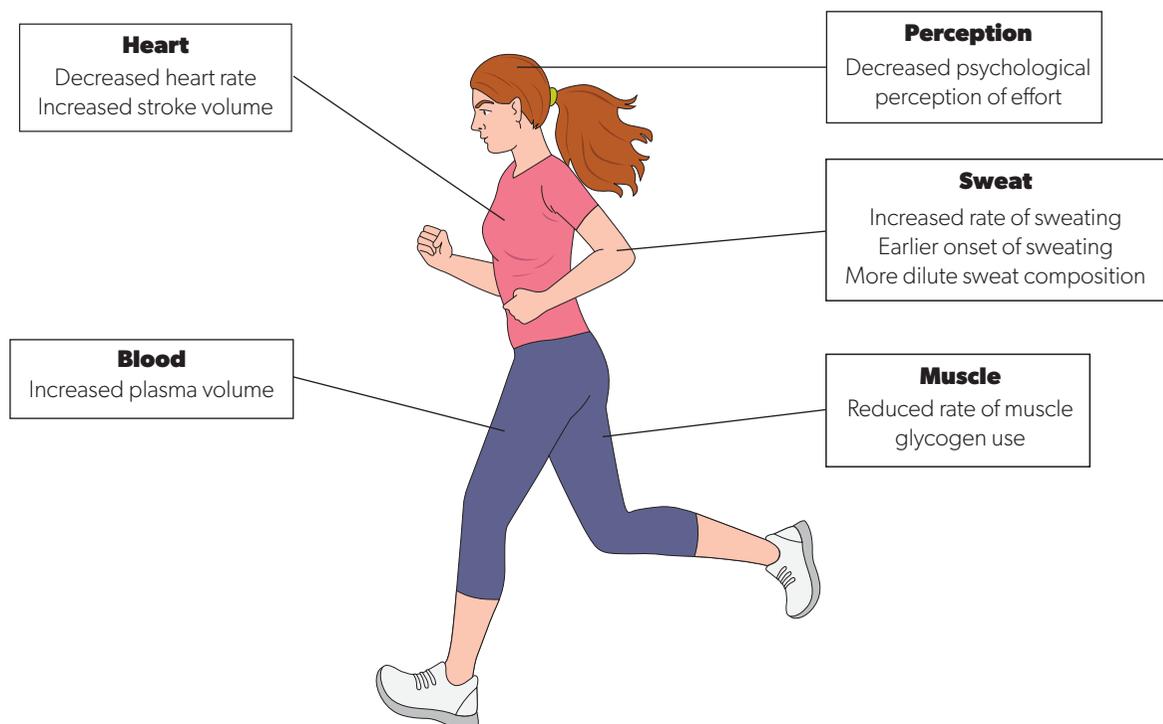
The acute acclimatization response, such as changes in core temperature and heart rate response, occurs in the first five days of exposure to heat. Whereas the chronic acclimatization response, such as changes in the onset of sweating and the rate of sweat production, takes about 9–14 days to be about 80% complete. However, the degree of acclimatization is highly variable between individuals, and some who engage in sports competitions in the heat never fully adapt.

In summary, heat acclimatization/acclimation is an essential heat safety and performance enhancement strategy in preparation for competitions in warm-to-hot conditions for both individual and team sports. The benefits of heat acclimatization/acclimation are clearly demonstrated in athletes competing in prolonged hot weather events. For example, Pryor et al. (2019) found running time-to-exhaustion and running time trial performance improved up to approximately 23% and 7%, respectively, following heat acclimatization/acclimation.

These improvements may be due to enhancements in:

- maximal oxygen consumption
- movement economy
- lactate threshold
- thermotolerance.

Additionally, note that enhanced thermal comfort is associated with performance optimization in the heat by removing reservations about high-intensity exercise and, for example, enabling proper pacing during competition. Figure 10 shows some of the heat acclimatization/acclimation adaptations that support exercise performance and safety in the heat.



▲ Figure 10 Adaptations that support exercise performance and safety in the heat

Heat illness

Hyperthermia, heat exhaustion and heat stroke are recognized as major risks during exercise in hot or hot and humid environments. Such problems can even occur in cool conditions with intense or prolonged exercise such as marathons or triathlons. Heat exposure can also be a significant clinical problem for non-exercising populations. For example, the 2021 summer heat wave in British Columbia in Canada (with a mean temperature of 36.3°C) was blamed for at least 434 deaths (Henderson et al., 2022). This can happen even where summers are traditionally very hot and the population is heat acclimatized (Yip et al., 2008).

For most people, a higher level of aerobic fitness can provide protection from heat stress during exercise in the heat, similar to that observed with acclimatization to hot environments.

These benefits include:

- greater evaporative heat loss through improved sweating response
- initiation of sweating at a lower core temperature
- greater sensitivity of sweating response to increasing core temperatures
- an elevated plasma volume, minimizing the competition for blood distribution between skeletal muscle and skin.

Individual variability in heat tolerance

Some of the major factors that may predispose individuals to heat intolerance during exercise in hot environments are:

- lack of acclimatization
- low fitness
- large body mass
- dehydration
- age (the elderly or pre-pubertal children).

Key point

Competing in sport, exercising or participating in physical activity in the heat can challenge individuals physiologically to maintain effective temperature regulation. This depends upon a range of factors including your age, fitness level and acclimatized status.



▲ Figure 11

ATL Research skills

In 2022, the soccer World Cup took place in Qatar. The event was moved from July to the cooler months of November and December.

Research the climate of Qatar and explain how you would plan an acclimatization training programme to:

- prevent heat illness
- optimize the performance of a sports team competing in these conditions.

Exercise capacity and performance in hot conditions

Fatigue and reduced exercise capacity in the heat can have many underlying causes, ranging from direct temperature effects on the brain's cognitive functioning through to changes in the muscular and cardiovascular systems. For example, in the cardiovascular system, this is likely due to competition for blood flow to both active muscles and the skin for conductive heat exchange. The loss of plasma volume through sweating and dehydration adds to the cardiovascular strain.

While mild muscle warming or warm ambient temperatures help muscle force generation, hyperthermia has a negative effect and impairs the level of maximal muscle force generation and muscle activation. Impaired mental activity associated with hyperthermia may be connected to decreases in brain blood flow. For example, the feeling of lethargy during exercise is often reported with people experiencing hyperthermia. This may reflect a reduced state of arousal and is commonly associated with higher ratings of perceived exertion during exercise. Thus, exercise in the heat increases thermal strain, such as during a game of tennis in a hot and humid environment, and can result in hyperthermia.



▲ Figure 12 Tennis in a hot and humid environment



▲ Figure 13 Novak Djokovic using a towel packed with ice in Melbourne

The development of hyperthermia impairs exercise capacity and performance in hot environments, and can often result in an earlier than planned reduction in intensity during exercise. One of the reasons for this is that the temperature of the brain depends on the temperature of the blood that supplies it. Some studies have shown benefits of cooling the head and neck during exercise in hot environments. This knowledge was used by Novak Djokovic—he placed a towel packed with ice around his neck between games during the Australian Tennis Open (Figure 13).

Minimizing exercise-related increases in core body temperature before exercise (pre-cooling) in hot environments is more frequently being used to try to lessen the effects of heat stress on performance. Wearing ice vests during the warm-up seems to reduce the physiological and perceptual results of exercise in the heat.

There is good evidence that pre-cooling interventions—such as ice baths and ice vests—may improve performance in events that rely on a high and sustained aerobic effort (such as running, rowing or long-distance cycling). Pre-cooling delays heat build-up during the warm-up. It can also decrease perceptions of heat stress and promote an up-regulation of work intensity (that is, a faster running pace/cycling speed or higher stroke rate in rowing). Thus, practical strategies, such as wearing an ice vest during the warm-up (pre-cooling) and using an ice-packed towel during breaks in the event, reduce heat stress and help performance in hot environments (Skein et al., 2011).



▲ Figure 14 Belgian heptathlete Nafissatou "Nafi" Thiam wears a cooling vest during the 19th IAAF World Athletics Championships



Global impact of science

Initial concern about the possible effects of global warming on infections has declined with the realization that the spread of tropical diseases is likely to be limited and controllable. However, the direct effects of heat already cause substantial numbers of deaths among vulnerable people in the summer. Action to prevent these deaths from rising is the most obvious medical challenge presented by a global rise in temperature. Strategies to prevent such deaths are in place to some extent, and they differ between countries. For example, air conditioning has reduced deaths in the USA, and older technologies such as fans, shade and buildings designed to keep cool on hot days have generally done so in Europe. Since the energy requirements of air conditioning accelerate global warming, a combination of older methods with air conditioning when necessary can provide the ideal solution. Despite the availability of these technologies, occasional record high temperatures still cause sharp rises in heat-related deaths.

When a heat wave strikes, anyone having dangerous heat stress needs immediate cooling (for example, with a cool bath). Such action at home can be more effective than transporting the patient to hospital.

Meanwhile, cold weather in winter causes many more deaths than heat in summer, even in most subtropical regions. So, measures to control cold-related deaths also need to continue (Keatinge, Donaldson, 2004).

Climate change with global warming may affect health, as reflected in the article above. Discuss the potential impact that global warming may have on using training heart rate to monitor exercise intensity.

ATL Research skills

There is wide inter-individual variability in response to a set environment and exercise load. Intra-individual response can also vary based on acclimatization, hydration, drugs (such as caffeine) and so on.

Moran et al. (1998, 1999) developed an individual heat strain index from a combination of heart rate and core body temperature, as well as a cold strain index based on core and skin temperatures.

Find out more about these indexes and how they are measured.

Cold environments

The main factors for environmental cold stress during outdoor activities in cold weather are air temperature and wind speed. Normally, when exposed to a cold environment, we dress to decrease sensations of cold, prevent dangerous drops in core body temperature and avoid cold injury including hypothermia.

Hypothermia can be defined simply as low body temperature, but there are different clinical categories (mild, moderate, severe, profound).

It is not uncommon to experience mild hypothermia, and the most commonly cited core body temperatures for mild hypothermia are around 34–35°C.

The warning signals for hypothermia include uncontrollable shivering, slurred speech, stumbling, drowsiness, and inability to stand and move after a rest.

Ironically, although wearing clothing helps ensure exposure to cold is minimized,

Key term

Hypothermia Low body temperature that has different clinical categories depending on the severity.



▲ Figure 15 Recreational activity in a cold environment



▲ Figure 16 Occupational activity in a cold environment

this can reduce the potential for heat loss from evaporative cooling, radiation and convection. In fact, you need to be careful during exercise in the cold because too much body insulation from clothing could lead to exercise-induced hyperthermia, as well as exercise-induced dehydration!

There is a large potential for heat loss from the head. The head represents only about 8% of the body's total surface area, but nearly 30%–40% of body heat is lost through the head region. This is because vasoconstriction does not seem to occur in the brain circulation during exercise in cold weather.

Humans possess much less capacity for adaptation to long-term cold exposure than to prolonged heat exposure. Nowadays, there are many recreational, competitive and occupational activities in cold environments, and increased participation in winter sports such as cross-country skiing, hiking and snowboarding all expose the body to cold air and wind chill. When the ambient temperature is colder than body temperature, heat loss occurs, and wind increases heat loss by convection.

The British Antarctic Survey team, as an occupational example, carry out research and surveys in the Antarctic and surrounding regions. For instance, they use observations from polar regions to improve our understanding of how natural and human-induced factors contribute to climate change.

Acute response

With cold exposure, skin and core temperatures decrease, and this stimulates the hypothalamus. The peripheral response to cold involves vasoconstriction of the skin and skeletal muscle circulations, decreasing blood flow and therefore convective heat transfer between the body's core and shell (skin, subcutaneous fat and skeletal muscle). Cold exposure results in the stimulation of shivering.

The characteristics of shivering include:

- involuntary, repeated, rhythmic muscle contractions
- can start immediately or after several minutes of exposure to the cold
- there is minimal movement
- highly effective method of heat production from metabolic energy
- usually begins in the torso and then spreads to limbs

- as shivering intensity increases, more muscles are used
- intense shivering can equate to more than 1 l min^{-1} of oxygen consumption.

Exercise in cold environments

If heat production from submaximal exercise during cold exposure is not enough to balance heat loss from the body to the cold environment, there will be an increase in oxygen uptake from shivering because of the added oxygen requirement for metabolism in the shivering muscles. Cold exposure can also affect cardiovascular responses to submaximal exercise. Compared with exercise at the same intensity in a temperate climate, exercise in the cold results in lower heart rates and increased stroke volume to maintain cardiac output. One explanation for the lower heart rates and stroke volume increase during exercise in the cold is increased central blood volume resulting from peripheral vasoconstriction.

During cold exposure the amount of clothing required to maintain thermal balance will depend upon the exercise intensity. It is good advice to dress in layers during exercise in the cold and remove layers as exercise intensity increases to prevent too much net body heat gain (because of too much clothing insulation).

Fuel utilization during cold exposure

Prolonged exercise is marked by the eventual depletion of carbohydrate stores and inability to maintain blood glucose. In cold environments, it is thought that the added energy requirements of shivering increase glycogen breakdown during exercise. There is good evidence that shivering, like low-intensity exercise, relies on fat (lipids) as the main energy source, and blood glucose, muscle glycogen and even protein can be used as well. The relative contribution of fats, carbohydrates and proteins to heat production during cold exposure depends on whether glycogen levels are low or high, shivering intensity, and the severity and type of cold exposure. It is suggested that more carbohydrate intake may be required for prolonged exposure or exercise in the cold (Haman, 2002, 2006).

ATL Thinking skills

During cold exposure there can be a reduction in muscle efficiency associated with:

- decrease in muscle contractility
- decrease in the velocity and power of muscle contraction
- change in the pattern of muscle fibre recruitment.

Body composition and size, exercise and cold stress

Cold stress depends on environmental temperature and exercise intensity (metabolic rate) as well as the resistance to heat flow provided by body fat. Fat is an effective insulator because its capacity for transferring heat is relatively low, helping to slow down heat transfer from the inside of the body to the body's surface. This enables individuals with greater amounts of body fat to retain more of their heat and reduce the effects of cold environments (by increasing the effectiveness of skin vasoconstriction). Thus, as the amount of fat increases, the rate of heat loss decreases; that is, heat loss is inversely related to the amount of (subcutaneous) fat. This partly explains why people with more fat can generally tolerate a lower water or air temperature than lean people before shivering begins.

ATL Research skills

Galloway and Maughan (1997) found that endurance cycling performance is optimal in an ambient temperature of 11°C , and there was a 13% decline in endurance cycling performance at 4°C .

Can you find out the optimal temperature for other sporting activities?

Key point

Body composition (ratio of body fat mass to lean muscle mass), body size (ratio of skin surface area to body mass) and training status influence ability to cope with cold exposure.

The ratio of body surface area to body mass affects the rate of heat loss. A larger surface-area-to-body-mass ratio makes heat loss easier, and this can be advantageous in a warm environment. In adults with the same body mass and similar surface areas, biological females typically have better insulation because of higher levels of body fat. However, biological females tend to have a relatively smaller total muscle mass than biological males. This reduces capacity for heat production from shivering.

Activity 4

During the same relative submaximal exercise intensity in a cold compared to a temperate environment, explain what happens to economy (the rate of oxygen uptake).

Key point

The human body is less able to adapt to the stress of cold environments than it is to hot environments. To protect against cold exposure, humans depend upon behavioural change, such as moving to shelter and wearing more clothes and/or more appropriate clothing.

Children are smaller and lighter than adults and, therefore, tend to have a larger surface-area-to-mass ratio than adults. This helps explain why children find it more difficult to maintain normal body temperature in cold environments, making them more at risk of hypothermia. During exercise in the cold, children can partly compensate for their high surface-area-to-mass ratio by being more active (increasing energy metabolism) with a more effective constriction of the blood vessels supplying the skin and the skeletal muscles (increased insulation of the shell of the body).

Human adaptation to chronic cold exposure

Individuals can adapt to cold environments, but they have less physiological adaptation to chronic cold stress than to prolonged heat exposure. The cold adaptation, which is slower to develop than heat acclimatization, results in less discomfort, enhances dexterity, helps prevent cold illnesses and injuries, and improves survival in a cold environment.

There are three main adaptive responses by which your body regulates its core temperature from chronic exposure to a cold environment:

- habituation—a desensitization of the normal response to cold
- metabolic acclimatization—for example, greater shivering response to increase heat production
- insulative acclimatization—increased vasoconstriction to enhance heat conservation.

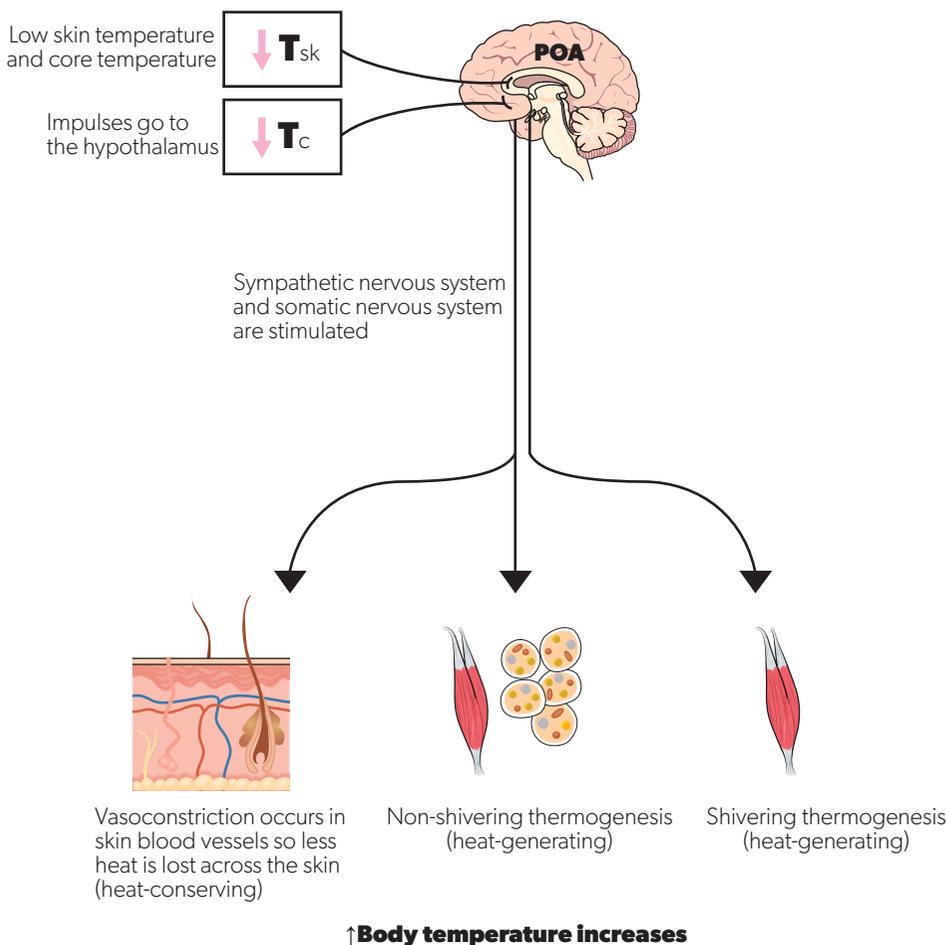


Figure 17 shows the physiological responses to cold exposure. Decreases in mean skin temperature and core temperature are sensed by peripheral (skin) and core body temperatures. This results in the hypothalamus initiating insulative (heat-conserving) and metabolic (heat-generating) responses to regulate body temperature during cold exposure.

Human adaptation to cold exposure also happens after repeated short-duration mild cold exposures, and seems to benefit individuals through increased skin temperatures and decreased shivering. Cold habituation also results in decreased sympathetic nervous system activation, the effects of which may offer benefits in other environments such as high altitude. However, further research is needed to determine whether central or peripheral mechanisms are key to this adaptation.

▲ Figure 17 Physiological responses to cold exposure

Wind chill

When exercising outdoors the air temperature is not the only factor in the amount of thermal stress from cold that you experience. Both air temperature and wind influence the coldness of an environment experienced by an individual. Therefore, there is a large difference in how cold we feel on a cold but calm day as opposed to a cold and windy day. Wind increases the rate of heat loss (via convection and conduction) because the warmer insulating air layer surrounding the body continually exchanges with the cooler ambient air.

Windproof clothing and/or doing strenuous exercise reduce wind chill effects. The wind chill index illustrates the cooling effect of wind on exposed skin for different temperatures and wind velocities. The effects of increasing wind speed with decreasing air temperature, including values for dangerous exposure to frostbite, are shown in Figure 18.

		Temperature (°C)												
		10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Wind speed (km h ⁻¹)	10	9	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
	20	7	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
	30	7	0	-7	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
	40	6	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
	50	6	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
	60	5	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
	70	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
	80	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81
	90	4	-3	-10	-17	-25	-32	-39	-46	-53	-61	-68	-75	-82
	100	4	-3	-11	-18	-25	-32	-40	-47	-54	-61	-69	-76	-83

10–30 minutes
2–10 minutes
less than 2 minutes

▲ Figure 18 The wind chill index



Activity 5

1. When running outdoors in an air temperature of -20°C on a windy day with wind speed 30 km h^{-1} :
 - a. what is the wind chill index?
 - b. how long before frostbite could occur?

Wind direction is important. For example, when running at 12 km h^{-1} into a 20 km h^{-1} headwind, this creates a relative wind speed of 32 km h^{-1} . When running at 12 km h^{-1} with 20 km h^{-1} wind at one's back, this creates a relative wind speed of 8 km h^{-1} .

2. When running at 15 km h^{-1} into a 25 km h^{-1} headwind, what is the relative wind speed?
3. When running at 15 km h^{-1} into a 25 km h^{-1} headwind in an air temperature of -25°C :
 - a. what is the wind chill index?
 - b. how long before frostbite could occur?

Cold air exposure, hypothermia and frostbite

In cold climates of the Earth, the main environmental stressors that disturb homeostasis are:

- air temperature below skin and core body temperatures
- air movement across the body (accelerating loss of body heat)
- cold, dry air
- cold water immersion (which causes faster cooling of skin and core body temperatures compared with cold air at the same temperature).

The main life-threatening cold injury is a dangerous loss of body heat leading to hypothermia as discussed above. The risk for hypothermia on land increases during cold, moist and windy conditions.

ATL Research skills

Explain why, during cold exposure, performers involved in more technical sports that demand fine motor control experience skilled performance decrements.

Key terms

Frostnip The initial freezing of the superficial skin tissue.

Frostbite The continued cooling and freezing of cells.

The fingers and toes are poorly designed for holding heat, both in their anatomical arrangement and in their pattern of circulatory control. Long and narrow digits result in a relatively high ratio of surface area to volume for convective heat loss. Also, the low muscle mass and low amount of fat in the feet and hands provide minimal heat-generating capacity and insulation against heat loss. Additionally, upon initial exposure to cold, vasoconstriction can very rapidly decrease distribution of blood flow to the extremities and divert blood and heat to the core and vital organs such as the heart and brain. Thus, freezing cold injuries like **frostnip** and **frostbite** are more likely to happen in the feet, hands and exposed parts such as the nose and ears. Factors that are associated with getting frostbite include alcohol use, low physical fitness, fatigue, dehydration and poor peripheral circulation, but it can happen to anyone. However, frostbite cannot occur if the air temperature is above 0°C (32°F).

The rates of local heat loss and cell damage from (convective) heat loss are the main determinants of frostnip and frostbite. Frostnip is the initial freezing of the superficial skin tissue. It is painful but typically does not produce long-term damage. Frostbite is continued cooling and freezing of cells. This can lead to the destruction of cells, with the damaged regions becoming insensitive to touch. Due to the risk of infection and gangrene, it is recommended that re-warming and frostbite treatment occur in a medical setting if possible.

ATL Thinking skills

Former Olympic champion Justin Gatlin (Figure 19) had an unfortunate experience in his preparation for the 2011 World Athletics Championships at Daegu (South Korea) when he entered a cryogenic chamber with wet socks (from sweat) and ended up suffering from frostbite on both feet.

For some reason the socks froze to my ankles. It felt like my feet were on fire ... and it hurt to walk.

Justin Gatlin, 2011



▲ Figure 19 Justin Gatlin



▲ Figure 20 Frostbite of the fingers and toes

Cold-wet injuries

Radiation and sweat evaporation are the primary mechanisms for heat loss in air. However, heat conduction away from the body is greater during exposure to a given cold air temperature when skin and clothing are wet. The body loses heat more quickly in water than it does in air of the same temperature. Further increases in heat loss occur in water when there is water movement over the body because of the increased contribution of convective heat loss. However, individuals vary greatly with respect to the water temperature they can tolerate.

Body heat loss from conduction is greatest during immersion in cold water. The most important predictors for the onset of cold-wet injuries are the water temperature and duration of exposure.

Too cold to exercise?

The direct effect of exercise in the cold is the breathing of cold (and dry) air. As alveolus tissue is thin, moist and fragile, the inhaled air must be warmed (and humidified) before entering the lungs. Therefore, one potential hazard is the possibility of asthma attacks. For asthmatic individuals and those with exercise-induced asthma, the breathing of cold air can trigger shortness of breath and reduced exercise capacity.

Stenstrud et al. (2007) compared exercise in a 20°C versus a -18°C air temperature environment. They found that individuals with exercise-induced asthma had a lower maximum oxygen uptake and slower running speeds in the cold air environment (-18°C) compared with the 20°C environment. For all athletes, high breathing (ventilation) rates during exercise in cold air temperatures can result in significant heat loss and potentially dehydration. Therefore, ensuring adequate hydration is important during exercise in the cold. However, even for people with respiratory issues aggravated by cold air inhalation, the health benefits of physical activity likely outweigh any potential health risks if appropriate precautions are taken.

Castellina et al. (2006) highlighted some important preventative measures to consider when exercising in the cold.

- Clothing insulation requirement depends on the exercise intensity and environment, and too much clothing insulation can lead to heat stress.
- In high wind chill conditions, people should ensure that exposed skin is kept to a minimum.

- The feet, hands, face and ears are the locations at highest risk for frostbite and other cold injuries. Therefore, care must be taken to provide insulation or supplemental heating to the feet, hands, face and ears.
- A higher core body temperature promotes blood flow to the extremities, so it is important to ensure that core body temperature is preserved.
- Carbohydrate ingestion is recommended to allow for increased glucose metabolism during exercise in the cold.

Cold water immersion

The initial respiratory and cardiac responses to cold water immersion are thought to be responsible for a significant number of open water deaths each year. The initial responses to cold water immersion include tachycardia, a reflex inspiratory gasp and uncontrollable hyperventilation, causing difficulty for individuals trying to hold their breath if submerged.

Tachycardia is an abnormally rapid resting heartbeat or pulse rate (over 100 bpm), and hyperventilation is a rate of respiration higher than that required to maintain a normal level of carbon dioxide in the blood. For example, average resting adult values of 12 breaths and 6 l min⁻¹ in ventilation may increase to more than 30 breaths and 80 l min⁻¹ in ventilation when immersed in 10°C cold water (Tipton et al., 1998).

The main stimulus for the cold shock response described above appears to be the rapid drop in skin temperature upon immersion in the cold water. Swimming in cold water results in significant redistribution of blood to the core, intense peripheral vasoconstriction and reduced muscle blood flow through the limbs. Additionally, sudden immersion in cold water can result in a reflex contraction of skeletal muscles making proper neural coordination difficult.



▲ Figure 21 Many people enjoy swimming outdoors in winter environments!

ATL Research skills

Arms have a greater ratio of surface area to mass and thinner subcutaneous fat compared with legs. How might this influence the design of cold-weather athletic clothing?

Effects of clothing

Various types of specialist clothing are available to provide protection during physical activity, exercise, sport, and recreational and occupational activity in cold conditions. The amount of clothing insulation required to maintain body temperature (and comfort) by insulating against excessive body heat loss during cold weather activity will depend upon the ambient temperature and the exercise intensity. The standard unit of clothing insulation is known as the clo.

The clo unit is a measure of the insulatory capacity provided by any layer of trapped air between the skin and clothing. The clo unit requirement is affected by an individual's metabolic rate at a given ambient temperature—more clo units are required as ambient temperature decreases and/or metabolic intensity reduces, and vice versa.

A clo unit of 1 is defined as maintaining a sedentary person at 1 MET (a unit of resting metabolism or energy expenditure at rest) indefinitely in an environment of 21°C and 50% relative humidity.

The wearing of suitable clothing can significantly decrease evaporative heat loss by slowing down the movement of water vapour across the clothing layers. In hot, humid environments the majority of sweat either drips from the body or is trapped within the fabric layers of clothing. When this happens there is a significant reduction in the capacity of evaporation to remove heat energy. In cold-weather environments this can create even more body heat loss during exercise because clothing loses much of its insulating qualities when it becomes wet.

However, often during exercise in cold air the challenge is not from inadequate clothing insulation, but from the clothing barrier preventing the loss of heat that is being created by the exercise itself. Cross-country skiers, for example, overcome this problem by removing layers of clothing as the body warms up, and this removal of layers of clothing helps maintain core temperature without reliance on evaporative cooling. Thus, the ideal winter clothing in cold, dry weather insulates the body while allowing water vapour to escape through the clothing if sweating occurs.



Linking question

How effective are experimental methods in creating double-blind experiments in varied environments? (Tool 1, Inquiry 2)

Consider:

- bias, reliability, validity and confounding factors
- drug/pharmacological/medical experiments/trials and placebo controls
- behavioural studies and unintentional researcher cues/behaviours/expectations
- use of computers/automated systems
- field experiments, randomized control trials and bias
- trustworthy findings.



Linking question

How do the challenges of performing in varied environments influence mental toughness and learning? (C.1.2)

Consider:

- environments such as cold, heat or high altitude can present significant challenges for individuals
- physical discomfort, fatigue and decreased cognitive function, and how this might challenge an individual's mental toughness
- the ability to adapt and overcome obstacles in the face of adversity
- the ability to remain focused, motivated and resilient in the face of adversity
- how learning to perform in these challenging environments can help individuals perform better under stress and overcome obstacles in other areas of life
- with exposure to challenging environments, individuals must learn to adapt and develop new skills to cope with the demands of the environment
- performing in extreme environments promotes the development of mental toughness and learning.



▲ Figure 22

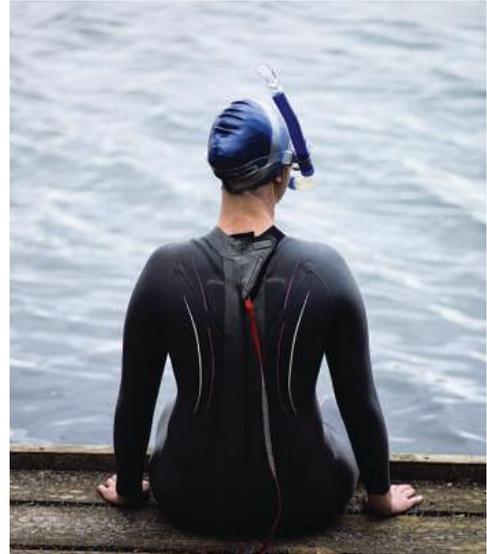


Linking question

Are the benefits from cold water swimming a result of the rejuvenating effects of immersion in cold water or the activity of swimming per se? (A.3.2)

Consider:

- adherence to and enjoyment of physical activity
- individuals' basic needs for autonomy, competence and social connection
- physical activity with others (support and positive interactions), but does not undermine a preference to be active alone
- where possible some physical activity should be undertaken outside in pleasant natural environments
- physical inactivity is inversely associated with mental health
- maintaining physical activity has been associated with reducing the prevalence, risks or deaths from non-communicable diseases
- physical activity has been identified as a potential tool to reduce symptoms such as depression in young people and adolescents
- depression is the second most prevalent mental problem in the world
- environmental stress that challenges our body's thermal equilibrium may produce health benefits, such as reduced depression and improved mood
- an increasingly popular form of environmental stress is exposure to cold water swimming, defined as "swimming when air and water temperatures are below 18°C."



▲ Figure 23

Altitude

The weight of the Earth's atmosphere is continuously pressing down on us, and the pressure of that column of air is called **barometric pressure (P_b)**. At sea level, P_b is 760 mmHg. Barometric pressure is a measure of the total pressure exerted on the human body by all the gases that make up the atmosphere (nitrogen \approx 78%, oxygen \approx 21%, argon \approx 0.9% and other trace amounts of gases). Oxygen molecules make up 20.93% of the air. The **partial pressure of oxygen (PO_2)** is the part of P_b exerted only by the oxygen molecules in the air. Therefore, at sea level, PO_2 is 20.93% of 760 mmHg, which is 159 mmHg.

When you ascend to a higher **altitude**, meaning height above sea level, low or reduced PO_2 can limit exercise performance. At high altitudes, this significantly impairs physical performance, and can be life-threatening. A hypobaric environment is when there is a reduced barometric pressure, such as at altitude. In a hypobaric environment, the inspired air will have a lower PO_2 , limiting movement of oxygen into the lungs, and from the lungs to the blood, and oxygen transport in the blood to the tissues. Low PO_2 in the air is termed **hypoxia** (low oxygen), and low PO_2 in the blood is known as hypoxemia.

Hypoxia limits pulmonary diffusion and oxygen transport into tissues, and this can impact both endurance athletes (for example, 5 km and 10 km runners) and

Key point

When there is insufficient oxygen to maintain normal tissue function, the environment is hypoxic. Severe hypoxia can lead to death.

participants in events that require speed-strength qualities (for example, 400 m and 800 m runners). However, short-term and explosive types of sports can benefit from lower air resistance. For example, at the 1968 Mexico Olympics (altitude of 2,200 m) Lee Evans broke the 400 m world record (Figure 24). This world record stood for two decades.

Case study

Bob Beamon long jump world record

The effects of altitude on sport became prominent in 1968 during the Olympic Games in Mexico City at an altitude of 2,200 m. At altitude, as the air is thinner, there is less air resistance, also known as drag. With less drag, objects (for example, long jumpers) tend to travel further. Helped by the decreased air resistance, Bob Beamon broke the long jump world record by an amazing 55 cm to record a distance of 8.90 m. The record stood for nearly a quarter of a century, and is one of the most memorable sporting achievements ever.



▲ Figure 25 Bob Beamon breaking the long jump world record in 1968



▲ Figure 24 Lee Evans (left) breaking the 400 m world record in 1968

Height ranges for different categories of altitude

When talking about altitude, the following ranges of height above sea level are commonly used:

- Near sea level (below 500 m) and low altitude (up to 1,500 m): no effects of altitude on well-being or exercise performance.
- Moderate altitude (1,500–2,000 m): there may be a reduced exercise performance, but this can be overcome with acclimation/acclimatization.
- High altitude (2,000–3,000 m): negative effects are likely for both well-being and aerobic-based performance, acclimation/acclimatization may or may not assist with achieving optimal performance.
- Very high altitude (3,000–5,500 m): adverse health effects (including acute mountain sickness), many individuals will experience a significantly reduced exercise performance (even post-acclimation/acclimatization).
- Extreme altitude (above 5,500 m): severe hypoxic effects are experienced.

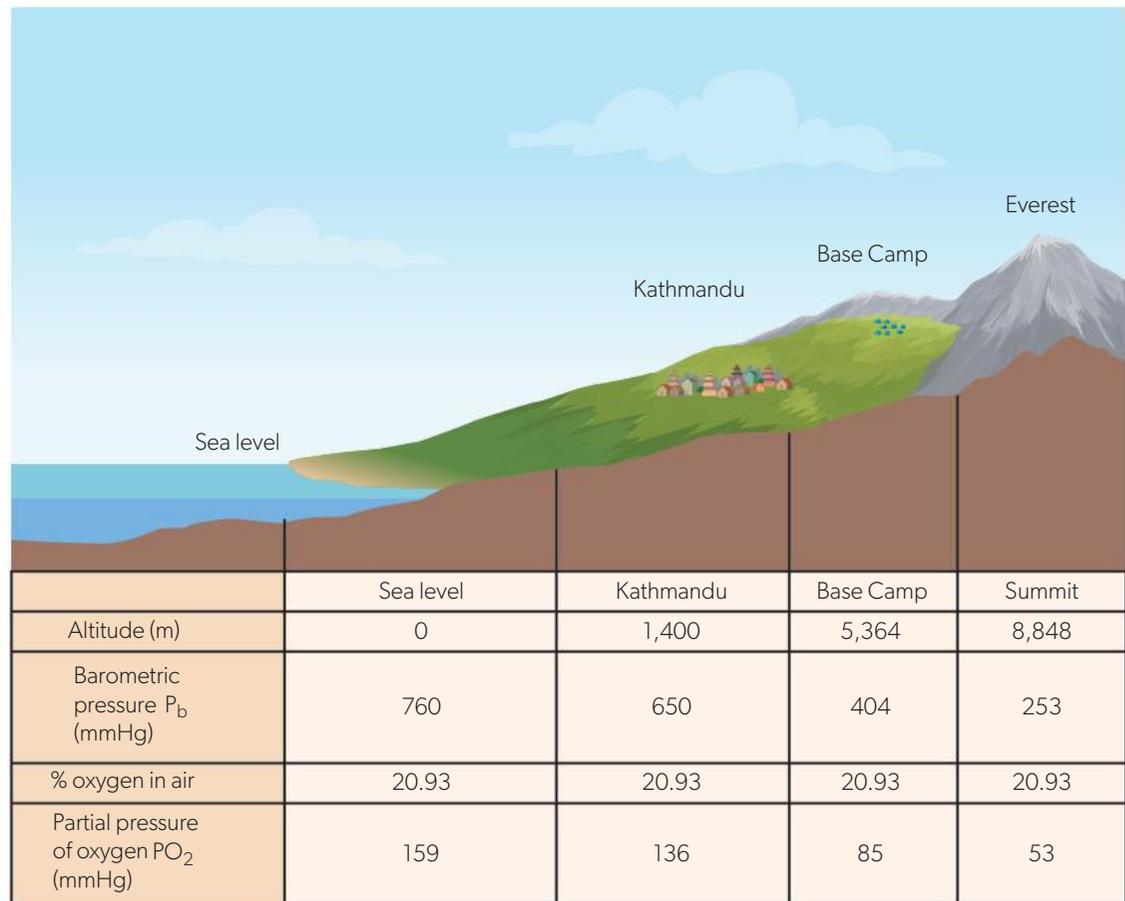
As there are very few negative effects on exercise performance below 1,500 m, above 1,500 m is commonly termed *altitude*.

The barometric pressure at any location on Earth is related to the weight of the air in the atmosphere above that point. This is why the P_b is higher at sea level (760 mmHg) and lower in locations at altitude (for example, on Mount Everest at 8848 m, $P_b = 253$ mmHg). However, although P_b varies, the percentage of gases in the air we breathe remains unchanged from sea level to altitude. That is, only the partial pressures of these gases change. The air always contains 20.93% oxygen from sea level to extreme altitude, as shown in Figure 26.

Key point

Benefit of altitude training

For endurance and aerobic events, if you are not acclimatized, your performance will decrease. With altitude training, the body reacts to the decreased atmospheric pressure by making more red blood cells to help the uptake of oxygen—an important benefit of altitude training.



▲ Figure 26 As altitude increases from sea level, barometric pressure and partial pressure of oxygen fall

Key point

The mixture of gases in the air at high altitudes has the same ratio as at sea level: 20.93% oxygen, 0.03% carbon dioxide and 79.04% nitrogen. With an increase in altitude, the partial pressure of each of the gases decreases in proportion to a decrease in atmospheric pressure, which leads to a decrease in the partial pressure of oxygen in the air. This has a negative effect on oxygen transport to working muscles, brain and other tissues.

Air temperature and humidity at altitude

Air temperature decreases at a rate of approximately 1°C for every 150 m of ascent. This means at altitude the air becomes cooler, and cold air holds very little water. The partial pressure of water vapour ($P_{\text{H}_2\text{O}}$) in the air is lower with increasing altitude.

$P_{\text{H}_2\text{O}}$ becomes extremely low at high altitude, resulting in evaporation of moisture from the skin, because there is a higher gradient between skin and air, promoting evaporation and potentially dehydration.

Other factors that contribute to dehydration include:

- water lost via respiratory evaporation (warm, moist air in the mouth and nose moving to dry air in the environment)
- increased respiration rate at altitude.

Respiratory responses to acute altitude exposure

At high altitude, resting and exercise ventilation increases within seconds, because chemoreceptors (in the aortic arch and carotid arteries) are stimulated by the low PO_2 . The brain responds to these signals and increases breathing, both tidal volume (V_T) and respiratory rate. This can remain elevated in proportion to the altitude exposure. Increased ventilation reduces the amount of carbon dioxide in the alveoli, and more carbon dioxide moves from the blood into the lungs to be exhaled.

This causes blood pH to increase (termed respiratory alkalosis), and this has several effects at higher altitudes:

- It is easier for oxygen to bind to the haemoglobin in the lungs.
- It is easier for oxygen to move from the blood to the (muscle) tissues.
- It prevents ventilation from rising too much.

ATL Research skills

At sea level, arterial PO_2 is about 100 mmHg and muscle PO_2 is about 40 mmHg (a pressure gradient of about 60 mmHg, to help move oxygen from blood to muscle).

However, when you move to altitude (above 1,500 m) this pressure gradient decreases. For example, if you ascend to Phari in Tibet, near the border with Bhutan, you would be at an elevation of 4,300 m. Here, the arterial PO_2 is only about 42 mmHg and the muscle tissue PO_2 is only 27 mmHg. So, there is a 75% reduction, from 60 mmHg to 15 mmHg, in the diffusion gradient for driving oxygen from blood to the muscle tissues. This partly explains why exercise at altitude is more challenging.

What is the altitude where you live, and what effect will this have on your arterial PO_2 ?

ATL Thinking skills

Why is solar radiation more intense at higher elevations at altitude?

Consider:

- light from the sun travelling through less dense air at altitude
- water in the air absorbs radiation from the sun.

Experiments

There are very few studies on the effects of altitude on biological females, children and the elderly.

What are the implications of this?

Cardiovascular responses to altitude

The cardiovascular response is important because it transports oxygen from the pulmonary capillaries to the systemic capillaries. Plasma volume progressively decreases within the first hours of arrival at altitude and this decline will plateau in weeks, mostly because of respiratory water loss and increased urine production. At plateau, this decline in plasma volume can be about 25%. Initially, plasma loss results in an increase in haematocrit (percentage of blood volume that is oxygen-carrying red blood cells). This allows the delivery of more oxygen for a given cardiac output to body tissues, including muscle. With adequate fluids ingested this 25% decline in plasma volume can return to normal in weeks at altitude.

More erythropoietin (a hormone) is released from the kidneys with continued exposure to high altitude. This stimulates red blood cell production (creating a greater blood volume) and partially compensates for the effects of lower PO_2 at altitude on the delivery of oxygen.

At rest and during submaximal exercise, an increased cardiac output is another way for the body to compensate for the reduced (arterial) PO_2 experienced at altitude—the volume of blood to the working muscles is increased.

However, with submaximal exercise, during the first few hours at altitude, stroke volume decreases compared with sea-level values. This is because of the reduced plasma volume. In these initial hours at altitude, there is a disproportionate increase in heart rate when performing submaximal exercise in order to increase cardiac output. After a few days at altitude, the arterial–venous oxygen difference increases, the muscles extract more oxygen from the blood, and heart rate during exercise starts to decrease. In other words, oxygen delivery becomes more efficient.

At high altitude, both maximal stroke volume and maximal heart rate are decreased during maximal exercise. This limits the delivery of oxygen to the muscles and reduces the capacity for either high-intensity or prolonged aerobic

ATL Research skills

Why is it important to consume iron-rich foods before and during altitude exposure? Consider what happens to red blood cell production at altitude.

ATL Research skills

Why do maximal stroke volume and maximal heart rate decrease during maximal exercise at high altitude?

Consider:

- plasma volume
- sympathetic nervous system.

exercise. For example, one study (Cheung, Ainslie, 2021) showed that HR_{max} decreased from 160 b min^{-1} at sea level to 118 b min^{-1} at 8,848 m during a simulated ascent to the top of Mount Everest.

ATL Thinking skills

Acute exposure to hypoxia is associated with impairments in mental performance. This can negatively impact motor skills, cognitive tasks, and senses such as visual and auditory performance. It is important that those who are acutely exposed to hypoxia, such as military personnel, pilots and in-flight medical professionals, are aware of this.

ATL Thinking skills

The effect of hypoxia on the central nervous system can accelerate fatigue. This is a consequence of lower tissue PO_2 on neural function and reduced brain oxygenation (compared with when there is an adequate supply of oxygen).

Metabolism and nutritional needs at altitude

Your basal metabolic rate increases, but appetite decreases when you ascend to altitude. It is important to ensure sufficient food intake (consume adequate calories) to maintain body weight at altitude, otherwise body weight will likely decrease.

**decreased energy consumption with
increased metabolic rate = daily energy deficit**

It is not uncommon to observe daily energy deficits of up to 500 kcal per day in people with less experience of altitude. Additionally, at rest and during submaximal exercise, there is a greater utilization of carbohydrates for energy at altitude. This is beneficial because glucose yields more energy than fats or proteins per litre of oxygen, but it means that carbohydrate stores will potentially become depleted more quickly.

When you ascend to altitude, the body will lose fluids in three ways:

- insensible water loss (through the skin)
- the respiratory system (ventilation of cold, dry air)
- the kidneys (increased urinary output).

In addition, there will be greater water loss with exercise because sweat evaporation increases in the relatively drier air at altitude, which is why it is important to stay well hydrated.

Key term**Maximal oxygen uptake ($\dot{V}O_2 \text{ max}$)**

An individual's maximal rate of oxygen uptake, which represents maximal aerobic capacity.

Effect of altitude on exercise and sport performance

Maximal oxygen uptake ($\dot{V}O_2 \text{ max}$) quantifies the maximum rate at which an individual can take in and use oxygen. $\dot{V}O_2 \text{ max}$ has been an international "gold standard" to evaluate cardiovascular-respiratory function (or aerobic fitness) since it was proposed by Hill in 1923. $\dot{V}O_2 \text{ max}$ has played an essential role in both

competitive sports and the public health agenda, such as selecting talented athletes, planning training, and estimating cardiovascular health and risks. We will study $\dot{V}O_2\text{max}$ in more detail in chapters A.1.3 and A.2.3.

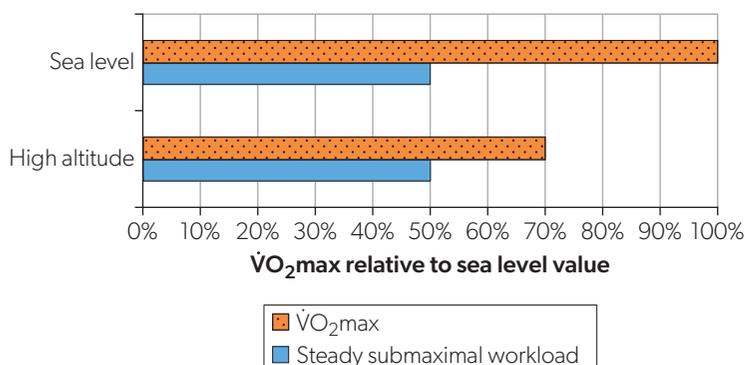
Altitude has almost no impact on $\dot{V}O_2\text{max}$ up to about 1,500 m, when the PO_2 drops below 131 mmHg. Above 1,500 m, $\dot{V}O_2\text{max}$ declines approximately 8%–11% for every 1,000 m increase (Figure 27). There may be a greater rate of $\dot{V}O_2\text{max}$ decline at very high altitudes.

During exercise at altitude, the athlete's body must adapt and respond to both exercise and hypoxia. To understand this, consider arterial oxygen saturation: the percentage of available binding sites on haemoglobin that are bound with oxygen in arterial blood (S_aO_2).

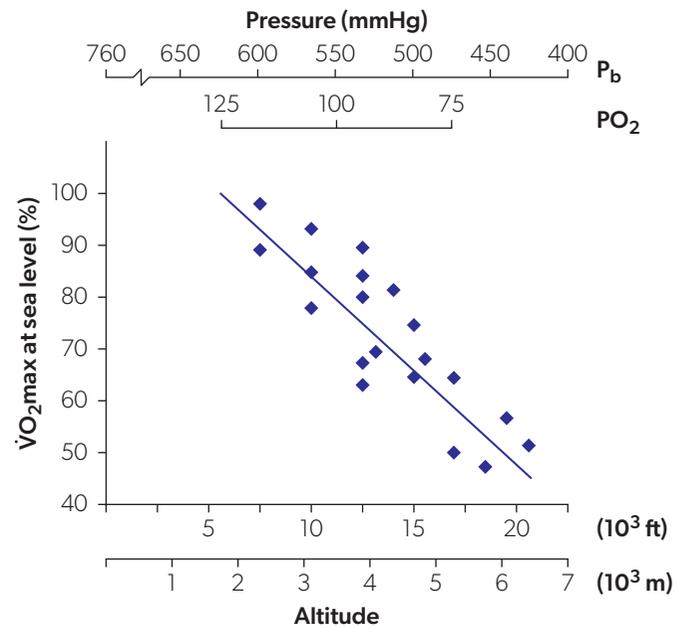
- At low altitude, resting S_aO_2 is well maintained (about 98%).
- At around 3,000 m (moderate altitude), there is a slight decrease in resting S_aO_2 to about 92%.
- At approximately 5,000 m (high altitude), resting S_aO_2 drops as low as 80%.

This, combined with the reduction in PO_2 , means that getting oxygen to our working skeletal muscles during exercise becomes more challenging with increasing altitude. Above moderate altitude there is less oxygen available from the blood for the exercising skeletal muscle tissue. This means when exercising at the same absolute workload at altitude compared with sea level, an athlete is experiencing a greater relative exercise intensity as a result of the decline in $\dot{V}O_2\text{max}$.

Figure 28 shows the effects of this $\dot{V}O_2\text{max}$ decline during submaximal exercise at the same power output, comparing sea level with high altitude. You can observe how the athlete would experience an increase in the relative exercise intensity at altitude. It is obvious that sport and exercise activities that place considerable demands on oxygen transport and uptake for optimal performance will be impaired by the decreased availability of oxygen to the tissues (hypoxia) at altitude. This means that prolonged endurance-based performance will suffer. In contrast, most anaerobic sprint activities (2 minutes or less) are not impaired at altitude, and sprint performance can be improved due to the thinner air providing less resistance to athletes' movements.



▲ **Figure 28** Relative exercise intensity increases when performing the same submaximal work at high altitude compared with sea level



▲ **Figure 27** Changes in $\dot{V}O_2\text{max}$ with reducing barometric pressure. Note that the decline in $\dot{V}O_2\text{max}$ begins at about 1,500 m.

Key points

- Interindividual variability in factors such as fitness, age, sex and acclimatization status will influence the physiological response to altitude.
- Aerobic capacity (represented by $\dot{V}O_2\text{max}$) is progressively reduced upon ascent to high altitude.

ATL Thinking skills

$\dot{V}O_2$ max and high altitude

$\dot{V}O_2$ max is progressively reduced upon ascent to high altitude. It has been reported that $\dot{V}O_2$ max for most people at the summit of Mount Everest (8,848 m) approaches the level of oxygen uptake required to meet basal metabolic needs. This begged the question: was it possible to reach

the summit without supplemental O_2 ? In 1978, two Italians, Reinhold Messner and Peter Habeler, climbed to the summit of Mount Everest without supplemental oxygen, a feat that has since been repeated, but it remains unusual. Why are most ascents of Mount Everest undertaken with oxygen?



▲ Figure 29 Edmund Hillary and Tenzing Norgay (left) and Reinhold Messner and Peter Habeler (right)

Key points

- Ventilation is greater at rest and during submaximal exercise at high altitude compared with sea level.
- Haemoglobin concentration increases with exposure to altitudes about 2,500 m and above.
- At submaximal workloads heart rate (HR) increases upon initial exposure to altitude.
- With prolonged high-altitude exposure (more than 1 week), HR_{max} reduces compared to sea level.

Activity 6

1. During submaximal exercise, what happens to stroke volume with initial and prolonged exposure to altitude?
2. During submaximal exercise, can skeletal muscles extract oxygen as needed to meet metabolic demand at altitude?

Acclimatization and acclimation to altitude

When going to high altitudes, acclimatization by slow ascent rates is necessary to:

- avoid high-altitude illnesses
- improve cognitive performance to near sea-level values
- boost submaximal exercise performance.

Preceding hypoxia exposures at real altitude (acclimatization) and/or in a simulated altitude chamber (acclimation) can support this process. An altitude chamber (Figure 30) mimics aspects of such environments (for example, hypoxia) to prepare individuals for altitude exposures.

Acclimatization guidelines are not to exceed an ascent rate of 500 m gain in altitude per day above 2,500 m. Additionally, plan to include extra rest days for every additional ascent of 1,000–1,500 m.

Acclimation in an altitude chamber (while still residing at/near home) has become an attractive alternative for many athletes, for a variety of reasons including:

- less cost
- reduced health risks associated with exposure to mountain environments (such as mountain sickness)
- the process can be “bespoke” (that is, tailored to individual athlete responses to hypoxia).

ATL Thinking skills

The transient phenomenon of acclimatization is distinct from the concept of **adaptation**, which refers to characteristics present in long-term high-altitude residents. Are these characteristics (such as haematological, respiratory, circulatory, metabolic and developmental traits) due to environmental factors operating during early growth or due to genetic causes?

Key adaptations with chronic exposure to altitude

Ventilation

There is an increase in resting and submaximal exercise ventilation upon arrival at altitude, via both an increase in tidal volume (V_T) and frequency of breaths (F_b), and there is evidence of individual variation (responders versus non-responders). The increase at rest levels off in days, but this higher ventilation can take weeks to level off during submaximal exercise, and is more pronounced at higher exercise intensities.

Blood

Within a few hours after arrival at altitude the blood's erythropoietin (the hormone that stimulates red blood cell production) concentration increases (and continues increasing for 2–3 days), and during the first 2 weeks at altitude the number of red blood cells (which transport oxygen and carbon dioxide to and from tissues) increases. Over months total blood volume increases (\uparrow red cell volume and \uparrow plasma volume), and along with haemoglobin concentration increases (within 24 hours of arrival at altitude) these adaptations improve the oxygen-carrying capacity of blood.

Muscle

Generally, prolonged exposure to altitude causes weight loss and changes in body composition (reductions in lean muscle tissue—muscle fibre cross-sectional area—and body fat). Studies have reported reduced appetite, an elevated basal metabolic rate and a noticeable weight loss with prolonged exposure at high altitude. There is an increased capillary density in the muscles, which allows more blood and oxygen delivery to muscle fibres, but the rate at which oxidative enzymes are able to carry out reactions decreases. The capacity to do work and be more active improves over time with altitude acclimatization. However, for any given workload, the relative exercise intensity increases as the partial pressure of oxygen is reduced. Although the decline in $\dot{V}O_2$ max seen with increasing altitudes improves, it does not return to sea-level $\dot{V}O_2$ max values.

This work must not be reproduced, stored, transmitted or circulated in any other form.



▲ Figure 30 Hypoxic (simulated altitude) chamber

ATL Thinking skills

Note that the increase in plasma volume does not mean it returns to sea-level values. Why not?

ATL Thinking skills

Where is erythropoietin produced?

Key point

Haematocrit is the percentage of cells or formed elements in the total blood volume. As more than 99% of the cells or formed elements are red blood cells, the percentage of total blood volume composed of red blood cells is referred to as the haematocrit. Sea-level residents have an average haematocrit around 45%–48%, but high-altitude residents tend to have an average haematocrit of 60%–65%.

Theories

Altitude training

Many physiological beneficial changes from altitude acclimatization (such as improved oxygen delivery from ↑red blood cells and ↑haemoglobin) are similar to improvements from aerobic training near sea level. Many of the beneficial changes from altitude exposure are transient for lowlanders who go to altitude; in other words, the changes only last for a few days when they return to sea level.

So, does training at altitude improve performance at sea level?

The original altitude training method was live high, train high (LHTH): athletes live and train at moderate altitude (2,000 m to 3,000 m). But most athletes are unable to train at the same intensity (and volume) when in a hypoxic environment (altitude) compared with when they train at sea level. If they train at altitude, the athletes can lose the adaptations associated with high-intensity training. This can be made worse when other factors are taken into account, such as ↑dehydration, ↓blood volume and ↓muscle mass.

Many athletes, therefore, live for periods at moderate altitude but go to train at (near) sea level (that is, they live high, train low (LHTL)). LHTL has become the popular way to gain the benefits of altitude acclimatization and not compromise training intensity. Numerous studies show the performance benefits from LHTL.

The development of hypoxic facilities has allowed athletes to live low, train high (LLTH). With LLTH, athletes live at sea level and receive intermittent exposure to hypoxia (simulated altitude) either at rest or during exercise training sessions.

Now, various altitude training formats are used by elite athletes. These include the original method of altitude training (LHTH) and LHTH at moderate intensity, train low at high intensity (LHTH_mTL_h), which is popular with elite track and field athletes, where moderate intensity is defined as below the lactate threshold, and high intensity is above the lactate threshold.

	Train High ↑cardiorespiratory improvements	Train Low ↑training intensity
Live High ↑red blood cells ↑haemoglobin ↑skeletal muscle capillaries	LHTH original training method 	LHTL gain benefits of altitude without compromising training intensity 
Live Low ↑hydration ↑blood volume ↑muscle mass	LLTH possible with use of simulated altitude chamber 	

▲ Figure 31 Potential physiological benefits from LHTH, LHTL and LLTH altitude training methods

There is still a lack of consensus on the best approach to altitude training, based on individual response patterns, to achieve optimal performance. Indeed, there remains some scepticism within parts of the scientific community about the efficacy of altitude training on performance—the literature on this is equivocal. For example, are performance improvements achieved by elite athletes following LHTH induced by altitude or

training? Standardization of hypoxic dose metrics and improved research study designs (including appropriate controls) might help establish better guidelines for altitude training. However, so far, the literature does not provide clear answers on which form of altitude training is best to enhance the performance of all athletes.





For elite athletes, two questions remain.

- How high and for how long should I use altitude training to achieve performance benefits?
- For any improved response from altitude training, for how long will it be maintained upon return to low altitude?



Experiments

The majority of altitude training studies demonstrating an improved elite athlete performance have study designs with no control group, and cannot account for the potential bias of placebo effects. What are the implications of this?



Thinking skills

It can take several weeks (possibly longer) to achieve total altitude acclimatization. So, what are the implications for athletes who live near sea level and are competing in a major event held at moderate altitude?

Consider the use of controlled indoor/laboratory conditions to simulate an altitude environment (such as hypoxia, cold) to prepare athletes for competing at moderate altitude.



Thinking skills

Why has LHTH not received the same degree of scientific inquiry as LHTL and LLTH?

Key points

The major benefits of acclimatization are to:

- protect against acute altitude sickness
- improve cognitive performance to near sea-level values
- boost submaximal exercise performance.

Key point

Acclimatization lessens the effects of the reduction in PO_2 as oxygen is transported through the body from the outside air to the tissues.

Even in the best-acclimatized person, the tissue PO_2 cannot be brought to sea-level values, and exercise performance is impaired.

Practice questions

1. The *Marathon des Sables* is a 6-day, 250 km run across the Sahara Desert in temperatures reaching 50°C . Describe how an athlete can acclimatize when preparing for the race. (4 marks)
2. Discuss the possible benefits of the live high, train low (LHTL) approach to altitude training. (4 marks)

Summary

- Muscle contraction is only about 20% efficient, with about 80% of energy released as heat. This heat must be lost from the body to avoid overheating.
- Core body temperature increases during exercise, and the intensity of the exercise determines the size of the increase.
- The control centre for temperature regulation is the hypothalamus, located in the brain.
- Four factors contribute to heat loss: radiation, conduction, convection and evaporation.
- Evaporation accounts for almost all heat loss during exercise and at high ambient temperatures.
- The effectiveness of evaporative heat loss is reduced significantly in warm, humid environments.
- The three factors that influence sweat vaporization from the skin are:
 - the amount of body surface exposed to the air
 - the ambient air temperature
 - the relative humidity.
- Too much sweating without fluid replacement can lead to dehydration.
- Homeostasis is a tendency towards a relatively stable, constant internal environment.
- Homeostasis is generally obtained by negative feedback mechanisms.
- Homeostasis is influenced by carbon dioxide concentration.
- pH is monitored via the respiratory control centre of the brain and chemoreceptors throughout the body.
- Regulation of the heart depends on intrinsic and extrinsic excitation.
- Regulation of body temperature maintains a core body temperature around 37°C.
- Regulation of blood glucose relies on insulin and glucagon.
- Heat acclimatization produces a lower resting core temperature, greater plasma volume and an increased sweating rate, which improve exercise capacity and reduce discomfort during heat exposure.
- Heat cramps, heat exhaustion and heat stroke are the main heat illness risks during exercise in hot (and humid) environments.
- During cold stress the body:
 - initially constricts blood vessels in the outer part of the body to prevent heat loss
 - begins the shivering response to produce heat, if there has been too much heat loss.
- In cold-air environments intense exercise can produce enough heat to maintain core body temperature.
- Fat provides an extremely good insulation against cold stress.
- Both ambient temperature and wind influence the coldness of an environment.
- Water conducts heat faster than air and this has serious effects if clothing is wet during exercise in cold air or if immersed in cold water.
- When you ascend to altitude reduced PO₂ limits and/or impairs performance.
- Acute exposure to high/extreme altitude can be life-threatening.

Check your understanding

After reading this chapter, you should be able to:

- outline homeostasis
- discuss the control of homeostasis
- outline the regulation of the heart
- discuss the regulation of blood glucose
- discuss the regulation of body temperature
- identify temperature, humidity and altitude as factors that affect individual heat stress
- introduce the challenge of exercise in hot and humid or cold environments
- explain the impact of altitude on exercise performance
- explain some aspects of the acclimatization process.

Self-study questions

- State which avenue for loss of body heat is most important for controlling body temperature during exercise.
- Outline the role of the shivering response to cold exposure as a mechanism for helping to generate body heat.
- Explain the body weight loss–dehydration relationship during exercise.
- Discuss how you would prepare your national soccer team to compete in a hot and humid environment.
- Explain why high humidity is an important factor when performing in hot environments.
- Sweating rates of up to 3.5 l hour^{-1} have been reported in trained athletes. For every ml of water that evaporates from the body surface, 2.43 kJ of heat is lost.
 - How much heat is lost for 1 l of sweat that evaporates?
 - Describe the role of sweating in thermoregulation.
- Outline why vasoconstriction in the skin capillaries during cold exposure is likely to have a detrimental effect on performance.
- Explain why elderly people might be less tolerant of the cold than young people.
- Distinguish between heat cramps and heat stroke.
- Describe the physiological adaptations that allow a person to acclimatize to exercise in the heat.
- Outline how the body minimizes excessive heat loss during exposure to cold environments.
- What impact does exercise in a hot environment ($\approx 30^\circ\text{C}$) have on the metabolism of carbohydrate?
- Describe how altitude conditions could limit exercise performance.
- Outline how to prepare a soccer team for high-altitude competition.

AHL



Data-based question

The performance of two groups of trained cyclists was studied in a hot environment (40°C). Group A was tested before and after a 10-day acclimation training programme in a hot environment (40°C). Group B (control) was tested before and after an identical 10-day training programme that took place in a cool environment (13°C).

The mean $\dot{V}\text{O}_2\text{max}$ and the amount of work done during a 60-minute cycling time trial in a hot environment (40°C) for both groups are shown in Table 1.

▼ Table 1 Adapted from Lorenzo et al. (2010)

	Group A		Group B	
	Before	After	Before	After
$\dot{V}\text{O}_2\text{max}$ ($\text{ml kg}^{-1}\text{min}^{-1}$)	53	59	53	54
Time trial work done (kJ)	709	762	735	714

- State which group had the highest $\dot{V}\text{O}_2\text{max}$:
 - before the 10-day training programme (1 mark)
 - after the 10-day training programme. (1 mark)
- Identify which group shows the greater change in the results of their time trial work, from before to after the 10-day training programme. (1 mark)
- Discuss the physiological adaptations that occur with heat acclimation. (3 marks)

A.1.3 Transport

Syllabus understandings

A.1.3.1 The cardiovascular system transports nutrients, hormones, gases, heat and waste to perform necessary bodily functions.

A.1.3.2 The respiratory system enables the exchange of gases between the external environment and the body to facilitate cellular respiration.

Introduction

Walter Cannon's seminal book *The Wisdom of the Body* (1932) set out a theory of homeostasis based on the stability of several key variables, achieved by changes in a number of physiological systems. It has since become apparent that many systems within the body are continuously working in a highly coordinated manner to keep a large number of variables at, or as close as possible to, resting levels. Exercise presents a number of challenges to the homeostasis of the body, and successful completion of exercise requires the systems within the body to function together, tightly regulating the conditions of the internal tissues.

TOK

Eliud Kipchoge (Figure 1) is a long-distance runner born in 1984 in western Kenya. He is currently regarded as one of the greatest marathon runners of all time. He began his career specializing at the 5,000m distance then switched to marathon running. In 2018, he set a new world record for the marathon, which both he and Kelvin Kiptum have since broken, as well as winning the Olympic gold medal in 2016 and 2020.



▲ Figure 1 Eliud Kipchoge

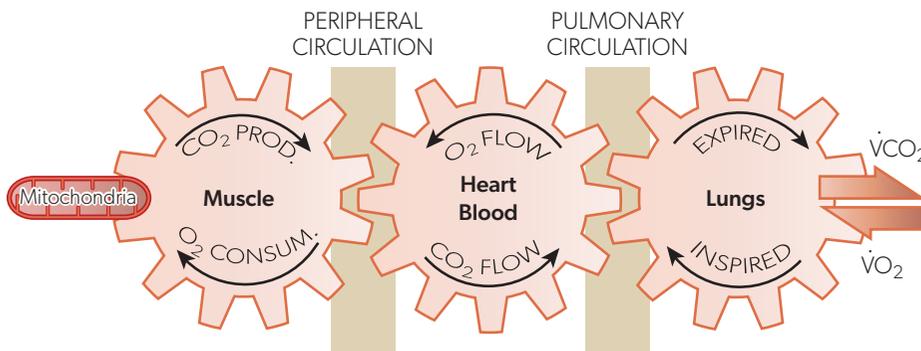
In 2019, he ran a marathon distance with a time of 1 hr 59 min 40.2s in a specially designed event called Ineos 1:59 Challenge. His achievement was recognized as the first marathon run under 2 hours by Guinness World Records but not by World Athletics since the event did not meet certain eligibility criteria.

What is the role of governing bodies in determining criteria for the eligibility of world record attempts?

The cardiovascular and respiratory systems are examples of systems that work together to regulate variables such as the oxygen content of arterial blood, acid–base status and core body temperature. The transport of oxygen is an excellent illustration

of the body's systems in action during exercise. This is a common theme when studying the cardiovascular and respiratory responses to exercise in this chapter. The rate at which oxygen is taken into the body and used (known as oxygen uptake, $\dot{V}O_2$) is an excellent indicator of how well these systems are working together.

Figure 2 shows how oxygen is transported from the atmosphere to exercising muscles for use in the aerobic energy systems. Note the representation of the systems as cogs that are required to fit together and work dependent on one another, which was described by American physiologist Karlman Wasserman. Note also the importance of oxygen and carbon dioxide transfer between the systems, known as gas exchange (taking place in the shaded areas where the cogs meet).



▲ **Figure 2** A version of Wasserman's three cogs, illustrating the stages in the process from oxygen being taken in and used (oxygen uptake, $\dot{V}O_2$) with carbon dioxide then being produced and removed (carbon dioxide output, $\dot{V}CO_2$)

In healthy humans these cogs work well at rest, irrespective of age. During exercise, when more oxygen is required by the active muscles, we can establish how well the systems are integrating by directly analysing the breathing responses and air content to calculate $\dot{V}O_2$. This makes $\dot{V}O_2$ a valuable marker of physiological function, and an exercise physiologist will measure this during exercise to evaluate health and fitness. The relevance applies to a patient with some form of respiratory or cardiovascular disease where exercise capacity is seriously compromised, as well as to the highly trained endurance athlete where adaptations to training have greatly increased exercise capacity.

ATL Thinking skills

The exercise test

Tests of physiological responses to exercise have changed considerably. Early experiments were interested in understanding the interaction of systems. Most testing was confined to research projects in specialist laboratories. They used early forms of heart monitoring and gas exchange equipment—people performed controlled exercise attached to considerable amounts of equipment.

Nowadays, exercise tests are routinely conducted in a very wide range of settings, such as:

- physical screening of employees to confirm fitness to do a job (for example, emergency services or military)
- health testing in hospitals to determine causes or impact of illness, as well as responses to treatment

Key term

Gas exchange The transfer of oxygen and carbon dioxide between the cardiovascular and respiratory systems, and body tissues.

Key point

The respiratory and cardiovascular systems work together in a highly coordinated manner to increase oxygen delivery during exercise. This is part of the body continuously trying to maintain a constant internal environment (homeostasis).



- monitoring of athletes to evaluate levels of fitness and responses to training.

Advances in technology mean that physiological responses to exercise can now be measured using a variety of online systems that are often portable and wireless. This removes many of the constraints on what can easily be achieved, further enabling the study of exercise physiology in action. The demands of many forms of exercise have now been well characterized, such that sport and exercise scientists can develop various methods of optimizing performance through interventions such as training, nutrition and cooling.



▲ Figure 3 An early exercise test



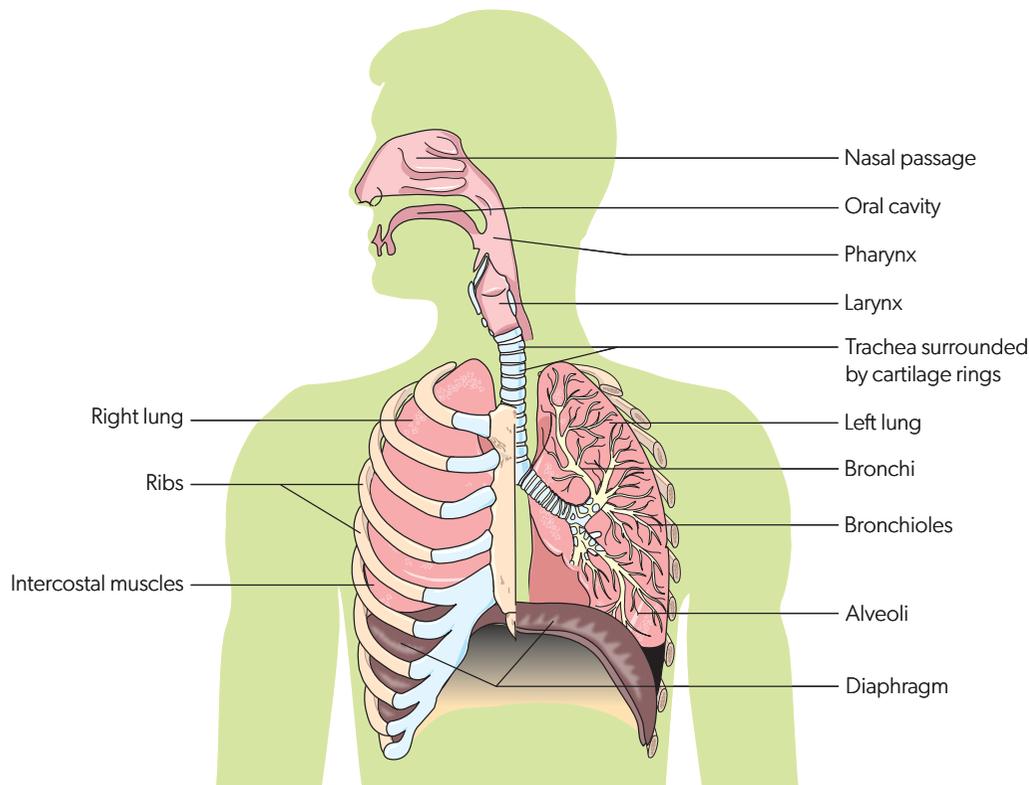
▲ Figure 4 More recent performance-monitoring technology

Respiratory system

The respiratory system enables the transport and exchange of oxygen for use in cellular respiration. The first stage in the oxygen transport system is the breathing in of oxygen-rich air through the mouth or nose and into the lungs. The action of breathing is mostly an involuntary process, although we can control it by choice to an extent (for example, you can hold your breath underwater, or blow up a balloon).

The basis of air movement by breathing during rest and exercise is a principle of physics: a substance will flow from an area of higher pressure to an area of lower pressure.

So, for inhalation (breathing in), the air pressure in the lungs needs to be lower than in the atmosphere. At rest this is almost entirely caused by contraction of the muscular diaphragm (Figure 5) at the base of the chest cavity (thorax). The diaphragm pulls downwards and, because of a vacuum between the lungs, chest walls and diaphragm, this increases the volume of the lungs. This increase in lung volume reduces the pressure in the lungs, causing air to flow from the atmosphere into the lungs to balance the pressure gradient.



▲ **Figure 5** Anatomy of the respiratory system

At rest, the exhalation (breathing out) process is passive (no energy required) as the diaphragm relaxes and therefore recoils back to its original position without any conscious muscular work. This recoil naturally reduces the volume of the lungs, increasing the pressure to greater than that of the atmosphere, causing air to flow back out again. The cycle then repeats and during exercise the principle remains the same.

However, during exercise when more oxygen is needed by the active muscles and more carbon dioxide is being produced by the muscles, more air needs to be inhaled and exhaled at a faster rate. To achieve this, some additional muscles in the chest wall (intercostal muscles), abdomen, and even the shoulders, can assist with increasing the lung volume during inhalation. Furthermore, contraction of these muscles during exhalation will also compress the lungs faster and more forcefully than the natural recoil. This is therefore an active process, requiring energy to fuel the muscles of the chest and abdomen.

The inhaled air initially passes through the conducting airways (the nasal and oral passageways, and the larger airways such as the trachea and bronchi) and although no gas exchange takes place here, the air is warmed, moistened and filtered by the lining of the airways.

The airways continuously branch into smaller bronchioles and eventually end in small air sacs, each one known as an alveolus. This is where gas exchange takes place, with oxygen and carbon dioxide moving across the very thin barrier that separates the alveoli from the passing blood for further transport.

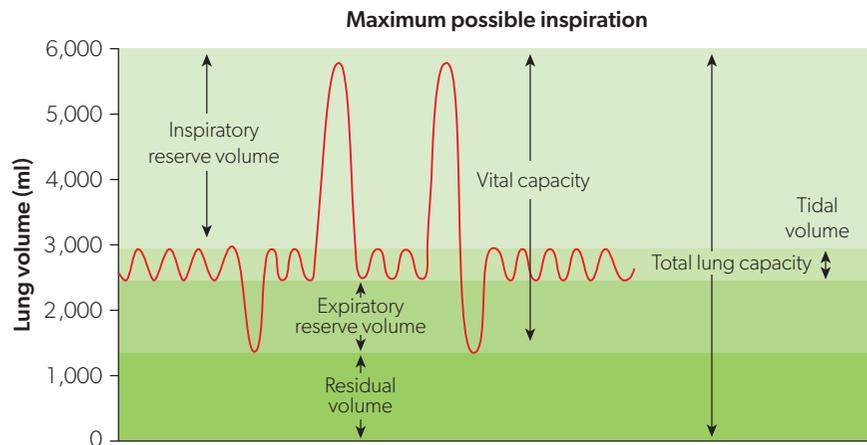
The lungs are ideally designed for gas exchange as they cover a very large surface area (millions of alveoli make a total of approximately 50–100 m², equivalent to around half a tennis court), have a good blood supply and have a very thin total distance between the alveoli and blood (0.4 μm).

Key point

The movement of air in and out of the lungs is achieved by repeated contraction and relaxation of muscles in the base of the chest cavity (diaphragm) and chest wall to alternately increase and decrease the volume of, and therefore pressure in, the lungs.

Activity 1

What do lung volumes tell us about fitness?



▲ **Figure 6** Trace showing change in volume during some resting breaths and some forced breaths

The above trace shows the change in volume during some resting breaths and some forced breaths (where the person breathes in and out as much as possible).

From the above trace, define:

- vital capacity
- residual volume
- tidal volume
- total lung capacity
- inspiratory and expiratory reserve volumes.

Key point

Static lung volumes are more related to size, as well as age and sex differences, than to health or fitness, although dynamic volumes are more functional and sensitive to illness.

Key point

Gas exchange is continuously occurring between air, blood and tissue. Gases move by a passive process called diffusion along a gradient from high pressure to low pressure. The challenge during exercise is to ensure that the gradient is maintained, requiring changes in ventilation and in the cardiovascular system.

Interestingly, when we compare trained and untrained people of similar size, it becomes clear that these lung volumes are not something that can be trained and are not related to aerobic fitness. Lung volume and lung capacities are affected by age, sex and body size.

- Lung volume was found to increase by 28 times, from around 200 millilitres at birth to about 2.2 litres at age 8 years, reaching around 5.5 litres at age 25 years (Inselman, Mellins, 1981).
- Biological females typically have lower lung volume and capacities compared with biological males.
- Vital capacity is generally higher in tall people than short people (Aung et al., 2019).

In contrast, the rate at which the air can be exhaled is a very sensitive marker of lung function. For example, the maximum volume that can be breathed out in one second (forced expiratory volume in one second, FEV₁) is often used as a test of dynamic lung volume.

An interesting area for research at present is whether training the respiratory muscles can assist performance. In contrast to original ideas in this field, there is some suggestion that training these muscles with special resisted breathing

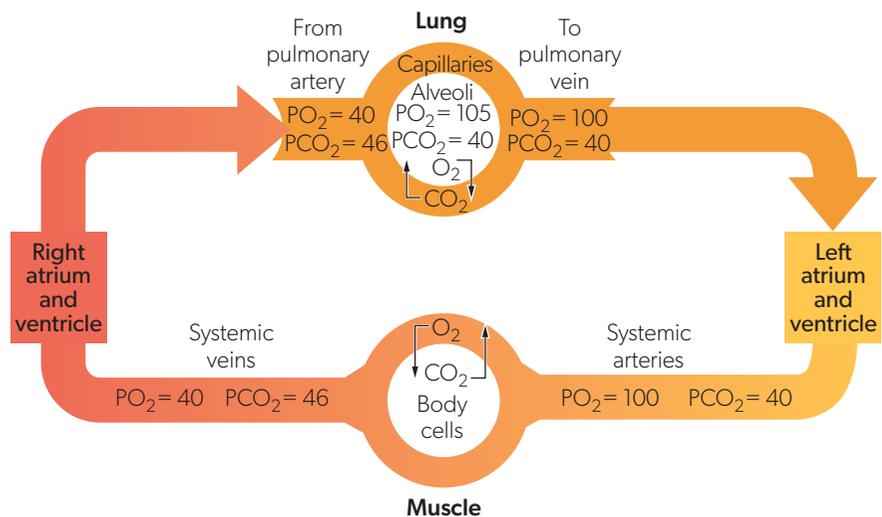
devices can improve long-duration endurance performance by making breathing easier without any changes in lung volume.

Gas exchange

Gas exchange in the lungs, as well as in other body tissues, takes place according to another passive process known as diffusion. This is another basic principle of physics. Gas will move along a gradient from an area of higher partial pressure to lower partial pressure. Partial pressure is similar to concentration, but represents the pressure exerted by a single gas (such as oxygen) within a mixture (such as air, blood or tissue fluid).

In the lungs, the air breathed in is high in oxygen and low in carbon dioxide. The blood being pumped to the lungs from the active tissues via the heart is lower in oxygen and higher in carbon dioxide. Therefore, oxygen will diffuse from the alveoli into the blood, and carbon dioxide will diffuse from the blood into the alveoli (Figure 7). The blood leaving the lungs, now high in oxygen and low in carbon dioxide, will be pumped to the tissues via the heart. At the tissues where oxygen is being used up and carbon dioxide produced, the pressure gradients will drive oxygen from blood into tissues and carbon dioxide from tissues into blood.

Pulmonary gas exchange is the movement of oxygen from air in the alveoli of the lungs to blood, and the movement of carbon dioxide in the opposite direction. As blood flows through pulmonary capillaries, it picks up oxygen from alveolar air and unloads carbon dioxide into alveolar air. Each gas moves from the area where its partial pressure is higher to the area where its partial pressure is lower. During exercise, the pressure gradient at the tissues and lungs becomes greater as more oxygen is being used up and more carbon dioxide is being produced. Alveolar partial pressure of oxygen must be higher than blood partial pressure of oxygen for oxygen to move from alveolar air into the blood. This is achieved by breathing out the air with less oxygen and more carbon dioxide and then breathing in fresh air to maintain the pressure gradients for diffusion to occur. Otherwise the exercise could not be sustained for long.



▲ Figure 7 Simplified version of partial pressure differences between the lungs, blood and tissues (all partial pressures are in the units of mmHg)

Ventilation during exercise

The **minute ventilation** (\dot{V}_E) describes the volume of air being exhaled per minute (and inhaled as we do not store air).

\dot{V}_E is determined as the product of the size of each breath (\dot{V}_T = **tidal volume**) multiplied by the number of breaths per minute, known as the **respiration rate** (B_f = breathing frequency).

$$\dot{V}_E \text{ (l min}^{-1}\text{)} = \dot{V}_T \text{ (l breath}^{-1}\text{)} \times B_f \text{ (breaths min}^{-1}\text{)}$$

Activity 2

Table 1 shows some data collected during an exercise test. Complete the table.

As exercise intensity increases, how is the increased ventilation achieved?

▼ **Table 1** Comparison of \dot{V}_E , \dot{V}_T and B_f

	Exercise intensity during running at progressively faster speeds (km h ⁻¹)						
	Rest	8	10	12	14	16	18
\dot{V}_T (l breath ⁻¹)	0.67	2		3.3	3.6		4
B_f (breaths min ⁻¹)	12		22.3	24.2		30	38
\dot{V}_E (l min ⁻¹)	8	40	58		98	115	

During exercise, \dot{V}_E typically increases by increasing both \dot{V}_T and B_f (Table 1) to maintain resting gas partial pressures in the lungs and arterial blood supply to the active tissues. As the exercise becomes harder, the ventilation increases further. In healthy individuals, the homeostasis of arterial partial pressure of oxygen is preserved, even at maximal exercise intensities (with the exception of some highly trained athletes). This tight regulation raises the question: how is the ventilation response to exercise controlled?

Despite a lot of research on this topic, there is no single factor in the body that regulates ventilation alone. Instead, researchers have identified a number of factors that can stimulate or inhibit ventilation according to the conditions, such as gas partial pressures, acidity, temperature and hormones. The relative contribution of these factors during exercise depends on the characteristics of the exercise, such as intensity, duration and environmental conditions. For example, we know that when exercising at altitude (where the atmospheric partial pressure of oxygen is reduced) receptors that are sensitive to the oxygen content of the blood stimulate increased ventilation. However, at sea level, in the majority of individuals, arterial oxygen content is kept constant. So, although oxygen can be a contributing factor, it would appear that during exercise the ventilation response is actually more sensitive to carbon dioxide increases, particularly during high-intensity exercise.

ATL Thinking skills

Examples of the importance of carbon dioxide

The term hyperventilation refers to an increase in ventilation above what is actually required to meet the oxygen demand of the exercise. Such a response means that we exhale more carbon dioxide than necessary and arterial blood levels of carbon dioxide fall. Such a drop in carbon dioxide will reduce our drive to breathe and there are two very different ways in which we can demonstrate this.

Rebreathing

In the past, some people recommended that a person having a “panic attack” should breathe into a paper bag. The theory behind this advice was that when a person suffers from an acute period of heightened anxiety, they will hyperventilate. This causes a drop in arterial carbon dioxide that reduces the stimulus to breathe, which, in turn, can cause the sensation of further panic as the person becomes confused and hyperventilates further. This is not caused by an excess of oxygen being detected by the brain. By breathing in and out

Key point

Ventilation increases in response to the increasing intensity of exercise to maintain resting oxygen and carbon dioxide levels in the arterial blood supplying exercising muscles. This is achieved by increasing breathing depth and rate. The control of ventilation is very complex and no single factor is responsible, although carbon dioxide plays an important role.





of a paper bag, the person breathes some of the carbon dioxide back in and this builds up over a few breathing cycles to restore arterial carbon dioxide levels. Provided the person is able to reduce their state of anxiety, their breathing should return to normal.

Note: This explanation and practice **only** applies when there is no further pathological cause for the hyperventilation. Otherwise, rebreathing could cause further problems and place the person at increased risk. This is why current first aid guidance advises against using such rebreathing techniques.

Holding breath

In 2021, a new world record for breath-holding (24 min 37 s) was set by 56-year-old Budimir Šobat, an athlete who takes part in the sport of freediving (diving as deep into water as possible without supplementary air). There is a lot of training and technique to extended breath-holding. It should not be attempted unsupervised as it can leave the person feeling dizzy and could result in drowning or falling once back on land.

Before the breath-hold, the diver uses a range of techniques, including meditation and breathing high concentrations of oxygen. One important technique is controlled hyperventilation for a number of minutes. This reduces the arterial carbon dioxide levels and delays the stimulus to breathe considerably, enabling the freediver to stay under water for much longer. As stated, this can be dangerous and should not be attempted unsupervised. The long-term effects of repeated breath-holding are currently unknown.



▲ **Figure 8** Current first aid guidance advises against using rebreathing techniques



▲ **Figure 9** Freedivers use a range of techniques, including meditation and breathing high concentrations of oxygen, before a dive

Cardiovascular system

Blood

During exercise, the primary function of blood is to transport gases, nutrients, waste products, hormones and heat to and from various tissues.

The total volume of blood in the body is around 5 litres for a person of mass 70 kilograms.

The major components of blood are as follows:

- **Plasma** (~55% of blood volume) is a fluid. It is a mixture of water and dissolved substances.
- **Platelets** (<1% of blood volume) assist in the process of repair following injury; they play a vital role in blood clotting.
- **White blood cells** (<1% of blood volume) are called leucocytes. They are primarily involved in immune function; they protect the body from infection.
- **Red blood cells** (around 40%–45% of blood volume) are called erythrocytes. They carry oxygen from the lungs to tissues, and carry carbon dioxide back to the lungs for exhalation. The percentage of red blood cells is referred to as the haematocrit. The haematocrit depends on factors such as how well trained an individual is and sex differences.

The increased volume of carbon dioxide produced during exercise is transported from the muscles to the lungs for exhalation, partly dissolved in blood but mostly in the temporary form of bicarbonate. Oxygen is less soluble in the plasma; only a few per cent of the total oxygen delivered to the active muscles is transported this way. Instead, oxygen temporarily attaches to an iron-rich pigment in the blood called haemoglobin. In the lungs, where there is high partial pressure, oxygen easily binds to the haemoglobin. In the active muscle where partial pressure is lower, oxygen detaches and diffuses from the blood into the active tissues. The deoxygenated red blood cells then return to the lungs (via the heart) where oxygen can bind.

If haemoglobin concentration can be increased by manipulating the hormone erythropoietin (EPO) responsible for stimulating red blood cell production, then more oxygen can be transported and aerobic exercise performance will improve. This is the reason why many endurance athletes often live and/or train at altitude, where lower oxygen availability naturally stimulates more haemoglobin production so that when athletes return to sea level they can perform better.

Key point

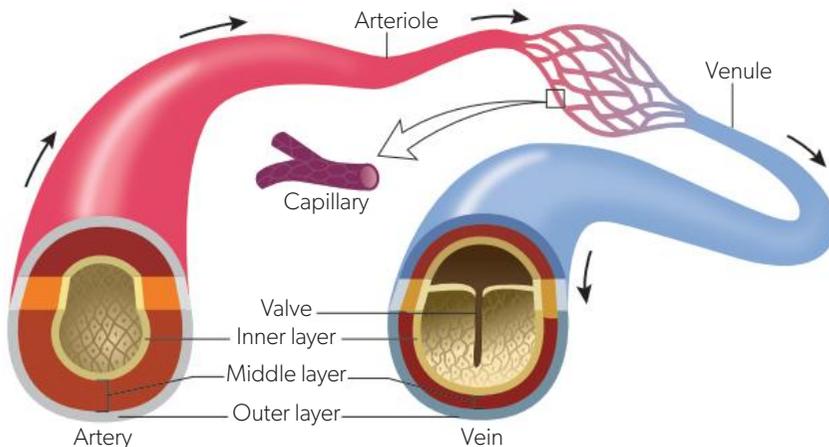
Blood performs a number of vital functions in the body and, during exercise, one of these is transport. Carbon dioxide is mostly transported in the form of bicarbonate, while oxygen is mostly transported attached to a special pigment called haemoglobin found in red blood cells.

Unfortunately, there are also illegal methods that are abused in sport to achieve the same goal. For example, blood doping involves removing some blood from an athlete weeks before a competition and storing it while the athlete's haemoglobin is restored naturally by EPO stimulation. Then just before the competition the stored blood is reintroduced so that the haemoglobin concentration is higher than normal, more oxygen can be transported and exercise performance is better. Or athletes can be injected with synthetic EPO to achieve the same goal without even removing blood. The detection of synthetic EPO or blood doping abuse remains a very significant challenge for the World Anti-Doping Agency, as significant immediate benefits can be achieved for athletes.

Circulation

Blood is transported around the body through an extensive network of blood vessels. These include the following.

- **Arteries** These are vessels that are relatively large in diameter. They have thick muscular walls as there is considerable pressure exerted from the oxygen-rich blood in these vessels. They are responsible for transport away from the heart to tissues. (Tip: remember that **a**rteries take blood **a**way from the heart.) Arteries then branch into narrower arterioles.
- **Capillaries** Supplied by the arterioles, these are very narrow vessels with very thin walls. They form an extensive branching network through tissues and are the sites of exchange between blood and tissues.
- **Veins** The capillaries link to larger vessels called venules and then to larger veins. The larger veins are the vessels that deliver mostly deoxygenated blood back towards the heart. They are less muscular and fibrous than arteries as pressure is lower. They are flexible and contain valves to prevent back-flow.



▲ Figure 10 Structure of blood vessels

The pump at the centre of the cardiovascular system is the heart, which is a sequence of chambers enclosed by walls of specialist muscle fibres called cardiac muscle fibres. The heart is the link between two distinct loops of circulation (look at the central cog in Figure 2).

- The pulmonary circulation delivers deoxygenated blood from the right side of the heart to the lungs for oxygenation and then back to the left side of the heart.
- The systemic circulation delivers this oxygenated blood from the left side of the heart to the other tissues of the body where oxygen is used up, and then delivers deoxygenated blood back to the right side of the heart for the cycle to continue. This includes the heart itself, which consists of specialized muscle tissue and therefore needs to be supplied with essential blood through the coronary arteries. Any disruption to the coronary arteries will result in a heart attack as the cardiac muscle is starved of oxygen and therefore cannot function correctly.

The cardiac cycle

The heart can be considered a four-chamber double-pump system. The left and right sides of the heart work in parallel simultaneously. Each has an atrium that first receives blood from a vein and then pushes it into a larger and thicker-walled

Key point

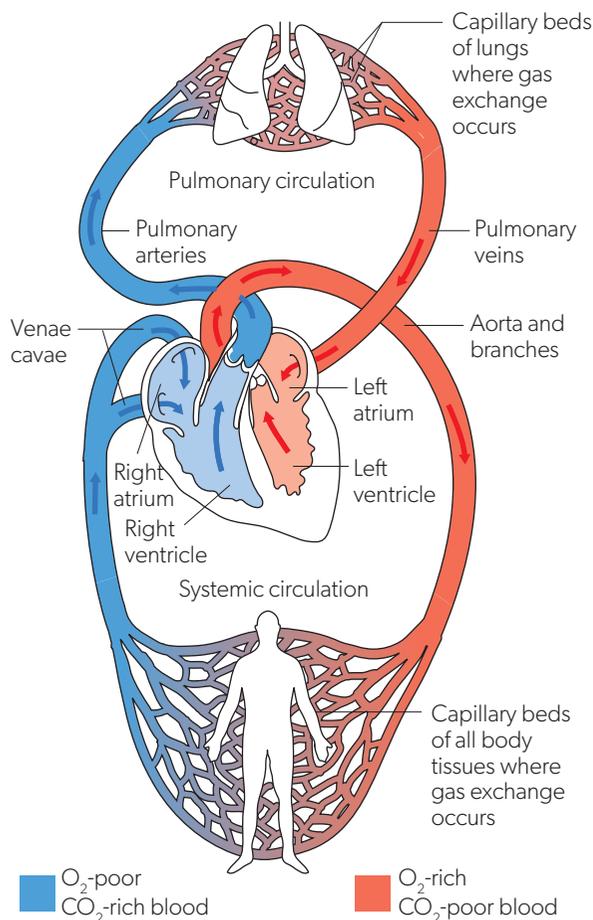
Blood is pumped around the body through a series of blood vessels, from large, muscular arteries to narrower arterioles, to very narrow and thin capillaries (where gas exchange occurs), to larger, flexible venules and then veins containing valves to prevent back-flow. The heart has the primary function of pumping blood around the body (systemic circulation) and to the lungs (pulmonary circulation).

ventricle. The ventricle then pushes blood out of the heart into an artery for transport away from the heart.

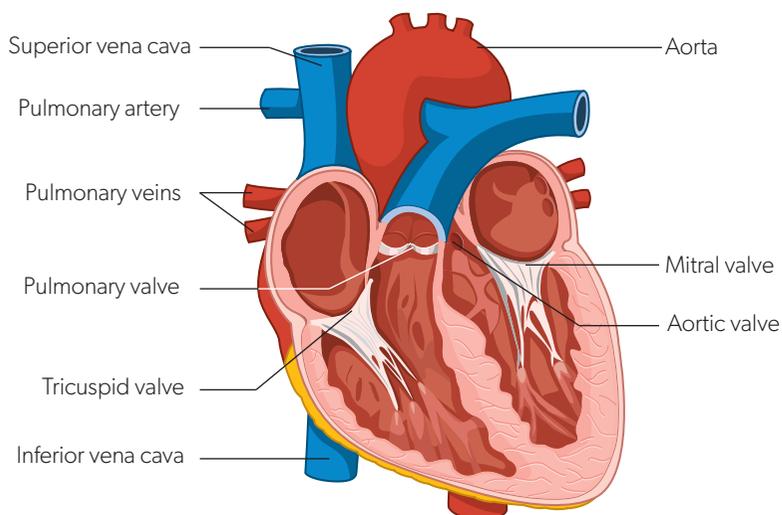
There is a series of valves between the heart chambers that close and open by force in response to a highly coordinated sequence of muscle contractions. The valves ensure that the system operates in one direction and enable heart muscle contractions to increase pressure in the chambers for ejection of blood (either from an atrium into a ventricle or from a ventricle into an artery and away from the heart).

Key points

- Hepatic veins drain the liver.
- Mesenteric vein carries nutrient-rich blood away from the intestines.
- Hepatic artery carries blood to the liver.
- Gastric artery carries blood to the stomach.
- Mesenteric artery delivers blood to our intestines.



▲ Figure 11 The circulatory system



▲ Figure 12 Structure of the heart

The heart is made up of four main chambers. The chambers have muscular walls and are separated by valves. The two sides of the heart each have an atrium (receives blood) and a larger ventricle (ejects blood from the heart). The blood is forced from atria to ventricles and then out of the heart by a series of closely coordinated contractions of the heart muscle. The contraction is initiated as an impulse in the sinoatrial node which then travels through the heart muscle causing the contractions in the correct sequence. Refer to chapter A.1.2 for more detail on excitation of the heart.

Key points

- Superior vena cava: large vein that collects blood from parts of the body superior to the heart and returns it to the right atrium.
- Inferior vena cava: large vein that collects blood from parts of the body inferior to the heart and returns it to the right atrium.
- Atrioventricular bundle: the part of the conduction system of the heart that begins at the atrioventricular node, passes through the cardiac skeleton (strong, connective tissue that forms a framework within the heart, and provides support and structure to the heart's walls, valves and blood vessels) separating the atria and the ventricles, before splitting into right and left bundles. Also called the bundle of His.
- Mitral valve: located between the left atrium and the left ventricle, and acts as a barrier that opens and closes to regulate the flow of blood.
- Aortic valve: blood passes from the left ventricle through the aortic valve. The aortic valve is like a door in the heart that controls the flow of blood as it leaves the heart to go to the rest of the body.
- Tricuspid valve: located between the right atrium and the right ventricle. When the heart beats, the tricuspid valve opens up, allowing blood from the right atrium to flow into the right ventricle. Then, when the right ventricle contracts to pump the blood to the lungs, the tricuspid valve closes, preventing blood from flowing backwards into the right atrium.
- Pulmonary valve: blood passes from the right ventricle through the pulmonary valve. It opens and closes to control the flow of blood, allowing blood to leave the heart and enter the pulmonary artery, and then closes to prevent any backwards flow, making sure the blood goes in the right direction to reach the lungs for oxygenation.

Blood pressure

The heart pumps blood around the body: the contraction and relaxation of the chamber walls cause changes in the pressure exerted on the blood to drive it through and out of the heart and around the body. If we measure the pressure in the blood vessels leaving the heart (arteries) directly, it fluctuates with the different phases of the cardiac cycle, between very high peaks as the ventricle contracts and forces blood out, and troughs where the ventricle is relaxing and no blood is being pumped out (semi-lunar valves are closed). These are known as the systolic (contracting) and diastolic (relaxing) pressures.

In a resting, healthy adult the typical blood pressure values would be in the range of 90–120 mmHg (systolic) and 60–80 mmHg (diastolic). A systolic reading of 120 with a diastolic reading of 80 would be described as “120 over 80 mmHg”. Blood pressure of 140/90 mmHg or higher is considered to be high blood pressure, while blood pressure of 90/60 mmHg or below is considered to be low blood pressure. Healthy blood pressure permits efficient emptying and filling of the heart, but with enough pressure in the system to maintain blood flow to the tissues of the body. The pressure (and extent of the fluctuations) lessens as the blood goes from the arteries to arterioles and then capillaries. The pressure in the venules and veins is comparatively low and consistent, but it is the arterial pressure that is most important and this is what is routinely measured by physicians.

Activity 3

Use a stethoscope placed on the chest wall over the left side and listen to the sounds of the heart as it contracts (you will hear the valves close in sequence) and then relaxes (no sound). The sound of the heartbeat that we can hear with a stethoscope (“lub-dub, lub-dub”) is actually the closing of the AV valves (“lub”) followed rapidly by the closing of the semi-lunar valves (“dub”). Now calculate the heart rate as the number of beats (“lub-dub” = 1 beat) in 15 seconds multiplied by 4 (beats per minute).



▲ Figure 13 Using a stethoscope to listen to the chest

Activity 4

Interpret blood pressure readings

Blood pressure can be measured manually using an adjustable pressure cuff (that can be inflated or deflated gradually to restrict blood flow) attached to a pressure-measuring device (a sphygmomanometer) and a stethoscope (to listen to an artery for what are known as the Korotkoff sounds). Alternatively, there are many commercially available automatic blood pressure-measuring devices, but the principle is exactly the same. The cuff is inflated to a pressure higher than systolic pressure (around 150–180 mmHg in a healthy, young person) to stop blood flow through the artery as it is compressed (there will be no sound in the artery below the cuff). The cuff is then very slowly allowed to deflate. As the systolic pressure is reached a tapping sound can be heard as blood is intermittently able to get through the blocked artery immediately after each heart contraction only—the systolic pressure is noted at this point. With further deflation the sounds will disappear as full blood flow is restored—at this point the diastolic pressure is noted.

▼ Table 2

	Activity	Diastolic pressure (mmHg)	Systolic pressure (mmHg)
80 kg healthy adult	Rest	75	116
	Running	80	180
	Lifting	150	240
100 kg unhealthy adult	Rest	95	150



Table 2 shows data for a healthy trained 80 kg adult at rest and performing two different actions (running fast, a dynamic activity; trying to lift a very heavy object, static but very high forces), as well as resting data for another untrained and unhealthy individual.

1. What effect does dynamic exercise have on blood pressure?
2. What effect does static exercise have on blood pressure?
3. Why is one higher than the other?
4. What difference is there between the two participants at rest?
5. Elevated blood pressure is known as hypertension. Why would a higher blood pressure present a challenge that may result in health complications?



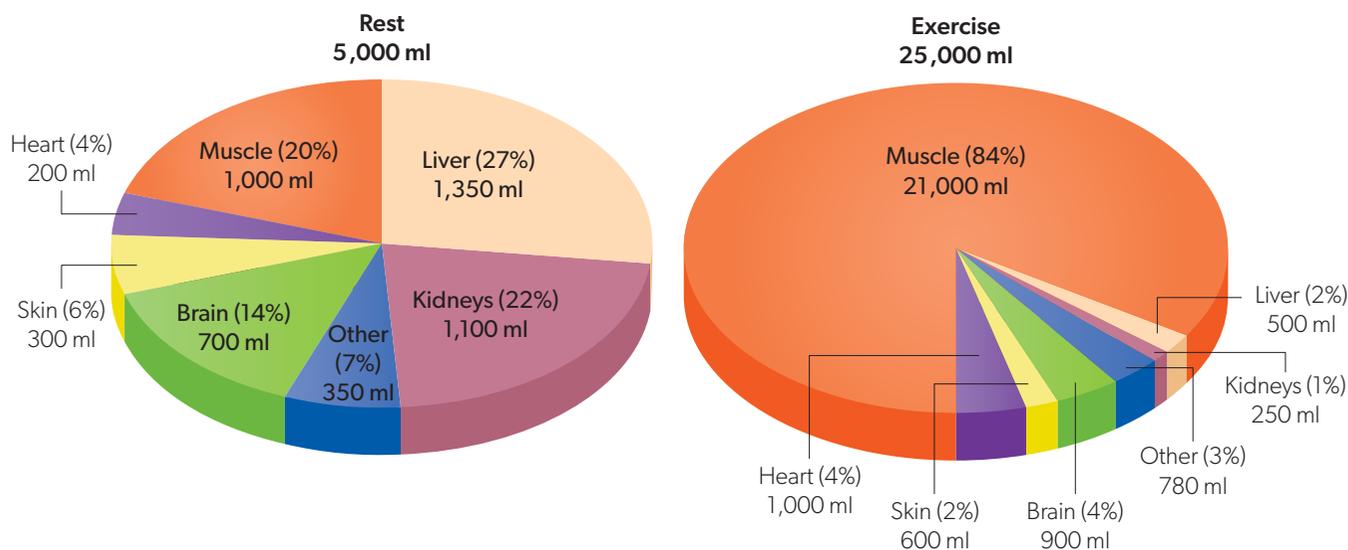
▲ Figure 14 Blood pressure monitors

Blood flow distribution

During exercise, and even at rest, the diameter of the arteries, arterioles and opening/closing of capillaries needs to be carefully regulated to keep blood pressure at a sufficient level to ensure cardiovascular function. This is achieved by involuntary control of the smooth muscle that lines the walls of the arteries and arterioles and also forms tiny sphincters throughout the network of capillaries. If all of this smooth muscle relaxed then there would not be sufficient pressure to return blood to the heart and the cardiac cycle could not function. Therefore, the nervous system and cardiovascular system interact carefully so that there is sufficient relaxation of some vessel walls and contraction of others to ensure that enough blood is passing through all organs requiring exchange, yet blood pressure is maintained.

During exercise the muscles that are being used become the main demand on blood flow, as more oxygen and nutrients are required and more waste products and heat need to be removed. Therefore, in addition to the increases in cardiac output (refer to next section), more blood is directed towards the active muscles by dilating the arterioles supplying the muscles and opening more of the capillary network within the muscles. As a general rule, the most metabolically active tissues receive the greatest blood supply. This redistribution, along with increases in cardiac output, allows up to 25 times more blood flow to active muscles. However, to prevent a resulting catastrophic drop in blood pressure throughout the whole system, the vessels supplying other organs in the body constrict and many of the capillaries are closed so that blood flow is reduced to these organs.

As shown in Figure 15, some essential organs such as the brain and heart are protected so that they still have sufficient supply (life could be compromised if either had insufficient blood flow), but active muscles can demand as much as 90% of the total blood flow during exercise compared with only 20% at rest.



▲ Figure 15 Blood flow distribution during exercise and at rest

Key point

Blood pressure must be maintained at the correct level so that there is sufficient blood flow around the body. Coordinated relaxation and constriction of some blood vessels maintains pressure, but also redistributes blood flow to the active muscles during exercise.

Acute cardiovascular responses to exercise

With respiratory responses deemed to be sufficient to maintain efficient gas exchange in healthy individuals, even during maximal exercise, the cardiovascular system is crucial to maintain function and attempt to maintain homeostasis in the face of the exercise challenge. Previous sections have highlighted various ways in which this is achieved to an extent, but it is the responses of the heart to dynamic exercise that can truly be considered “central”. Accordingly, the responses of the heart are very accurately regulated according to the demands of the exercise.

This is nicely illustrated by exploring the increase of blood flow out of the heart during exercise and how this is achieved. **Cardiac output** is defined as the amount of blood ejected from the left side of the heart (and therefore supplying the whole body except the lungs) in litres per minute. Cardiac output is determined by how quickly the heart is beating (heart rate in beats per minute) and the amount of blood being ejected with each contraction (**stroke volume** in millilitres per beat), according to the following equation:

$$\text{cardiac output} = (\text{heart rate} \times \text{stroke volume}) \div 1000$$

To achieve the increases in cardiac output required during exercise, the heart beats faster (increased heart rate) and fills and empties more during each contraction (increased stroke volume). As exercise becomes progressively harder, the heart rate and stroke volume both increase until their respective maximum rate and volume are achieved. As maximum cardiac output is reached so too is exhaustion, and exercise cannot continue at this intensity (refer to following section).

In contrast, during prolonged submaximal exercise at a fixed intensity (endurance activities), the cardiac output is maintained at the same level throughout as the demand stays constant with stroke volume and heart rate at values higher than at rest. Interestingly, however, while cardiac output stays constant eventually the heart rate starts to increase slightly and progressively. This is known as

Key point

Cardiac output increases in proportion to the intensity of the exercise up to a maximum attainable value. Increased cardiac output is a product of increased stroke volume multiplied by increased heart rate.

cardiovascular drift and reflects a decline in stroke volume, primarily due to changes in thermoregulation.

Activity 5

Table 3 shows the cardiovascular responses during dynamic whole-body exercise for two adults of similar age (20 years old) and size (1.8 m, 70 kg). One is sedentary and the other is a well-trained endurance athlete. Data reflect three levels of exercise intensity: rest; submaximal exercise (Submax.) walking at the same speed; and maximal exercise (Max.) at the point of exhaustion.

▼ Table 3

	Intensity	Untrained adult biological male	Trained adult biological male
Heart rate (beats min ⁻¹)	Rest	75	50
	Submax.	110	80
	Max.	197	195
Stroke volume (ml beat ⁻¹)	Rest	60	90
	Submax.	85	112
	Max.	120	190
Cardiac output (l min ⁻¹)	Rest	4.6	4.5
	Submax.	9.4	9.0
	Max.	19.7	32.2

1. Evaluate the effect of training on the cardiovascular responses to submaximal and maximal dynamic exercise.
2. Aside from any differences in training status, predict any differences that you would expect if the data in Table 3 were compared with an adult biological female.

ATL Research skills

What mechanisms help return blood back to the heart during exercise?

Linking question

To what extent do cardiorespiratory measurements indicate stress and arousal levels? (Tool 1, C.4.1)

Consider:

- what happens to heart rate and respiration rate when the sympathetic division of the autonomic nervous system is activated
- lower heart rate variability (variation in time intervals between successive heartbeats)
- respiration rate (and depth) and stress and arousal levels
- reliability and other factors that can affect heart rate and breathing
- inter-individual variation
- triangulation with other measures (such as self-report).

ATL Thinking skills

Submaximal cardiovascular responses are different in children and adults. Regardless of sex differences, children have a lower cardiac output than adults at a given absolute submaximal rate of work. This lower cardiac output is attributable to a lower stroke volume, which is partially compensated for by a higher heart rate.

Table 4 shows the data from a study comparing cardiovascular responses to cycling and treadmill running in 7- to 9-year-old children versus 18- to 26-year-old adults.

▼ Table 4

	Cardiac output (l min ⁻¹)		Stroke volume (ml)		Heart rate (beats min ⁻¹)	
	Child	Adult	Child	Adult	Child	Adult
Cycle 60W	9.4	12.4	61.9	126.8	153.1	97.8
Run 3 mph	6.7	12.3	57.3	135.7	116.0	92.0

Differences in submaximal cardiovascular responses between children and adults are related to the smaller hearts and a smaller amount of muscle doing a given rate of work in the children.



Linking question

How do specific qualities in long-term training influence the structures and functions of the cardiovascular system? (A.3.1)

Consider:

- intensity, duration and frequency of training
- effects on cardiac output
- delivery of oxygen and nutrients to exercising skeletal muscle tissue
- what happens to blood pressure at rest and during exercise
- improved blood flow.

Key term

$\dot{V}O_2\text{max}$ An individual's maximal rate of oxygen uptake, which represents maximal aerobic capacity.

Functional capacity of the cardiorespiratory systems

It is clear that the response of the human body to exercise requires the successful integration and regulation of a number of systems in the body. There are limits to how hard these systems can be pushed, and this is reflected in the varied durations and intensities of exercise that people can tolerate. The most commonly used marker of an individual's aerobic fitness brings us back to the importance of $\dot{V}O_2$ discussed at the start of this chapter.

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) quantifies the maximum rate at which an individual can take in and use oxygen. The $\dot{V}O_2$ is directly assessed by measuring the gas concentration and volume of air being breathed out at progressively increasing intensities of exercise. As the oxygen demand increases so too does the $\dot{V}O_2$, until the person approaches their limit, that is, their $\dot{V}O_2\text{max}$. At this time, even if intensity (and therefore oxygen demand) is further increased, the $\dot{V}O_2$ cannot increase any further and the person will stop exercising as they can no longer continue.

For this reason, the $\dot{V}O_2\text{max}$ is sometimes known as aerobic capacity and this is why it is a parameter of interest for physiologists working with both severely limited patients and elite endurance athletes. The patients will have a very low $\dot{V}O_2\text{max}$ and therefore cannot cope with what may seem relatively easy exercise to others. Whereas, the elite endurance athletes will have very high $\dot{V}O_2\text{max}$ values and are therefore capable of the impressive endurance performances that are observed in high-performance sport. We will further consider factors affecting $\dot{V}O_2\text{max}$ in chapter A.2.3.

Fick equation

In maximum exercise the Fick equation summarizes the important relationship between maximum cardiac output, maximum arterio-venous oxygen difference, and $\dot{V}O_2\text{max}$:

$$\dot{V}O_2\text{max} = \text{maximum cardiac output} \times \text{maximum arterio-venous oxygen difference}$$

As well as a larger cardiac output, other positive endurance training adaptations include both more effective blood redistribution and increases in skeletal muscle microcirculation (ratio of capillaries to muscle fibre). This helps to increase tissue oxygen extraction during intense exercise for both children and adults. Higher heart rates in children compared with adults during submaximal exercise do not fully compensate for the smaller stroke volume of the children. Children have a smaller cardiac output relative to adults at a given submaximal exercise oxygen consumption. As a result, the arterio-venous oxygen difference increases to meet the oxygen requirements of the children.

During submaximal exercise a higher arterial-mixed venous oxygen difference $[(A-V)O_2]$ in children also helps compensate for their lower cardiac output compared with adults to achieve a similar $\dot{V}O_2$.

Table 5 shows the data from a study comparing responses to cycling and treadmill running in 7- to 9-year-old children versus 18- to 26-year-old adults.

▼ Table 5

	Cardiac output (l min^{-1})		$(A-V)O_2$	
	Child	Adult	Child	Adult
Cycle 60W	9.4	12.4	11.1	8.9
Run 3 mph	6.7	12.3	8.7	8.4

Activity 6

From the data provided in Table 5, use the Fick equation to calculate the $\dot{V}O_{2\text{max}}$ of children and adults when cycling at 60W.

Patterns and trends

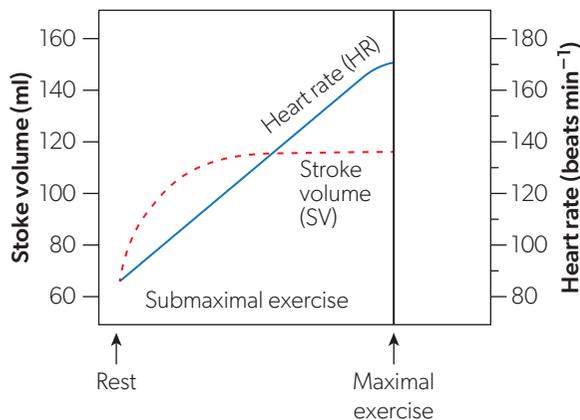
Since the 1960s, East African athletes have clearly dominated endurance events, holding all of the male world records over distances from 3,000m to marathons and many of the female world records over this range as well. Genetics has recently been explored in an attempt to explain why athletes with origins from a few tribes in Kenya and Ethiopia have been so successful. Interestingly, it appears that genetics may play a role, but does not adequately explain the pattern. Explore what other geographical, physiological, training, psychosocial, economic and cultural factors could also contribute to their success.



▲ Figure 16

Practice question

The graph shows the changes in heart rate and stroke volume as exercise intensity increases.



◀ Figure 17

Which statement best describes the effect on cardiac output as an individual reaches maximal exercise? (1 mark)

- A. The increase in cardiac output is due solely to increased stroke volume.
- B. Cardiac output remains unchanged due to increased heart rate.
- C. The increase in cardiac output is due solely to increased heart rate.
- D. Cardiac output remains unchanged due to constant stroke volume.

Summary

- The respiratory and cardiovascular systems function together to maintain homeostasis during exercise.
- Ventilation functions to ensure that blood leaving the lungs is oxygenated and low in carbon dioxide. Breathing occurs by repeated contraction and relaxation of muscles around the chest cavity.
- No single factor controls the ventilation response, although carbon dioxide plays an important role.
- Static lung volumes are more related to size than to health or fitness, although dynamic volumes are more functional and sensitive to illness.
- Gas exchange in the lungs and tissues occurs by diffusion from higher partial pressure to lower partial pressure, through thin capillary, alveoli and cell walls.
- During exercise, ventilation is increased by increasing the depth and frequency of breathing.
- Blood consists of fluid (plasma) and cells with various functions including transport. Oxygen attaches to haemoglobin in red blood cells for transport.
- The circulation system is made up of a pump (the heart) and a series of blood vessels, whose diameter and opening can be controlled by smooth muscle in the vessel walls and sphincters.
- The heart contains four chambers (two atria and two ventricles), with the left side supplying blood to the systemic circulation and the right side supplying the pulmonary circulation.
- Blood pressure must be maintained to ensure blood flow is high enough. This is achieved through constriction and relaxation of vessel walls and sphincters. During exercise this ensures that more blood is diverted away from other organs towards the muscle.
- Total blood flow (cardiac output) increases in proportion to the intensity of exercise up to a maximum value. This is achieved by increasing heart rate and stroke volume.
- Body size, age and sex differences all affect the functional capacity of an individual's cardiorespiratory systems.
- Training increases the functional capacity of an individual's cardiorespiratory systems primarily through increases in maximal stroke volume, although other peripheral adaptations can also contribute.
- $\dot{V}O_2\text{max}$ is the maximal rate of oxygen uptake achieved during maximal aerobic exercise.

Check your understanding

After reading this chapter, you should be able to:

- describe the structure and function of the respiratory system
- consider the relative importance of static and dynamic lung volumes
- explain the processes of gas exchange and transport
- state the structure and function of blood cells
- describe the structures and functions of the cardiovascular system
- detail the main responses of the respiratory and cardiovascular systems during exercise, including how training affects these responses
- discuss the importance of blood pressure and redistribution of blood flow
- identify age, sex differences, body size and level of fitness as factors that affect the cardiovascular and respiratory systems
- introduce the functional importance of maximal oxygen uptake ($\dot{V}O_2\text{max}$).

Self-study questions

- Why might a doctor be interested in assessing $\dot{V}O_2$ in an exercise test?
- Describe the process of breathing and comment on how exercise affects this process.
- Insert “higher” or “lower” and “from” or “to” in the correct places in the following statements.
 - The partial pressure of oxygen is in arterial blood supplying exercising muscles than in the muscle tissue. Therefore, oxygen will diffuse the blood the muscle.
 - The partial pressure of carbon dioxide is in the lungs (alveoli) than in the blood returning from exercising muscles. Therefore, carbon dioxide will diffuse the lungs the blood.
- What is the name of the pigment that binds oxygen for transport in the blood? Which type of blood cell is it found in?
- Draw and label the four chambers of the heart, including the valves.
- List the names of the specialist cells found in the heart that generate and then relay the electrical signal that causes the heart to contract.
- Explain what will happen to the smooth muscles in the arterioles and capillaries within active muscle, compared to within the kidney during exercise.
- Describe the responses of heart rate, stroke volume and hence cardiac output during exercise.
- Define $\dot{V}O_{2\max}$ and discuss why it is considered to be of functional importance from a health and sports perspective.
- How does aerobic training increase the functional capacity of an individual’s cardiorespiratory system?

Data-based question

Thirteen children (9–10 years old) completed two tests to determine their $\dot{V}O_{2\text{peak}}$ (l min^{-1}). The “ramp” test involved cycling for 3 min at 10W and then increasing the workload by 10W per minute. The “supra-maximal” test commenced with 2 min cycling at 10W and then involved cycling at 105% of

the peak power achieved during the “ramp” test. Both tests stopped when the children had a drop in cadence below 60 rpm for five consecutive seconds, despite encouragement to maintain the required workload. Their physiological responses—mean (\pm SD)—are shown in Table 6.

▼ Table 6

Variable	Ramp test	Supra-maximal test
$\dot{V}O_{2\text{peak}}$ (l min^{-1})	1.690 (0.284)	1.615 (0.307)
Heart rate peak (beats min^{-1})	202 (7)	196 (8)
Respiratory exchange ratio (RER) peak	1.11 (0.06)	1.07 (0.13)
Cardiac output peak (l min^{-1})	15.10 (4.82)	14.64 (4.51)
Oxygen extraction peak (ml min^{-1} per 100 ml)	12.61 (2.57)	12.28 (2.50)

- State which test resulted in:
 - the highest $\dot{V}O_{2\text{peak}}$ (1 mark)
 - the highest heart rate (1 mark)
 - the lowest cardiac output. (1 mark)
- Distinguish between the standard deviations for:
 - RER peak (2 marks)
 - oxygen extraction peak. (2 marks)
- Suggest reasons for the different physiological responses to the two tests. (4 marks)

A.2

Hydration and nutrition

How do nutritional and hydration status influence the body's ability to perform a variety of activities?

This topic begins with a focus on the body's water and electrolyte balance, and describes water content and electrolyte balance at rest, how exercise affects these, and the impact on performance when water or electrolyte balance is disturbed. The topic progresses to fuelling for health and performance, including consideration of relative energy deficiency in sport (RED-S) and the interplay between exercise and the gut microbiome for health and performance. Finally, it examines the energy systems and the processes of energy release in muscle cells during exercise, factors affecting maximal oxygen uptake, the lactate inflection point and the concept of critical power.

A.2.1 Water and electrolyte balance

Syllabus understandings

A.2.1.1 Water and electrolyte balance is necessary for effective functioning of the body and is influenced by the environment.

Introduction

Water is one of the defining features of all biological systems. It is essential for life in humans and in every other organism. There are multiple reasons why water is so essential.

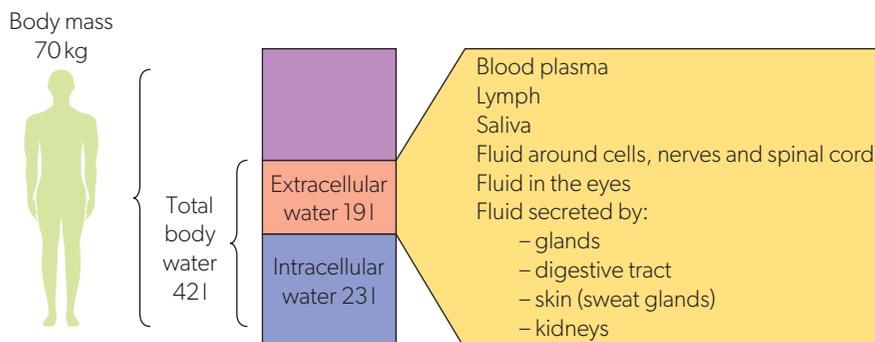
Water:

- is an effective solvent, so it can transport nutrients to cells, remove waste products from cells and transport other metabolites produced by cells such as hormones
- allows us to redistribute heat around the body and reduce body temperature through evaporation from the surface of our skin as we sweat
- makes an excellent lubricant as it is difficult to compress; for example, it is present around sliding surfaces in the body such as joint spaces and around tendons and muscles
- provides the medium essential for the biochemical reactions of metabolism inside and outside cells.

Water in the body

Around 50%–70% of total body mass is made up of water. The figure can vary between people depending on how much body fat they have. This is because the fat inside fat storage cells (called adipocytes) does not contain any water. Therefore, in people who are overweight, a large proportion of body mass can be made up of tissue containing little water. Fat-free tissue, however, is comprised of 60%–80% water. So, leaner individuals have a greater percentage of body mass made up of water.

The distribution of water in a healthy person of typical weight is shown in Figure 1.



▲ **Figure 1** The proportion of water in the body of a 70 kg person, and its distribution inside and outside cells

Key points

It is useful to clarify some definitions regarding dehydration.

- Dehydration is the dynamic process of losing body water.
- Euhydration refers to a normal/appropriate body water content. It is the absence of hyper- or hypohydration.
- Hyperhydration refers to a state of excess body water content.
- Hypohydration is a state of insufficient/suboptimal body water content.

In summary, dehydration is the *process* of body water loss. Hypohydration, euhydration and hyperhydration are *states* of fluid balance.

Key term

Diuretic A substance that increases the rate at which urine is produced.

Fluids are present in two main compartments: inside cells and outside cells.

- About two-thirds of body fluid is **intracellular fluid (ICF)**, inside cells.
- The other third, called **extracellular fluid (ECF)**, is outside cells.
- About 80% of the ECF is **interstitial fluid** found in the spaces between the cells of tissues.
- The other 20% of the ECF is plasma.

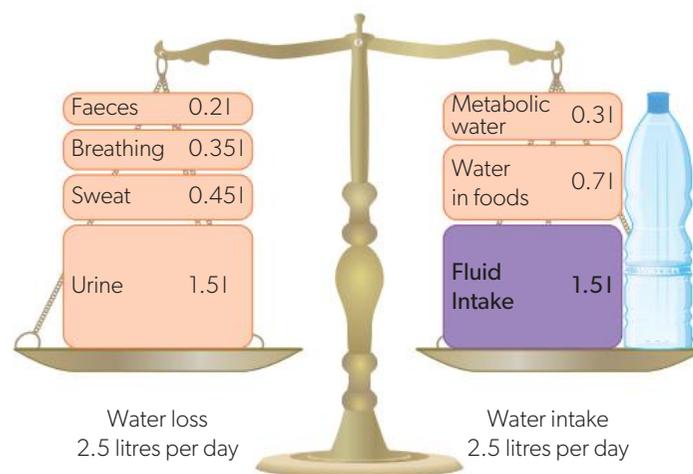
ICF and ECF are not just defined by their different locations; they are also very different in terms of the composition of solutes. ICF has a higher concentration of potassium (K^+) salts, whereas ECF has a higher concentration of sodium (Na^+) salts. The resulting concentration gradients across cell membranes are maintained by active transport (requiring ATP), which results in substantial, continuous energy expenditure. Although different in composition, the overall osmotic concentration of ICF and ECF is the same.

Water balance

Day-to-day fluctuation in body mass is relatively small; even though there is a turnover of around 2.5 litres of body water per day, in healthy people there is usually no substantial net gain or net loss of water (Figure 2). In non-exercising people, the water losses of around 2.5 litres per day are replaced through ingestion of food, drinking fluids and oxidation of substrates (metabolic water). Water from food and fluid is taken in via the large intestine.

Water loss occurs via four main routes:

- evaporation from the skin (sweat)
- evaporation from the respiratory tract (breathing)
- excretion from kidneys (urine)
- excretion from large intestine (faeces).



▲ Figure 2 Water loss versus water intake

Negative feedback regulates water balance

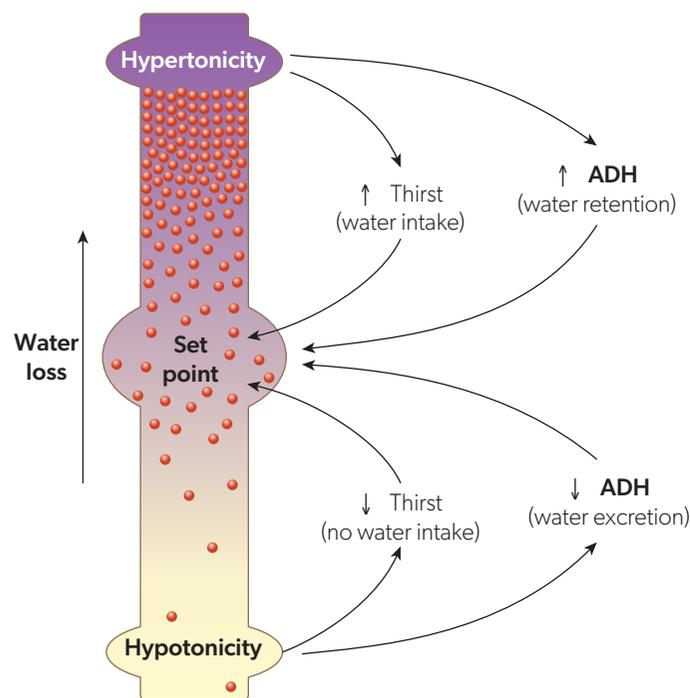
There is a complex interplay between the hypothalamus, pituitary gland and the kidneys to regulate water and electrolyte balance. This regulation involves a hormone called **antidiuretic hormone (ADH)**, which acts on the kidneys to

regulate water balance in the body. When the body is dehydrated or has high levels of electrolytes, the hypothalamus signals the pituitary gland to release more ADH. This causes the kidneys to reabsorb more water, produce less urine and help maintain the body's electrolyte balance. Also, the kidneys are responsible for filtering blood and removing waste products from the body, including excess electrolytes, by adjusting the amount of electrolytes that is reabsorbed into the bloodstream and the amount that is excreted in urine.

When water balance is threatened and there is a net loss of body water, the concentration of body fluid increases. This change is detected in the hypothalamus. The hypothalamus responds by:

- activating the sensation of thirst, which increases the desire to drink fluids
- triggering the pituitary gland to secrete ADH, which causes the kidneys to retain fluids and reduce urine production.

These two mechanisms “gain and retain” water. The consequence is increased water availability in ECF. The resulting dilution of solutes in ECF is detected in the hypothalamus and the response is the opposite of that described above. Thirst is “switched off” and ADH secretion is reduced (Figure 3).



▲ **Figure 3** Control of water balance; negative feedback in action

The mechanisms above are a good example of how subtle changes in a biological variable are monitored by receptors that trigger a response that corrects the detected fluctuations within a remarkably narrow range of normal functioning (set point). This process is called negative feedback.

The kidneys

The kidneys control retention and loss of water. Water and electrolytes are small molecules and are physically filtered from blood cells and large molecules in the glomerulus. This filtered fluid moves into the descending loop of Henle into the medulla of the kidney (Figure 4).

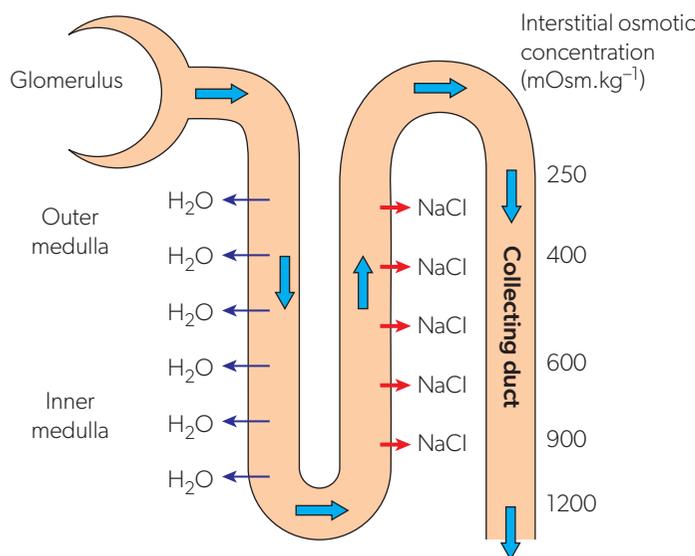
Key points

- The pituitary gland secretes hormones, including ADH. Some of these hormones regulate the secretion of hormones from other endocrine glands.
- The pituitary gland is controlled by the hypothalamus.

Key point

The amount of water in our bodies stays reasonably stable from day to day, with water lost through urine and sweat being replaced by water in our food and drink.

- The wall of the descending loop is permeable to water but not electrolytes. Since the surrounding medulla has a high osmotic concentration, water is absorbed passively into the medulla due to the concentration gradient; this increases the concentration and reduces the volume of fluid in the tubule.
- The wall of the ascending limb of the tubule actively transports sodium chloride but is impermeable to water. Sodium chloride, but not water, is transported out of the fluid in the tubule, therefore resulting in redilution of the now reduced volume of fluid.
- In the collecting duct the reabsorption of water occurs, and it is at this point that ADH is involved in regulation. The presence of ADH increases the permeability of the collecting duct wall, increasing passive water reabsorption and reducing urine volume. Thus, it is this phase that dictates the final urine volume and concentration.



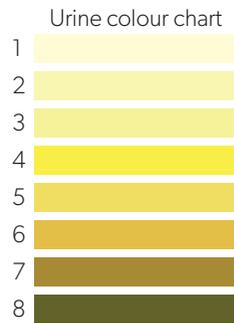
▲ **Figure 4** Movement of fluid along a nephron (→) results in: **a** exposure to osmotic gradients causing passive diffusion (→) and **b** active transport mechanisms (→); this concentrates, dilutes and finally regulates urine volume and concentration

Monitoring hydration status in athletes

The sensation of thirst is an indicator that our hydration status is not optimal and that we need to take in fluid to restore homeostasis. However, sometimes there is a need to have a more precise measure of hydration status, for example, in certain groups of patients or athletes. While becoming dehydrated is a potential health risk for all, a principal concern for athletes is that being dehydrated can impair performance in both competition and training. A number of methods exist to monitor hydration status—changes in body mass is one of the simplest.

Techniques for analysing urine to monitor dehydration

Urine analysis offers another means of monitoring the hydration status of athletes. Loss of body water results in smaller amounts of more concentrated urine due to the effect of ADH. This means that concentrated urine is indicative of a dehydrated state, and this is easily seen just by looking at the colour. Large amounts of pale urine are associated with normal hydration while small amounts of darker-coloured urine indicate risk of dehydration.



▲ **Figure 5** The colour of urine can be used as a subjective indicator of dehydration, with a darker colour suggesting dehydration; use of colour scales can assess this more objectively



▲ **Figure 6** A hydrometer measures the specific gravity of urine and offers a simple way of assessing the concentration of urine



▲ **Figure 7** Using an osmometer to measure freezing point in urine; increased solute concentration reduces the freezing point, and this can be used to quantify the osmotic concentration of urine

Case study**Using body mass to monitor dehydration—a simple example**

An athlete's fluid loss and fluid replacement strategy are being monitored during one of their training sessions. Their body mass is monitored before and after training and their drinking behaviour recorded. They attend training with a typical 750 ml drink bottle and consume all of this during training.

Body mass prior to training	75.8 kg
Body mass after 2 hours' training	74.1 kg
Fluids consumed during training	750 ml
Urine produced during training	0 ml

From these data we can estimate:

Total water loss from sweating (without fluid replacement):

$$75.8 - 74.1 + 0.75 = 2.45 \text{ l}$$

Total water deficit remaining after fluid replacement (750 ml):

$$75.8 - 74.1 = 1.70 \text{ l}$$

This deficit is equivalent to:

$$\frac{1.70}{75.8} \times 100 = 2.2\% \text{ of total body mass}$$

- What are the assumptions in this simple approach?
- What was this athlete's sweating rate?
- What advice could this athlete be offered based on these data?

ATL Thinking skills

When training and exercise occur in a hot climate, maintaining fluid balance is even more challenging and can mean fluid intakes of up to 10–15 litres of water per day.

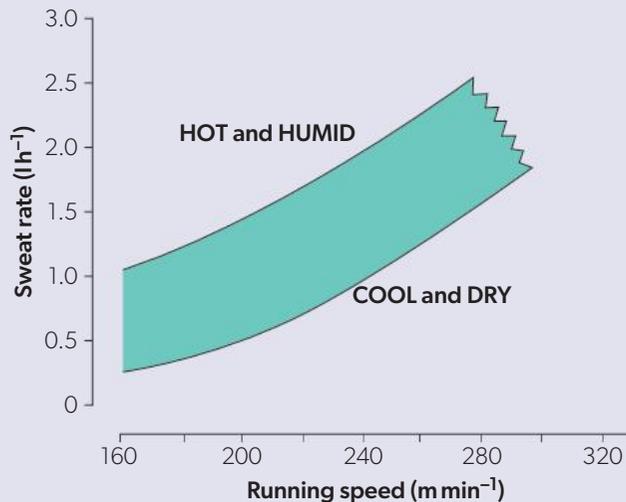
The Olympic athlete in Figure 8 is using water during exercise in the heat.

Should she pour the contents of the bottle on herself or would drinking be more beneficial?

Exercising harder means increased rates of metabolic heat production, and this heat needs to be lost to the environment to control body temperature. Sweating faster helps achieve this but increases dehydration. The graph in Figure 9 shows how faster running speeds up sweat loss; combining this with a hot environment makes the situation worse and fluid balance is harder to maintain.



▲ Figure 8



▲ Figure 9

Why do athletes need more fluid?

Water balance can be disrupted dramatically when we exercise or are exposed to hot environmental conditions. Much of the metabolic heat generated from muscle contraction during exercise is lost to the environment because of evaporation of sweat from the surface of the skin. Therefore, sweat losses tend to be greater during exercise or exposure to a warm climate. Both of these scenarios mean that fluid intake must be increased to compensate for losses and maintain fluid balance.

Factors that determine the amount of sweat produced during exercise include environmental temperature, humidity, air velocity, body size and metabolic rate. When large amounts of water are lost from the body (for example, during exercise), the balance between water and electrolytes in the body can be disrupted, as electrolytes are lost in sweat.

Dehydration during participation in sport and exercise is often unavoidable. But the degree of fluid loss must be controlled. Exercise in a dehydrated state has health risks (such as heat stroke) and it can impair sporting performance. Evidence suggests that athletes should aim to drop no more than 2% of their body mass due to fluid losses.

Regulation of electrolytes during exercise

At the onset of exercise, water moves from the plasma to the interstitial and intracellular spaces. The amount of water that moves from the plasma to the interstitial and intracellular spaces is determined by the amount of muscle that is active and the intensity of effort. Metabolic by-products in the muscles increase the osmotic pressure there (water moves passively into these areas by diffusion). Muscular activity also increases blood pressure (water is forced out of the blood as sweating increases during exercise), which leads to a plasma volume decrease. The hypothalamus, the pituitary gland and the kidneys have major roles in monitoring water levels and electrolyte balance, both at rest and during exercise.



Activity 1

1. Describe **two** techniques for monitoring hydration in athletes.
2. During exercise, why must more fluid be consumed than thirst suggests?

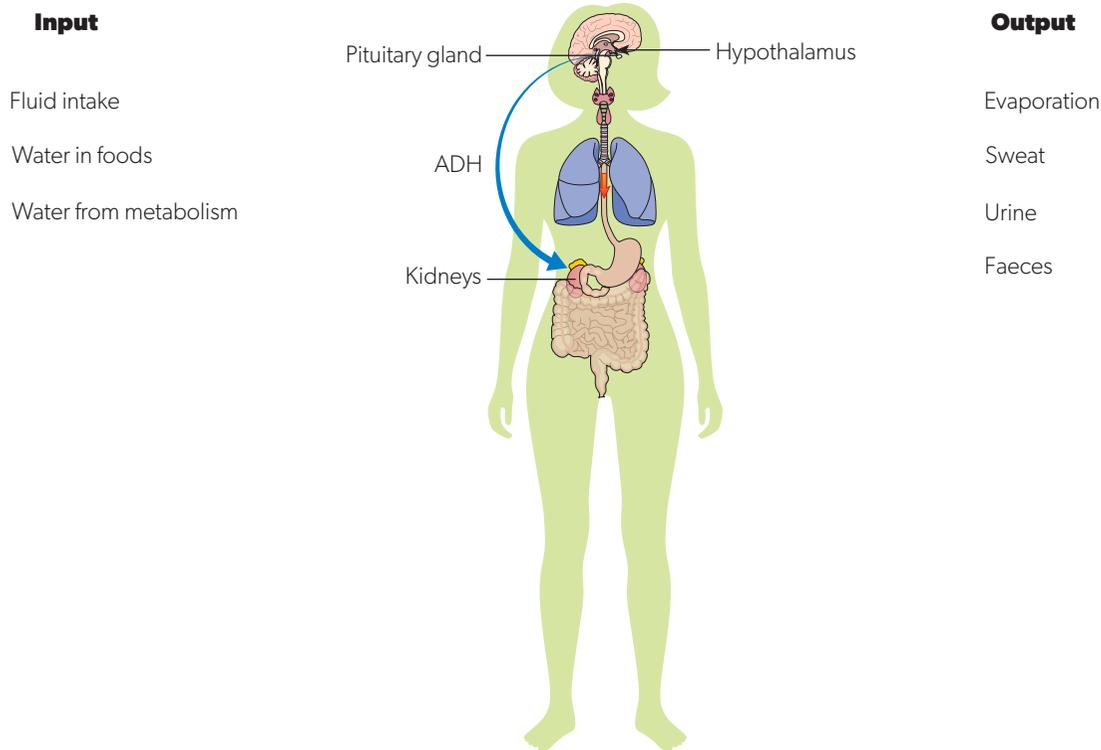


Linking question

What is the relationship between the external environment and electrolyte balance? (A.1.2 HL)

Consider:

- impact of the environment (hot and dry, or cold at altitude) on the rate of water loss—at rest and during exercise
- functions of water in the body
- electrolytes/ions and muscle contraction, nerve transmission, and fluid balance within and between cells
- electrolyte loss in sweat (and urine)
- individual variability in sweating rate and the electrolyte composition of sweat
- homeostasis to maintain a constant water and electrolyte balance involves the coordination of many inputs/outputs, including neural pathways and integrative centres in the brain and peripheral effectors (Figure 10).



▲ Figure 10 Regulation of water and electrolyte balance

Hyponatremia and hypernatremia

Fluid replacement during exercise is beneficial, especially during prolonged exercise in hot weather, but too much of a good thing is potentially bad. Drinking too much fluid with too little sodium can lead to **hyponatremia**, which is a low plasma concentration of sodium. Hyponatremia is defined as a sodium concentration below the normal range of 135–145 mmol l⁻¹. Early signs and symptoms include bloating, nausea, vomiting and headache. With increasing severity, there can be swelling in the brain and eventually seizures, coma and potentially death.

Hyponatremia often occurs during endurance sports. The prevalence of exercise-associated hyponatremia depends on:

- the duration of an endurance performance (for example, it is low in marathon running, high to very high in ultramarathon running)
- the sports discipline (for example, it is rare in cycling, frequent in running and triathlon, and very frequent in swimming)

ATL Thinking skills

Nitric oxide helps regulate force production within skeletal muscle and improved blood flow to exercising muscle. How might this impact performance and cardiovascular drift during prolonged aerobic exercise?

- biological sex (increased risk in biological females with several reported deaths)
- the ambient temperature (increased risk in hot temperatures)
- the country where competition takes place (very common in the USA, very little in Europe, practically never in Africa, Asia and Oceania) (Knechtle et al., 2019).

Hypernatremia occurs when there is a deficit of total body water relative to total body sodium content. It occurs as a result of dehydration (leading to a state of hypohydration) or excessive sodium in the diet. Water moves from body cells into ECF, causing cell dehydration. Hypernatremia is defined as sodium concentration $>145 \text{ mmol l}^{-1}$. It can have symptoms similar to those of exercise-associated hyponatremia, making it challenging to distinguish between the two. Hypernatremia occurs during or up to 24 hours after prolonged physical activity.

Key terms

Hyponatremia A condition in which the concentration of sodium in body fluid is too low.

Hypernatremia A condition in which the concentration of sodium in body fluid is too high.



Global impact of science

Hyponatremia

Hyponatremia is a condition where the concentration of sodium in body fluid is too low. It is classified as a plasma sodium concentration $<135 \text{ mmol l}^{-1}$. One effect of this is transport of water into cells. Brain cells, confined by the skull, are adversely affected by the increased pressure and this can lead to death in severe cases. Many people, however, develop hyponatremia without symptoms.

Hyponatremia can arise in a number of clinical situations. Exercise is associated with hyponatremia under certain conditions and this occasionally has been implicated in deaths. Today most athletes are well informed about the risk of hyponatremia, but incidents still occur. For example, one runner suffered a seizure after completing the London Marathon in 2018 due to hyponatremia.

How might this arise? Losing salt and fluid through sweating in hot conditions and replacing only with water, thus “diluting” the blood, has been suggested as a possible cause. This makes the idea of salt-containing sports drinks seem logical. However, it is not that simple!

Current data suggest that exercise-associated hyponatremia is caused principally by excessive drinking

of fluids during long-duration exercise (sometimes evidenced by gain rather than loss of weight during exercise).

Consuming commercial sports drinks may make little difference since their concentration of Na^+ is very low. One reason for this is sales-related; salty-tasting drinks are less desirable and may reduce sales among the general population, the biggest share of the market.

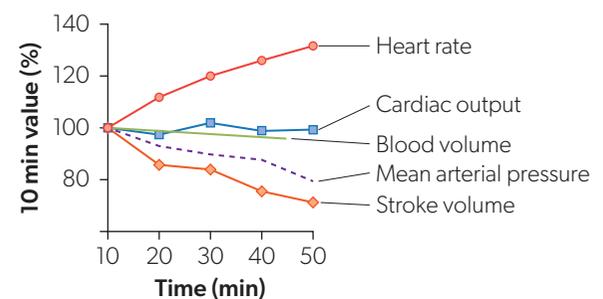
There has been some controversy about whether the involvement of commercial sports drink manufacturers has influenced the availability of scientific information on how common hyponatremia is and advice on drinking behaviour during exercise (Shephard, 2011; Noakes, 2011).

Any kind of sponsorship by a commercial company represents a conflict of interest that should be examined carefully.

- A company may deliberately or inadvertently downplay scientific evidence that contradicts what they say about their products.
- A company may be more likely to draw attention to scientific evidence that supports their products.

Cardiovascular drift

Cardiovascular drift is a phenomenon characterized by a rise in heart rate and a fall in stroke volume over time, during prolonged aerobic exercise at a steady-state intensity (such as walking, cycling or running), in both thermoneutral and hot environments. With prolonged exercise, stroke volume gradually decreases and heart rate increases to try to maintain cardiac output—but mean arterial blood pressure also declines.



▲ Figure 11 Cardiovascular drift

Case study**Found in the field**

A 23-year-old soldier was found in the woods, unresponsive, during field training on a hot summer day (30°C; 64% relative humidity). The soldier was physically fit and heat acclimatized. They had no significant medical history, no recent illnesses, and denied any medications or supplement use. They had successfully passed the week-long, physically demanding assessment phase of an elite military training school. The next week of training consisted of a variety of outdoor field events performed in full uniform with a loaded rucksack. On the day of collapse, they recall performing both low-level activity (planning and preparing for patrols) and intense drills. They also recall eating everything in the pre-packaged “meals ready to eat”, including the salt packet. During one of the drills, they recall the intense heat and reacting more slowly than usual. Approximately 10 minutes later, they were found face down and unresponsive.

They were brought to a field medical station, where their initial core temperature was 42°C. They were immediately placed in an ice water immersion tub for approximately 20–25 minutes. Emergency medical services were called, and upon their arrival, they were out of the immersion tub with a core temperature of 38°C. They were alert but had persistent altered mental status and a serum sodium of 132 mmol l⁻¹. They were taken to an intensive care unit and given appropriate water and electrolyte fluids. Within 12 hours from the time they were found, their serum sodium had corrected to 139 mmol l⁻¹. When they were discharged, they were in good condition, and on a 1-week follow-up, they had normal sodium levels.

1. Which condition was diagnosed: hyponatremia or hypernatremia?
2. Identify one risk factor that was present in this situation for the condition you identified.


Theories

There are two predominant theories that attempt to explain the cause(s) of cardiovascular drift. First, there is the peripheral displacement of blood to the skin to facilitate heat loss and attenuate the increase in core body temperature. More blood in the skin as part of thermoregulation means less blood is available to return to the heart. Tachycardia (a resting heart rate greater than 100 beats min⁻¹) decreases ventricular filling time. Thus, both peripheral displacement of blood to the skin and decreased ventricular filling time contribute to a reduced stroke volume. Add to this that there is also a small decrease in blood volume because of sweating as well as plasma moving into surrounding tissues—and reduction in stroke volume is the most striking component of cardiovascular drift during prolonged effort. In order to maintain cardiac output, heart rate increases to compensate for the decreased stroke volume (and decrease in mean arterial blood pressure).

Debate has been ongoing regarding the cause of cardiovascular drift for several decades. The decrease in mean arterial blood pressure could be related to vasodilation induced by free radicals, such as nitric oxide, to increase skin blood flow and sweating to attenuate the increase in body temperature. Therefore, it is argued by some that cardiovascular drift during exercise could be partially influenced by nitric oxide-induced vasodilation during exercise (second theory). However, to date there is no study that has assessed the

influence of nitric oxide on cardiovascular drift during submaximal exercise.

Recently, others have suggested that the first theory is lacking because, for example, the progressive decline in stroke volume persists even when skin blood flow reaches a plateau during prolonged aerobic exercise in both thermoneutral and hot environments. They highlight that there are several factors that modulate the magnitude of cardiovascular drift, such as: exercise intensity, duration, training status, dehydration and environmental conditions. They suggest that a reduction in cardiac performance (or contractility) has not been considered as a factor in cardiovascular drift.

In conclusion, cardiovascular drift is a multifactorial phenomenon. It cannot be explained only by vasodilation or heart rate increase. All of the following factors could contribute to cardiovascular drift in a time-dependent manner:

- increased skin blood flow
- reduced ventricular filling time due to heart rate increase
- negative cardiac force-frequency relationship
- exercise intensity
- ambient temperature
- dehydration.



Linking question

How reliable is the sensation of thirst as an indicator of dehydration?

(NOS, A.1.1)

Consider:

- increased plasma osmotic concentration and the hypothalamus
- baroreceptors and low blood volume
- when the body begins to sense thirst
- if you can feel thirst when your body is not dehydrated
- individual differences
- drinking when thirsty versus drinking “to stay ahead of thirst”.



Linking question

Which techniques are most suitable for generating valid and reliable data on the internal conditions of the body during exercise?

(Tool 1, Inquiry 2 and 3)

Consider:

- heart rate monitoring (for example, exercise intensity)
- oxygen consumption measurement (for example, metabolic rate)
- blood lactate analysis (for example, determining lactate threshold)
- gas exchange analysis (for example, oxygen uptake and carbon dioxide production)
- muscle biopsy (for example, enzyme activity)
- other techniques (for example, monitoring core body temperature, monitoring brain activity via functional magnetic resonance imaging).

Practice question

Discuss regulation of electrolyte balance in endurance exercise. (3 marks)

Summary

- Water is essential in humans; it is used for transport and thermoregulation, and acts as a lubricant.
- The majority of human body mass consists of water (50%–70%); the proportion is greater the less body fat we have.
- Water and electrolyte intake occurs via the large intestine.
- Loss of fluids and electrolytes occurs via evaporation and excretion.
- In healthy humans, water and electrolyte intake (via the large intestine, from food and drink) is usually similar to water loss (from sweat, respiration, urine and faeces), which results in maintenance of a stable body mass.
- Turnover of around 2.5 litres of water per day typically occurs in healthy humans.
- Water intake is controlled by thirst, and water loss is controlled by the kidneys.
- Dehydration, hypernatremia and hyponatremia are three states that can occur if water and electrolyte balance is not maintained.
- The hypothalamus, pituitary gland and the kidneys work together to regulate water and electrolyte balance via a feedback mechanism involving antidiuretic hormone (ADH).
- Severe dehydration can lead to death; dehydration of more than 2% body mass can reduce the exercise capacity of athletes.
- Hypernatremia refers to an increased serum sodium concentration, specifically one that is elevated above 145 mmol l^{-1} . Normal sodium levels in the blood typically range from 135 to 145 mmol l^{-1} .
- Hyponatremia is defined by a serum sodium level of less than 135 mmol l^{-1} .
- Athletes may turn over substantially more than 2.5 litres of water per day due to increased sweat losses arising from exercise and training, particularly if this occurs in a hot environment.
- Water and electrolyte balance can be measured in a variety of ways, including body weight, urine colour and osmotic concentration.
- Electrolyte balance is regulated by the hypothalamus, pituitary gland and kidneys.
- Cardiovascular drift is a phenomenon characterized by a rise in heart rate and a fall in stroke volume during prolonged exercise.

Check your understanding

After reading this chapter, you should be able to:

- describe the reasons water is essential to humans
- explain how the body controls its water content
- explain the causes of dehydration, hypernatremia and hyponatremia
- explain why monitoring hydration in athletes is important, and some techniques for doing so
- describe the phenomenon of cardiovascular drift.

Self-study questions

1. Describe the hormonal mechanism that helps maintain body water balance.
2. Suggest why sports drinks are a popular nutritional intervention for athletes.
3. Outline how water intake is controlled at rest and during exercise.
4. Distinguish between hypo- and hypernatremia.
5. Explain how cardiovascular drift can be caused by exercise duration.

Data-based question 1

A study (Webb et al., 2016) investigated the hydration status of 52 university athletes before and after a 90-minute training session, using urine colour and weight loss as indicators. Dehydration was defined as a body mass loss of 2% or greater, and hyperhydration was defined as a body mass gain of more than 1%. Table 1 shows the percentages of athletes by hydration status for different sports pre- and post-training.

▼ Table 1

Sport	Pre-training		Post-training	
	Hyperhydrated (%)	Dehydrated (%)	Hyperhydrated (%)	Dehydrated (%)
soccer	5.8	13.5	1.9	21.2
basketball	11.5	3.8	0.0	13.5
cricket	3.8	1.9	0.0	5.8
swimming	3.8	5.8	13.5	1.9
volleyball	5.8	3.8	0.0	13.5

1. Identify the sport with the highest percentage of athletes who were dehydrated post-training. (1 mark)
2. Explain the hydration status of the basketball and cricket players from pre- to post-training. (4 marks)

Data-based question 2

A study (Krabak et al., 2017) assessed the incidence of exercise-associated hyponatremia (sodium concentration less than 135 mmol l^{-1}), hypernatremia (sodium concentration more than 145 mmol l^{-1}) and normonatremia (sodium concentration between 135 and 145 mmol l^{-1} , the body's normal range of sodium concentration) and hydration status during a multistage ultramarathon of 250 kilometres across the Atacama Desert in Chile. Analysis of blood sodium concentration was obtained from 124 participants immediately after completion of the race. Hydration status was based on body weight changes. The post-race participant data are shown in Table 2.

▼ Table 2

Hydration status	Number of participants exhibiting hypernatremia	Number of participants exhibiting normonatremia	Number of participants exhibiting hyponatremia
overhydration	2	13	5
euhydration	8	25	2
dehydration	17	45	7

1. Calculate the difference between overhydrated runners who experienced normonatremia and overhydrated runners who experienced hypernatremia. (1 mark)
2. Explain how a runner can overhydrate but experience either hypernatremia or hyponatremia. (3 marks)

A.2.2

Fuelling for health and performance

Syllabus understandings

A.2.2.1 Macronutrients (carbohydrate, proteins and lipids) provide sources of energy to maintain bodily functions during growth, rest and physical activity.

AHL

A.2.2.2 Micronutrients play highly specific roles in facilitating energy transfer and tissue synthesis.

A.2.2.3 The gut microbiome influences the health and performance of an individual.

Introduction

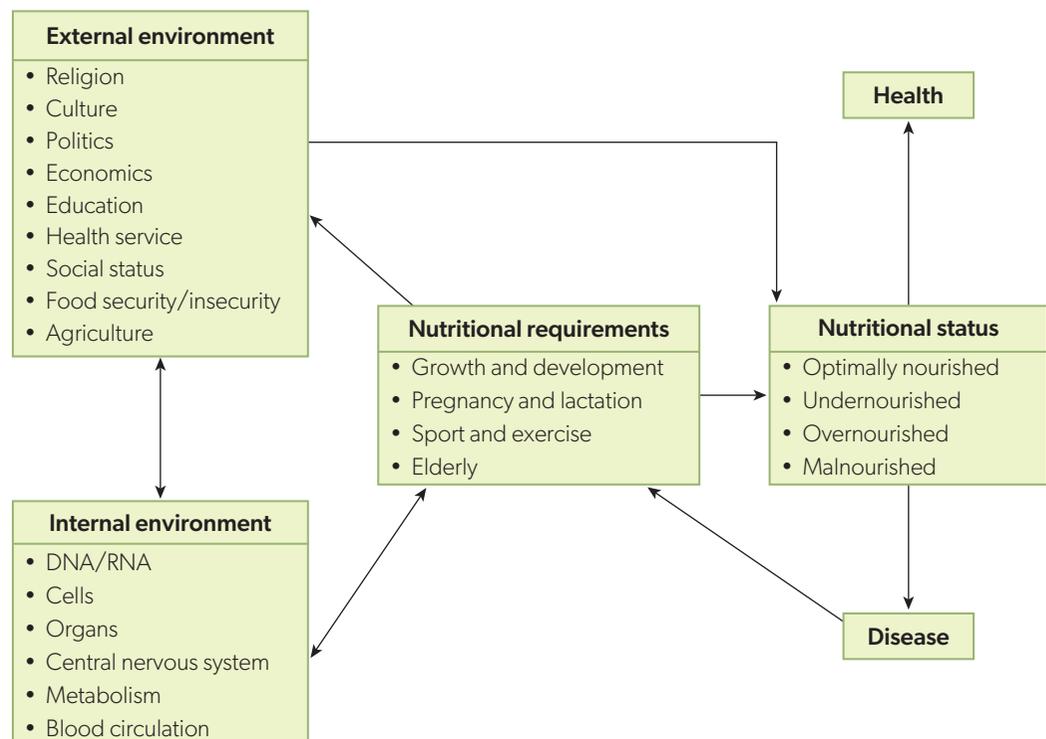
Humans have always known about the importance of food for growth and health. The choice of what to eat and drink is influenced by biological needs and the environment, which determines the quality, quantity and balance of food supply.

Figure 1 shows the relationship between the internal environment and external environment, and nutritional requirements, status and health.

Although health is also influenced by factors other than nutritional status, such as lifestyle, nutrition is a powerful and modifiable factor for health promotion.

Optimal nutritional status results in normal development, good health and a high quality of life. Undernutrition (hunger), malnutrition (for example, vitamin deficiency) and overnutrition (obesity) can cause impaired growth and/or development, and diseases.

► **Figure 1** The relationship between nutrition, environment and health



Food consists of a combination of several nutrients that influence the function of the human body. The combination and amount of nutrients a person takes in determine health and well-being. We eat food that is then digested and its nutrients absorbed in the gut system. Nutrients are transported via the bloodstream and metabolized in the cells of different organs. Naturally nutrients do not function in isolation. They interact with each other in food, in the digestive system, in the blood and in the final site of function, the cell.

Nutrients are classified into **macronutrients** and **micronutrients**. Macronutrients are nutrients that our body needs in larger amounts to maintain health. These include carbohydrate, fat, protein and water. The relative contributions of macronutrients to bodily functions depend on an individual's body composition, age and sex. For example, the female reproductive hormones oestrogen and progesterone can influence carbohydrate metabolism and fat storage (chapter A.1.1). Micronutrients, vitamins and minerals are required in smaller amounts. The function and main food sources of macro- and micronutrients are summarized in Table 1.

▼ **Table 1** Nutrients, food sources and functions

Type of nutrient	Food sources	Functions
Macronutrients		
carbohydrate	cereals, sweeteners, root crops, pulses, vegetables, fruit, dairy products	fuel, energy storage, cell membrane, DNA, RNA
fat	meat, milk, dairy products, eggs, fish oil, vegetable seeds, nuts, vegetable oil	fuel, energy storage, cell membrane, hormones, precursor of bile acid
protein	meat, fish, milk, dairy products, eggs, pulses, cereals	structure, transport, communication, enzymes, protection, fuel
water	beverages, fruits, vegetables	medium for biochemical reactions, transport, thermoregulation, excretion, lubrication
Micronutrients		
vitamins	fruits, vegetables, fatty fish (such as salmon, mackerel), fish oil, liver, meat	energy release from macronutrients, metabolism, bone health, blood health, immune function, eyesight
minerals and trace elements	meat, fish, milk, dairy products, salt, cereals, fruits, vegetables, water	mineralization of bones and teeth, blood oxygen transport, defence against free radicals, co-factors for energy metabolism, muscle function, maintenance of acid-base balance and cellular fluid balance

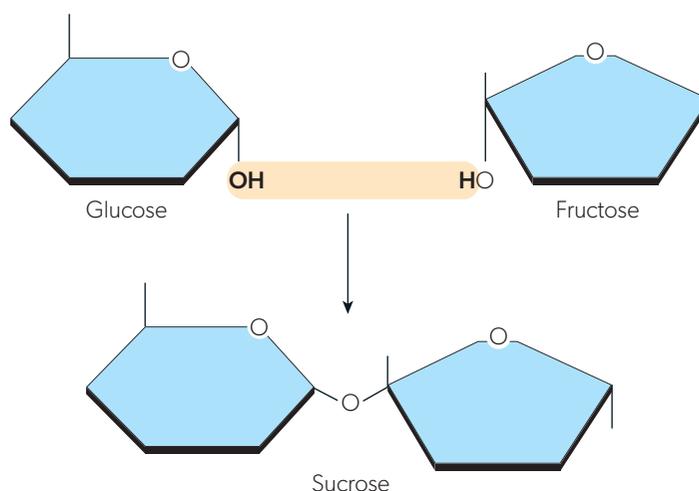
Macronutrients

Carbohydrates

Carbohydrates are synthesized by plants from water and carbon dioxide using energy from the Sun. Carbohydrates are organic compounds made up of

carbon, hydrogen and oxygen atoms. Their general formula is $(\text{CH}_2\text{O})_n$, where n is the number of carbon atoms in the molecule.

- **Monosaccharides** The simplest form is made of one molecule and is easily absorbed by the human body. Examples include glucose, fructose and galactose.
- **Disaccharides** Two monosaccharides form disaccharides with the loss of one molecule of water. For example, sucrose is a glucose–fructose combination (Figure 2).
- **Oligosaccharides** These are carbohydrates with three to nine molecules, for example, maltodextrin.
- **Polysaccharides** These are molecule chains longer than 10 molecules, for example, starch and glycogen (Figure 3).



▲ **Figure 2** Formation of sucrose from glucose and fructose by removal of water (condensation reaction)

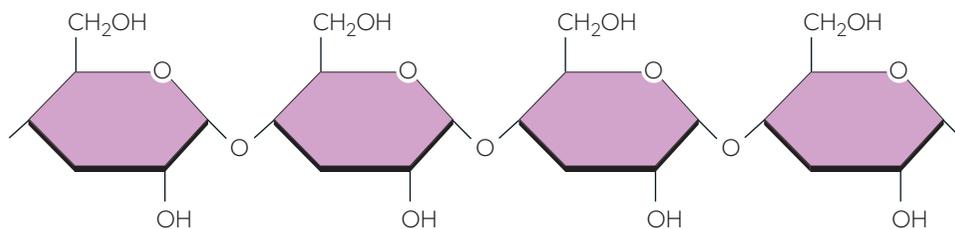
Key term

Joule (J) A unit of energy; in nutrition, joules measure the energy obtained from food that is available through cell respiration.

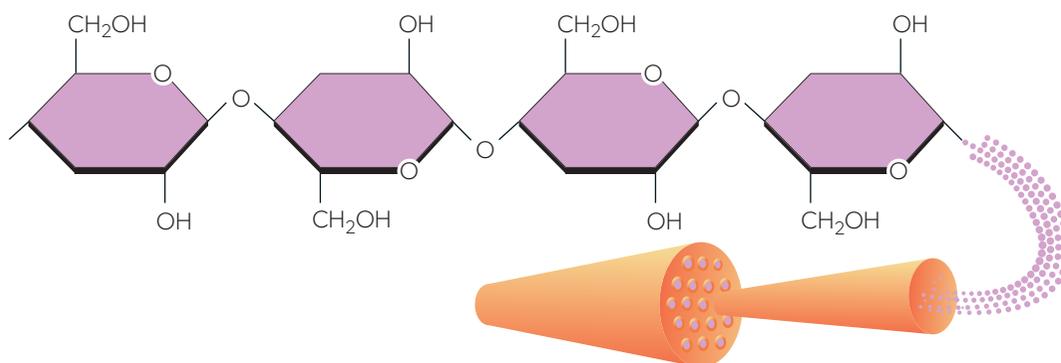
Di-, oligo- and polysaccharides need to be broken down to monosaccharides in the gut before they can be absorbed and transported to the organs. Some oligo- and polysaccharides are indigestible or poorly digestible and are called dietary fibre. Mostly found in the cellular walls of plants, these carbohydrates, such as cellulose, play an important role in the prevention of diseases.

The main function of carbohydrates is to act as metabolic fuels and energy stores. In the cells, carbohydrate (glucose) is oxidized back into water and carbon dioxide. This reaction produces energy that is used for further metabolic processes requiring yet more energy. All living cells contain carbohydrates and, on a worldwide basis, carbohydrates represent the most widespread source of food energy. In plants carbohydrate is stored as starch and in animals in the form of glycogen. One hundred grams of carbohydrate yield 1,760 kJ (kilojoules). Later in this chapter you will find out that carbohydrates are an important source of energy for intense and prolonged periods of exercise.

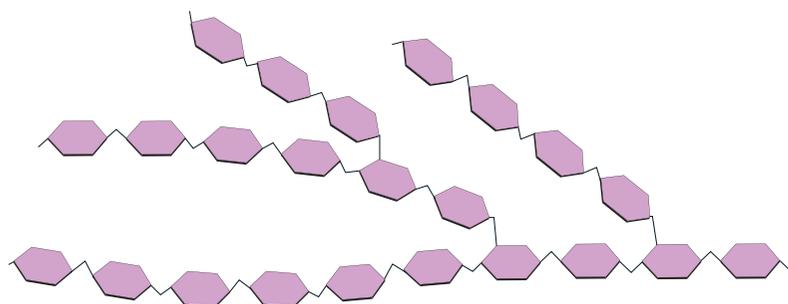
The major food sources vary in different areas of the world. The variability depends on availability and cultural preference. A list of the major carbohydrate sources in different countries is shown in Table 2. Carbohydrates are also used to build structures such as cell membranes in the body and to synthesize DNA and RNA.



a Structure of amylose, a form of starch—a sugar storage compound in plants. Oxygen bridges link the glucose subunits.



b Structure of cellulose. In cellulose fibres, chains of glucose monomers stretch side by side and hydrogen-bond at $-OH$ groups. Together the bonds stabilize the chains in bundles that are organized in fibres. Like many other organisms, humans lack the enzymes required to digest cellulose, which is a component of plant-derived products such as cotton thread used in clothing.



c Glycogen, the form in which excess glucose is stored in the human body (and other animals). It is especially abundant in the muscles and liver.

▲ **Figure 3** Comparison of the polysaccharides **a** starch, **b** cellulose and **c** glycogen

▼ **Table 2** Major carbohydrate sources in different countries according to the Food and Agriculture Organization of the United Nations (FAO)

Country	Major carbohydrate source
China	rice
Peru	potato
Mexico	corn
Nigeria	cassava
Italy	wheat
Papua New Guinea	sweet potato

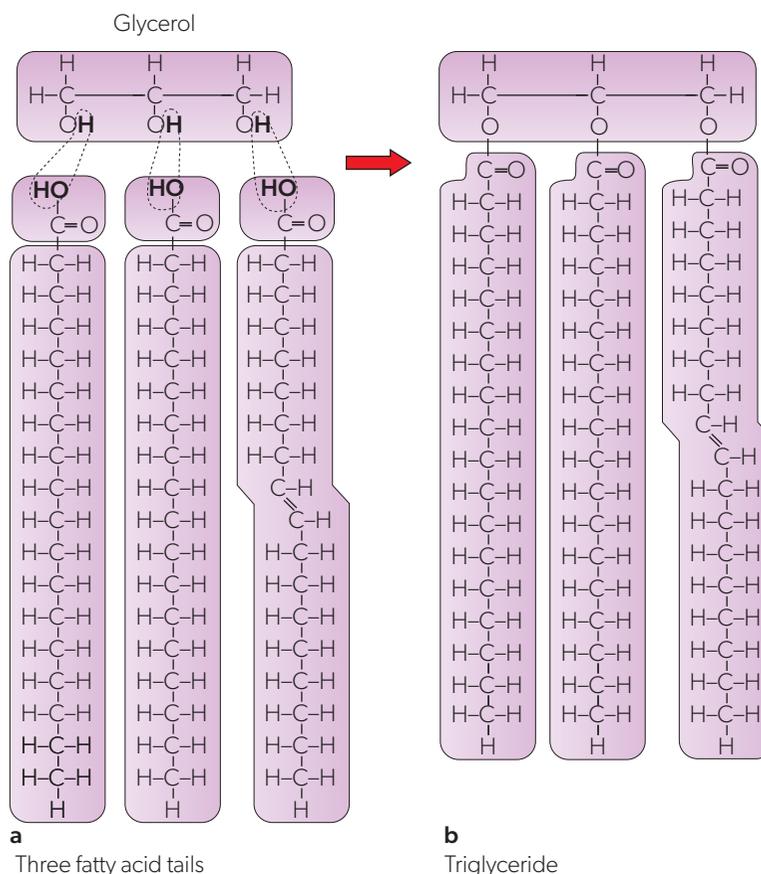
Key point

Carbohydrates are the most important source of food energy in the world, with different food sources available in different countries depending on availability and cultural preferences.

Carbohydrates are an important source of energy for intense and prolonged periods of exercise.

Lipids

Lipids, which include fats and fatty acids, are found in a variety of animal and plant sources (Table 1). The major dietary fats are triglycerides, phospholipids and sterols. Triglycerides make up to 95% of dietary fat and one molecule consists of one glycerol molecule and three fatty acids (Figure 4). These fatty acids can be identical or a combination of different fatty acids. The structure of the fatty acids determines the characteristic and biological function of triglycerides.



▲ **Figure 4** Formation of triglycerides from glycerol and three fatty acids with removal of water

Some fatty acids are classified as essential because our body lacks the enzymes necessary to synthesize them and therefore depends on their supply through food. Essential fatty acids are found in plant oils such as from sesame seeds, corn, linseeds and walnuts.

Fatty acids are a chain of carbon atoms with hydrogen attached, and a methyl group (CH_3) and a carboxyl group (COOH) on each end (Figure 4). There are different kinds with different structures:

- saturated fatty acids (SFA) with the maximal number of hydrogen atoms (four) on each carbon atom
- unsaturated fatty acids, where two hydrogen atoms are missing, form double bonds between two carbon atoms and become unsaturated
- monounsaturated fatty acids (MUFA) with a single double bond in the chain
- polyunsaturated fatty acids (PUFA) shaped by multiple double bonds

- omega-3 fatty acids (PUFAs) that have their first double bond located between the third and fourth carbon atoms from the methyl end
- omega-6 fatty acids (PUFAs) that have their first double bond located between the sixth and seventh carbon atoms from the methyl end.

Research has shown that an optimal balance of omega-3 and omega-6 fatty acids in the diet is important to maintain adequate inflammatory and immunological responses.

Fat is an important source of food energy. The intake of 100 grams of fat provides 4,000 kJ; about three times more than carbohydrates. Triglycerides can be stored in adipose tissue, which builds up an energy store over a prolonged period of time. Later in this chapter you will find out that although fat cannot be used during high-intensity exercise, it is an important source of energy in the recovery period between bursts of high-intensity exercise, as well as during prolonged exercise.

Moreover, fat in adipose tissue provides physical protection of vital organs and helps to control body temperature (thermal insulation). Dietary fat also plays a major role in the synthesis of hormones, vitamin D (sterols) and cell membranes (sterols, phospholipids). Fats are important for the transport of fat-soluble vitamins.

Key point

Essential fatty acids are called “essential” because our bodies cannot synthesize or create them so we have to get them from the food we eat.

ATL Thinking skills

Food manufacturing alters dietary fat

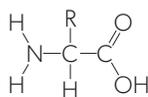
Biscuits, chocolate, cakes and margarines are produced with fat that has been altered by the food manufacturers to make it solid at room temperature. Mono- and polyunsaturated fats, mainly plant oils, are converted into saturated fat by adding hydrogen atoms to the double bonds. This process is called hydrogenation. Hydrogenation also changes the position of hydrogen atoms on the remaining double bonds. In the naturally occurring cis form, the two hydrogen atoms are attached on the same side of the double bond. This form is changed into a trans form where the hydrogen atoms are placed on opposite sites of the double bond. Trans fatty acids are known to harm the body in the same way as an excess of saturated fatty acids in the diet.



▲ Figure 5 Cakes and biscuits contain harmful fatty acids

▼ **Table 3** Essential amino acids

Essential amino acids
Isoleucine
Leucine
Lysine
Methionine
Phenylalanine
Threonine
Tryptophan
Valine
Histidine



▲ **Figure 6** Basic structure of amino acids (R indicates another atom or molecular structure attached to the carbon atom)

Proteins

Proteins are the second most abundant compounds in the body (water is the most abundant). Proteins are formed by amino acids, compounds made of carbon atoms, nitrogen atoms, oxygen atoms and hydrogen atoms. Most amino acids are characterized by the same central structure (Figure 6) and a side chain that distinguishes the physical and chemical properties. Amino acids are linked in chains through peptide bonds. Each protein has a characteristic amino acid composition. Twenty amino acids have been identified as being required for the synthesis of proteins. Of the twenty, nine are essential and need to be provided in the diet. Table 3 lists the essential amino acids.

Foods rich in proteins are meat, fish, milk, dairy products, eggs, pulses and cereals. The quality of proteins in the diet depends on whether all essential amino acids are included. In pulses and grains we find proteins that are lacking in essential amino acids. Pulses are short in isoleucine and lysine. Grains lack methionine and tryptophan. The quality of these proteins is low. In order to avoid diseases, pulses and grains should be combined as part of the diet.

Proteins are also a source of energy; the metabolism of 100 grams of protein yields 1,720 kJ. The functional activity of proteins is determined by their structure, size and shape. Proteins have a wide range of functions in the body. They can be summarized in four functional groups:

- structural: muscles, bones, skin, cells
- transport/communication: plasma proteins, hormones, receptors, neurotransmitters
- protective: antibodies, mucus, anti-inflammatory proteins
- enzymatic: digestion, metabolic pathways, O₂ and CO₂ transport.

Dietary protein deficiency is common in developing countries and a cause of undernutrition. A lack of protein in the diet is associated with impairment in growth and development, life-threatening diseases and death. In the western world usually overconsumption of protein occurs because the main protein source is meat. The digestibility of animal protein is higher than the digestibility of plant proteins.



Science as a shared endeavour

There is general agreement on which amino acids should be considered essential but this has not always been the case.

Research different views on whether histidine should be considered as an essential amino acid. Why is it important to agree common conventions and terminology in science?

Case study

Protein-energy malnutrition in children

Children are in the process of growing and developing. For example, in the first year of life a child triples its body weight and increases its height by 50%. Growth and development require energy and proteins that must be provided by food. A child needs much more energy in relation to body weight than an adult. When children do not get enough macronutrients they will suffer from protein-energy malnutrition. This





form of malnutrition can cause extreme wasting where children appear like “skin and bone” (syndrome called marasmus), where children have abnormal amounts of water under the skin and in the body (syndrome called kwashiorkor) or both (syndrome called marasmic kwashiorkor). Children who suffer from malnutrition are more likely to have impaired growth, suffer from infection, have disabilities and die at a young age. Malnutrition is not only caused by inadequate diet but also by environmental factors, infectious diseases and poverty.

1. What are the consequences of a lack of carbohydrate, fat and protein in the diet?
2. Why are children at greatest risk of suffering from undernutrition/ malnutrition?



▲ **Figure 7** Nutrition is extremely important in children

Micronutrients

Vitamins

Vitamins are organic compounds that are vital for health and well-being and are found in fruits, vegetables and some meat. They are regulators in processes of energy release from food and important co-factors in various chemical reactions. Vitamins are grouped into water-soluble and fat-soluble vitamins. As the name indicates, water-soluble vitamins are soluble in water and therefore an overdose is not toxic in healthy individuals for most vitamins. They are simply excreted with the urine.

In contrast, excessive intake of fat-soluble vitamins can result in poisoning because they can be stored in adipose tissue and the liver. An overdose of those vitamins, however, is rare and only needs to be considered under particular conditions (for example, during pregnancy). Table 4 lists the water- and fat-soluble vitamins and their food sources. All vitamins are classified as essential and need therefore to be supplied in food.

There are two compounds that are considered to be vitamins but they can be synthesized by the body. Vitamin D is produced through precursors in the skin in combination with sunlight, and the B vitamin niacin is synthesized from the amino acid tryptophan.



▲ **Figure 8** Daily consumption of colourful fruits and vegetables provides essential vitamins important for health and well-being

▼ **Table 4** Water-soluble (light blue) and fat-soluble (dark blue) vitamins and their food sources

Vitamins	Food sources
C	citrus fruits, green vegetables
B (such as B12, folic acid)	whole grains, pulses, seeds, vegetables, meat, fish, milk, eggs
E	whole grains, seeds, nuts, fatty meat, plant oils, green leafy vegetables
D	fatty fish, fish oil, liver, beef, egg yolk
A	yellow, orange and red fruits and vegetables, green vegetables
K	green leafy vegetables, milk, liver

Major minerals and trace elements

Minerals and trace elements are inorganic compounds that must be supplied through food and fluids. The main sources are meat, fish, milk, dairy products, cereals and green leafy vegetables. Minerals are distinguished from trace elements by the occurrence in the body, with approximately 4% of body mass consisting of minerals while trace elements make up approximately 0.001% of body mass.

They also differ in the amount that is required in the diet for the maintenance of health. Optimal mineral intake varies between grams and milligrams per day and those for trace elements between milligrams and micrograms per day. Minerals and trace elements are involved in processes that range from maintaining bone and blood health to the release of energy, muscle function and maintenance of cellular fluid balance.

The minerals that the body needs are:

- calcium (Ca)
- chloride (Cl)
- magnesium (Mg)
- sodium (Na)
- potassium (K)
- phosphorus (P).

The trace elements that the body needs are:

- iron (Fe)
- iodine (I)
- fluoride (F)
- zinc (Zn)
- selenium (Se)
- copper (Cu)
- chromium (Cr)
- manganese (Mn)
- molybdenum (Mb).

Key point

Food consists of different nutrients that play different roles in contributing to our health and well-being. We need to eat a range of foods to get all the nutrients we need.

ATL Research skills

Choose five of the minerals or trace elements listed and find out what the daily recommended intake of each is.

Calcium

Calcium is the most abundant mineral in the body. It is important for building and maintaining healthy bones, and it plays a major role in muscle contraction. Calcium is stored in the sarcoplasmic reticulum of muscles and is released when the muscle fibres are stimulated. It is essential for the formation of the actin-myosin cross-bridges that cause muscles to contract. Additionally, calcium is involved in nerve impulse/message transmission, enzyme activation and regulation of cell membrane permeability.

Iron

Iron is present in the body in relatively small amounts. About 66% of iron in the body is in the haemoglobin of blood. Iron is also part of myoglobin. Haemoglobin, located in the red blood cells, binds with oxygen in the lungs and transports it to the body tissues. Myoglobin, found in the sarcoplasm of muscle fibres, has a high affinity for oxygen. Myoglobin combines with oxygen and stores it until needed.

Sodium, potassium and chloride

Sodium, potassium and chloride are important electrolytes in fluids and tissues throughout the body.

- Sodium is primarily found in extracellular fluids, such as blood plasma and the fluid surrounding cells. Sodium is involved in nerve transmission, muscle contraction and regulating blood pressure. It also supports the absorption of nutrients.
- Potassium is primarily found inside cells (intracellular fluid). Potassium is vital for maintaining the electrical potential across cell membranes, and helps nerve and muscle function. It also aids in muscle contraction and helps regulate fluid balance.
- Chloride is present in both extracellular and intracellular fluids. Chloride works with sodium to maintain fluid balance and osmotic pressure. It also plays a role in nerve function and helps regulate pH levels in the body.

A healthy balanced diet

Dietary advice can range from anecdotal sayings, such as “an apple a day keeps the doctor away”, to scientifically derived amounts of nutrient intake. Once the essential nutrients were understood and established, quantitative advice for individual macro- and micronutrients was developed. These types of dietary advice are dietary recommendations for a population’s daily intake of nutrients.

Broader dietary advice for the individual’s general nutritional well-being is given by dietary guidelines. For example, in countries including the UK, USA, New Zealand and Germany, there is some version of a “Five a day” campaign to promote the consumption of five portions of fruit and vegetable per day. In Mongolia the recommendation is for three or more servings of vegetables and at least two servings of fruit per day. The World Health Organization (WHO) currently recommends a daily fruit and vegetable intake of 400 grams.

Dietary recommendations

Dietary recommendations set standards for what constitutes an adequate intake of essential nutrients to promote health. They are developed by governments

Key terms

Balanced diet A diet that provides all nutrients in the right amount to maintain health and prevent nutrient excess or deficiency diseases.

Dietary recommendations Recommended amounts of essential nutrients in the diet.

Dietary guidelines Recommended amounts of foods, food groups or meals.

and health authorities based on scientific evidence to assess whether the diet of a population or a population subgroup meets its nutritional needs. The amount of nutrients required for a healthy balanced diet is influenced by factors including age, sex differences, body composition and activity level.

- Individuals with higher levels of physical activity require more carbohydrates to fuel their energy needs.
- During infancy and childhood, protein is essential for building tissues and supporting growth, carbohydrates are needed to provide energy for active play, and fats are important for brain development.
- In elderly people, protein helps maintain muscle mass and helps prevent sarcopenia (chapter A.3.2).
- Males typically have a higher basal metabolic rate and therefore might need slightly more carbohydrates.
- Males typically have a higher proportion of lean muscle mass and therefore might have a slightly higher protein requirement.
- In females, nutritional requirements may be affected by hormone fluctuations across the menstrual cycle as well as blood loss during menstruation.
- During pregnancy and breastfeeding, nutritional requirements are increased to support the growth of the developing fetus and provide nourishment to the breastfeeding infant.

The adequate nutrient intake is chosen so that the needs of 97.5% of the population are met. In the case of the total energy intake, however, a value adequate for 50% of the population is considered. This is because over time even a small imbalance of energy intake over energy expenditure would lead to individuals becoming overweight or even obese and would cause severe health problems.

The methods used to determine nutritional requirements are:

- observation of nutrient intake in a healthy population
- observation of nutrient intake in a diseased population
- studies on the maintenance of the balance of nutrients in the body
- studies that involve removing or adding a nutrient in the diet
- measurement of nutrient levels in biological tissues or fluids
- measurement of nutrient-specific biological markers
- animal experiments.

Internationally, there is no agreement about dietary recommendations. Different countries prefer their country-specific recommendations. The methods used to identify the level of an adequate intake of nutrients vary between countries. The availability of new research data in one country and not in another also contributes to different dietary recommendations. For example, the intake of carbohydrate as percentage of total daily energy intake for an adult is set in the USA at 45%–65%, in Sri Lanka at 50% and in the Netherlands as at least 40%. In 2003, the WHO and the FAO developed dietary goals for both developed and developing countries for the prevention of long-term chronic diseases (Table 5).



Activity 1

A balanced diet that provides all nutrients in sufficient amounts is important for human development and health. In some countries and cultures people do not consume meat (vegetarian diet) or base their diet on plant-derived foods only (vegan diet).

1. Discuss the concept of a balanced diet in the context of different religions and cultures.
2. Evaluate how people who follow a vegetarian or vegan diet ensure a balanced diet.

▼ **Table 5** International dietary recommendations for fat, carbohydrate, protein and salt published in a joint report by the WHO and FAO

Dietary factor	Dietary recommendation (% of total energy or grams per day)
Total fat	15%–30%
Saturated fatty acids (SFA)	<10%
Polyunsaturated fatty acids (PUFA)	6%–10%
Omega-6 polyunsaturated fatty acids	5%–8%
Omega-3 polyunsaturated fatty acids	1%–2%
Trans fatty acids	<1%
Total carbohydrate	55%–75%
Sugars	<10%
Protein	10%–15%
Sodium chloride (salt)	<5 g
Fruits and vegetables	→400 g

Activity 2

Table 5 shows the international dietary recommendations for fat, carbohydrate, protein and salt. The recommendation for carbohydrate intake, for example, is higher than that from a single developed country (for example, the recommendation of 45%–65% in the USA) because of the high risk of under- and malnutrition in developing countries.

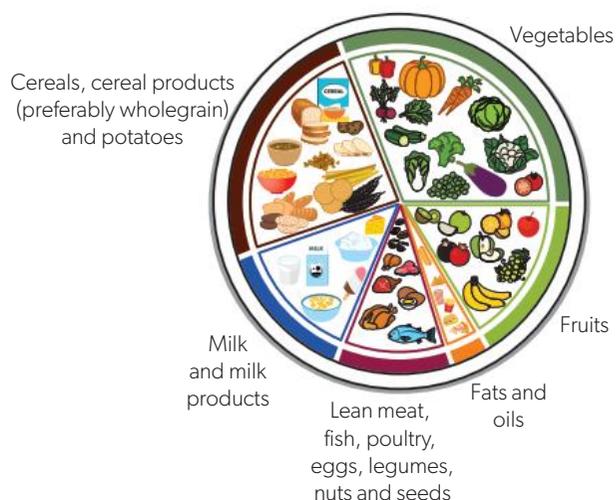
1. What could be the rationale for countries to use their own dietary recommendation rather than the international one?
2. What is the advantage of an international dietary recommendation over a national recommendation?

Dietary guidelines

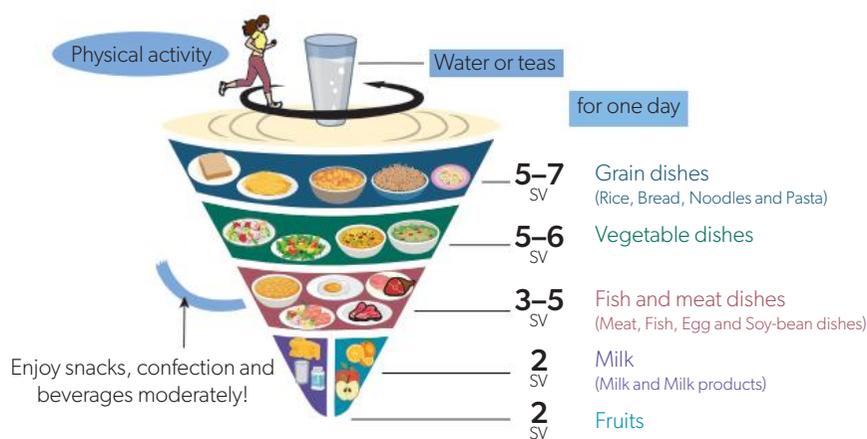
Dietary guidelines target foods, food groups or meals and are set by a country to guide its people towards a healthy balanced diet. The development of dietary guidelines can be based on dietary recommendations—it can be a practical interpretation of nutrient intake recommendations. Dietary guidelines are influenced by sociocultural factors of the country including:

- religious beliefs
- social norms
- preparation preferences
- food consumption patterns
- food availability
- food security
- income
- food prices.

The visual presentation used for dietary guidelines differs between countries, as does the advice given on the food groups that should be eaten most or least. Most graphical images illustrate the proportions of fluids, fruits, vegetables, cereals, milk, dairy products, eggs, meat, fish, oil and sweets in the diet. Visual presentations used include a food pyramid (in Sri Lanka), a food tower (in Korea), a food circle (in Finland) and a food plate (in the UK).



▲ **Figure 9** The visualization of country-specific dietary guidelines for Malta



▲ **Figure 10** The visualization of country-specific dietary guidelines for Japan (SV = servings)

▼ **Table 6** Comparison of the recommended daily dietary energy distribution from carbohydrate, protein and fat for non-athletes and endurance athletes

Nutrients	Non-athlete from North America		Endurance athlete	
	% of total energy	body weight (g kg ⁻¹)	% of total energy	body weight (g kg ⁻¹)
carbohydrate	45–65	3–6	55–75	6–10
protein	10–15	0.8–1	10–35	1.2–1.4
fat	15–30	–	20–35	–

ATL Thinking skills

Dietary guidelines

Dietary guidelines can differ between countries. However, all have the primary aim of promoting the health of the population. In a food pyramid, or similar visualization, food groups that should be eaten the most are given the largest area and those that should be eaten less are given a smaller area. Recommendations for water and other beverages are illustrated outside the food pyramid.

1. Describe the differences between the dietary guidelines of the two regions shown in Figures 9 and 10.
2. Why do the food guides differ between countries?
3. Based on the visualizations, what are the principles of a healthy balanced diet?
4. What factors might influence your own individual nutritional needs?

Nutritional strategies for sportspeople

Nutritional intake can have a profound effect on exercise performance; the intake of carbohydrate can have a particularly noticeable effect.

ATL Thinking skills

Population-specific recommendations: endurance athletes versus non-athletes

An optimal level of nutrition is essential for the health and performance of an athlete. An athlete's diet must meet their increased physiological requirements.

The most important differences between a non-athletic person and an athlete are the increased energy and fluid requirements of athletes.

In addition to variation due to body composition, age and sex differences, nutritional needs for athletes vary depending on the type of sport and between the periods of training, competition and recovery. For example, an endurance athlete (such as a marathon runner) needs more carbohydrates than a non-athlete to meet their energy requirements and delay the onset of fatigue. Most of their total daily energy intake is provided by carbohydrates. This means there is a proportionally lower energy intake from proteins and fat (Table 6). Nevertheless, protein intake should be slightly increased in endurance athletes to maintain, build and repair muscle mass and connective tissue. Slightly more protein is also required to synthesize certain hormones and enzymes. Dietary fat recommendations for endurance athletes are also slightly higher than for non-athletes. This is because dietary fat is a source of energy, fat-soluble vitamins and essential fatty acids, which are crucial for athletic performance. Endurance athletes also need to drink to replace the fluid lost through sweat. Since endurance athletes sweat more than non-athletes, their water intake is higher.

Carbohydrates for performance

Carbohydrate is used by both the aerobic and anaerobic systems to synthesize ATP. This means that carbohydrate plays a key role in driving muscle contraction

across a very wide spectrum of exercise intensities. This can range from short-duration high-intensity exercise lasting less than 1 minute to longer-duration endurance-type efforts lasting several hours, such as marathon running.

Despite the importance of glycogen for muscular work, the amount of carbohydrate in the body is relatively small. There is around 400 g in muscle, 100 g in the liver and a few grams circulating in the blood. Because the energy density is relatively low ($1,760 \text{ kJ } 100 \text{ g}^{-1}$ compared with $4,000 \text{ kJ } 100 \text{ g}^{-1}$ in fat) it represents a limited source of energy.

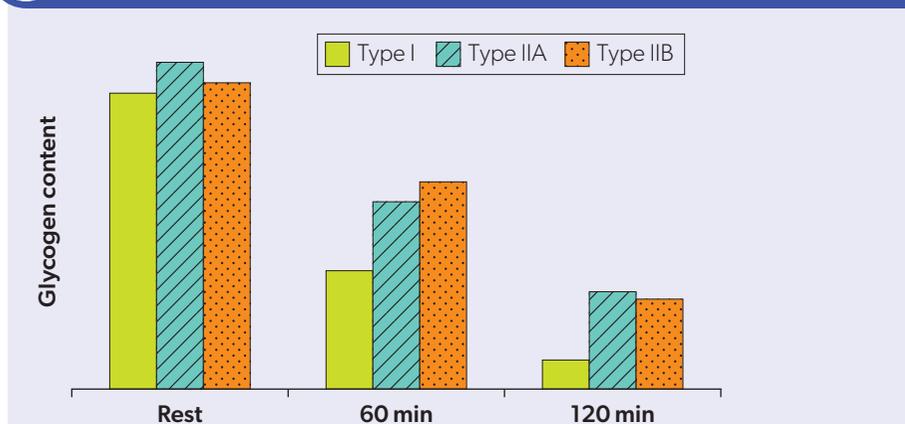
In healthy, active people there is sufficient glycogen to allow between one and a half and two hours of continuous activity. However, exercise intensity can affect the way glycogen is used up.

During moderate-intensity exercise most muscular work is due to the activation of slow twitch muscle fibres. **Slow twitch (type I) muscle fibres** have higher aerobic endurance and are well suited to low-intensity endurance activities. As intensity increases fast twitch muscle fibres are recruited too. **Fast twitch (type II) muscle fibres** are better suited for anaerobic activity and play a major role in high-intensity activity. Since glycogen is only used for energy metabolism within the cells in which it is stored, exercise intensity changes the pattern of glycogen use within a muscle.

Figure 11 shows how glycogen is depleted in type I fibres but more muscle glycogen remains in fast twitch muscle fibres after a long period of moderate cycling. This is because the slower twitch fibres would have been activated.

Since glycolysis is a very fast metabolic pathway it has the potential to use up glycogen very quickly! All-out cycling exercise of just 30 seconds can substantially reduce glycogen stores.

ATL Thinking skills



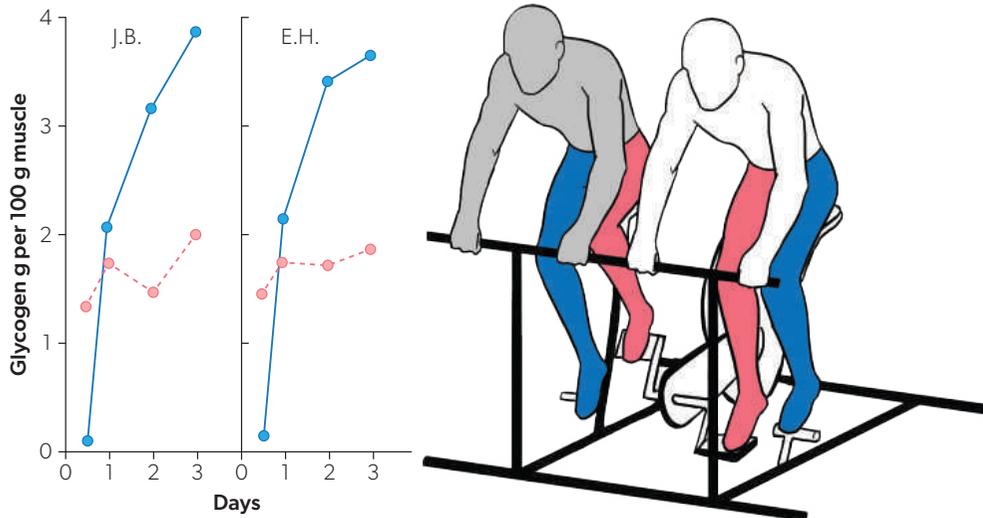
▲ **Figure 11** Relative muscle glycogen content of slow and fast twitch muscle fibres before, during and after 2 hours of moderate-intensity cycling exercise

Applying what you know about the activation of the different muscle fibres, how might the pattern of glycogen use in fast and slow twitch muscle fibres change if shorter-duration, more intense exercise was performed instead?

ATL Thinking skills

How could you access muscle to measure its glycogen content?

Figure 12 shows the data from a classic exercise physiology study in 1966. Jonas Bergström (J.B.) and Eric Hultman (E.H.) sat on different sides of the same exercise bike, the first turning the left pedal with their right foot and resting the left, and their companion doing the opposite. Measures of muscle glycogen in each leg of both cyclists were made before and after one-legged cycling which they continued until they were exhausted. During recovery over the next 3 days the cyclists consumed a high-carbohydrate diet.



▲ **Figure 12** Glycogen content of each leg of two cyclists (J.B. and E.H.) immediately after exhausting one-legged cycling and during 3 days of recovery (Bergström, Hultman, 1966)

The study demonstrated several important concepts.

- Muscle glycogen is utilized locally within the muscle in which it is stored.
- Depletion of glycogen is connected with fatigue and exhaustion; when carbohydrate is limited, exercise is limited or prevented. The fatigue and drop in exercise capacity when carbohydrate runs out is sometimes referred to as “hitting the wall” by athletes who experience this.

In addition the study suggested that:

- high carbohydrate intake during recovery can restore glycogen stores in 24 hours
- rest and carbohydrate intake result in a “supercompensation” where additional glycogen is stored; in this example, glycogen stores have more than doubled the initial levels seen in the rested legs.

The research of Bergström and Hultman started the idea that ingestion of carbohydrates can increase muscle glycogen stores. A similar effect can be achieved simply by reducing training and increasing carbohydrate intake; this avoids the need for hard exercise to empty the muscles of glycogen. This process is known by athletes as carbohydrate loading, carbo-loading or carb-loading. Some athletes do this because a larger glycogen store represents a greater energy store; this permits exercise to continue for longer before the glycogen store becomes depleted. This delaying of fatigue may be of particular value in long-duration endurance events or tournament-type situations where glycogen might run low. However, while the link between carbohydrate loading and performance has been well documented in males, far less research has examined the efficacy of carbohydrate loading for females. There is some evidence that this may vary according to menstrual cycle phase and hormonal changes. More research on carbohydrate loading in female athletes is needed.

If sports allow, it is possible to eat foods or drink fluids containing carbohydrate during exercise or at breaks in exercise. This boosts the supply of glucose in the blood that can be taken up by muscles and used as a substrate. Maintaining blood glucose helps reduce perceived level of effort and maintains concentration, both of which can benefit performance.

ATL Thinking skills

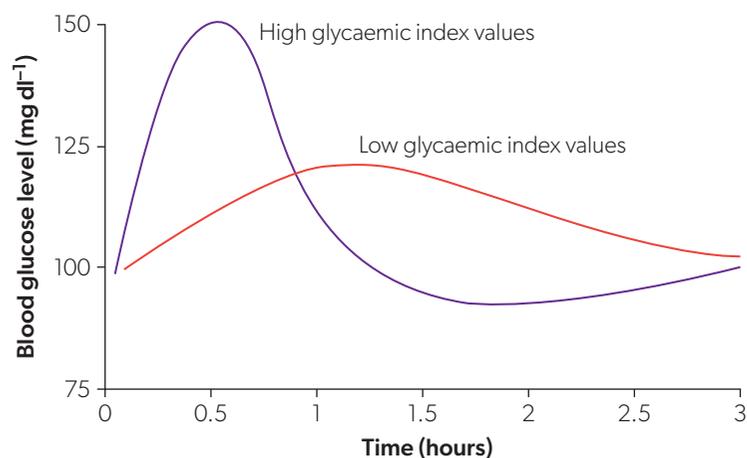
It has been observed that the Fiji rugby team rarely performed to the level expected in major competitions despite seemingly adequate preparation and training. Fatigue in the second half of matches may be a factor. One reason for this could be glycogen depletion.

A survey of the eating habits of the Fiji rugby team suggested that they consumed insufficient amounts of carbohydrates to maintain high intensities of exercise throughout the full duration of a rugby match. This may be the result of local food preferences and availability (Lako et al., 2010).

Types of carbohydrate

A plentiful supply of carbohydrate-containing foods is important in the lives of sportspeople. However, not all carbohydrate-containing foods are equal! The physical structure of food and the chemical form of carbohydrate within it influence how efficiently carbohydrate is extracted and the rate and extent to which it increases the concentration of glucose in the blood after ingestion.

One approach to classifying foods is termed the glycaemic index (GI). If a range of carbohydrate-containing foods are ingested, even if they contain the same amount of carbohydrate, the rate of its appearance in the blood can be very different (Figure 13).



▲ **Figure 13** The effect on blood glucose of foods with a high and low GI

The GI represents the ability of a food containing 50 grams of carbohydrate to raise blood glucose in comparison with a 50-gram reference dose of carbohydrate, usually given as glucose or white bread; these have a GI of 100. Sugary foods tend to have a high GI, whereas high-fibre foods and those requiring greater physical and chemical digestion have lower values.

▼ **Table 7** GI values from International Table of glycaemic index and glycaemic load values

Food	GI value
Coca Cola soft drink	58
White rice	50–70
Full fat cow's milk	30
Peanuts	14
Sports bar (Power Bar)	56
Apple, raw	38
Carrots, raw	16
Carrots, boiled	30–50



Activity 3

Search on the internet for an international table of GI values for foods from around the world.

1. Can you work out whether you had a low or high GI breakfast this morning?
2. Can you speculate whether a high or low GI breakfast is best for a morning of schoolwork?

Key point

Carbohydrates are an important source of energy for athletes as they are used in different types of energy production. Athletes may choose to eat large amounts of carbohydrate-rich food before training or competition to increase glycogen stores. Likewise they may eat large amounts after training or competition to replace what has been used.



Linking question

How should nutritional periodization be linked to training programmes? (A.3.1)

Consider:

- training goals
- nutrient requirements
- macronutrient ratios
- timing of nutrient intake
- nutrient intake as the training programme progresses.

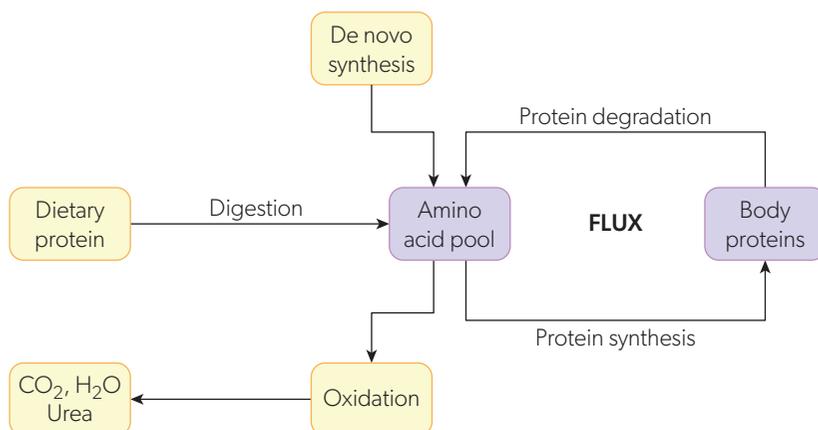
Recovery from training

The same principles that allow carbohydrate loading can be applied to recovery after exercise. As athletes finish one training session they may already be thinking about the next one; this may be the following day or even later the same day. Therefore, it is important to maintain high levels of muscle glycogen and replace quickly what has been used in training. It is the foods with a high GI value that provide the fastest, most efficient way of replacing glycogen.

Protein for performance

Unlike fat and carbohydrate, there is no storage capacity for protein in the body. All protein is present with a specific biological function (for example, as enzymes or structural proteins such as muscle). All protein in our bodies is in a state of flux; that is, molecules are constantly being broken down into their constituent amino acids and resynthesized (Figure 14).

The steady loss of amino acids from the body along with no storage means that a regular daily intake of protein is required to sustain biological function and health. The current level of intake recommended for healthy adults is 0.8 grams per kilogram of body mass per day ($0.8 \text{ g kg}^{-1} \text{ day}^{-1}$).



▲ **Figure 14** Processes of protein and amino acid turnover

Influence of strength training and endurance training

The basic requirement for protein intake can increase in certain groups at certain times, such as in growing children, in people recovering from illness and in breastfeeding mothers. When sportspeople are engaged in strength and endurance training the requirements also increase.

Table 8 shows how proteins are used in different groups of people.

▼ **Table 8** Use of proteins in different groups of people

Population	Amino acid oxidation	Muscle repair	Muscle hypertrophy	Dietary protein requirement ($\text{g kg}^{-1} \text{ day}^{-1}$)
untrained people	✓	✓	✗	0.8
endurance athletes	✓✓✓	✓✓	✓	1.2–1.4
strength athletes	✓	✓✓✓	✓✓✓	1.2–1.7

ATL Thinking skills

What is a vegetarian?

The International Vegetarian Union defines vegetarianism as “a diet derived from plants, including mushrooms, algae and salt, and excluding any animal meat, with or without the use of dairy products, eggs and/or honey”.

How many of your classmates are vegetarian? Why have they decided to follow this diet?



International
Vegetarian
Union

▲ **Figure 15** The logo of the International Vegetarian Union

Nutritional ergogenic aids

Sports drinks, bars and gels are products intended as a convenient means of ingesting fluid and/or macronutrients in an exercise setting when “normal” food may be impractical.

There are also numerous compounds and supplements that are not based on essential components of the diet that are marketed as commercial sports nutrition supplements. However, there are few real “quick fixes” in sports nutrition and only a handful of these products are supported by good evidence (Table 9).

▼ **Table 9** Dietary supplements

Supplement	Mechanism of action	Dosage	Benefits	Adverse effects
caffeine	CNS stimulant that can reduce the sensation of discomfort and effort during continuous exercise and increase force production during strength-type exercise	2–6 mg per kg body mass before or during exercise. Sensitivity varies between individuals	increases exercise performance at a range of exercise intensities	anxiety, insomnia, mild diuretic, weakly addictive
creatine	increases muscle creatine content, facilitates rapid creatine phosphate resynthesis in the rest period during repeated high-intensity exercise creatine ingestion may also augment the effects of strength training by stimulating muscle anabolism	15–20 g per day for 4–7 days followed by a maintenance dose of 2 g per day	benefits exercise that relies on the creatine phosphate energy system such as strength, power and sprinting sports	increase in body mass may be detrimental for some
bicarbonate	a buffer that increases blood pH can improve tolerance during high-intensity exercise by reducing the acidity in muscle cells (and bloodstream)	0.3 g per kg taken before exercise	increases performance during high-intensity exercise lasting 1–7 minutes	gastrointestinal upset

ATL Research skills

The Australian Institute of Sport has a supplement programme aimed at advising Australian athletes on how best to incorporate sports foods and supplements into their nutrition plans.

Search on the internet to find out more about what the Australian Institute of Sport recommends.

ATL Research skills

Some other supplements are emerging as important.

- Beta-alanine
- L-Arginine
- Nitrate

How do these supplements work and who might benefit from taking them?



Linking question

How can an athlete manage fuel and liquid intake during an event to minimize the onset of fatigue? (A.3.1 HL)

Consider:

- nutrition intake and hydration planned ahead for the event
- starting the event well hydrated
- during the event, consuming carbohydrates
- drinking fluids regularly throughout the event
- choosing sports drinks that contain carbohydrates and electrolytes
- practising nutrition and hydration strategies during training.

Gastrointestinal discomfort

Gastrointestinal problems are common, especially in endurance athletes, and are perhaps the most common cause of underperformance in endurance events. Symptoms include nausea, vomiting and diarrhoea, and these can not only have negative effects on performance but also an impact on subsequent recovery. Many of the gastrointestinal functions are not affected at low-intensity exercise but become progressively affected at higher intensities. The main causes of gastrointestinal symptoms are physiological, mechanical or nutritional in nature.

Physiological: during exercise, blood flow to the intestines is decreased, and this is often acknowledged as the main mechanism for the emergence of the symptoms.

Mechanical: the mechanical causes of gastrointestinal problems are related to either impact or posture. For example, symptoms are more common in runners

than in cyclists, probably a result of the repetitive high-impact mechanics of running and subsequent damage to the intestinal lining. This repetitive gastric jostling is also thought to contribute to lower gastrointestinal symptoms such as flatulence, diarrhoea and a sudden need to rush to the toilet to empty one's bowels (urgency). Posture can also have an effect on gastrointestinal symptoms. For example, on a bicycle, upper gastrointestinal symptoms are more prevalent possibly due to increased pressure on the abdomen because of the cycling position, particularly when in the "aero" position. "Swallowing" air as a result of increased respiration, and drinking from water bottles, can also lead to mild to moderate stomach distress.

Nutrition: nutrition can have a strong influence on gastrointestinal distress, although many of the problems can occur in the absence of any food intake before or during exercise. Consuming fibre, fat, protein and fructose have all been associated with a greater risk of developing gastrointestinal symptoms. Dehydration may also make the symptoms worse.

Advice to athletes includes:

- avoid high-fibre foods in the day or even days before competition
- avoid aspirin and some anti-inflammatory drugs, such as ibuprofen, because both can increase intestinal permeability and may increase the incidence of gastrointestinal complaints
- avoid high-fructose foods (in particular, drinks that are exclusively fructose), but a fructose and glucose combination may not cause problems/be better tolerated
- avoid dehydration (start the exercise well hydrated)
- choose drinks with lower carbohydrate concentrations to prevent very high concentrations in the stomach
- practise nutrition strategies, to work out what does and does not work, and reduce the chances of getting gastrointestinal symptoms.

More research is needed to obtain a better understanding of the causes of the gastrointestinal problems and to improve the recommendations to athletes. However, we do know that fatigue, mood disturbances, underperformance and gastrointestinal distress are common among athletes during training and competition. More elite athletes seem to be suffering from gastrointestinal discomfort conditions that can be linked to the gut. Students studying the HL course will consider how the gut microbiome influences the health and performance of individuals later in this chapter.

LEA and RED-S

LEA

Participating in physical activity, exercise and sport (elite and recreational) can bring about health benefits when the body is properly fuelled with sufficient energy. However, failure to consume enough energy can lead to a state of **low energy availability (LEA)**. Energy availability is defined as dietary energy intake minus exercise energy expenditure divided by fat-free mass (FFM). LEA can be caused by disordered eating behaviours and/or excessive exercising, for example during training or competition.

Figure 16 indicates three different states possible, with the central row highlighting the athlete with adequate energy availability (EA)—energy intake being sufficient to cover the demands from exercise and daily functions.

	Energy intake	Energy demands of exercise	Energy for daily functions	
Insufficient energy intake	Too low	Regular energy demands	Not enough energy for daily functions	
Energy intake balanced with energy needs	Balanced with energy demands	Balanced with energy intake	Sufficient energy for daily functions	
Excessive exercise	Regular energy intake	Too high	Not enough energy for daily functions	

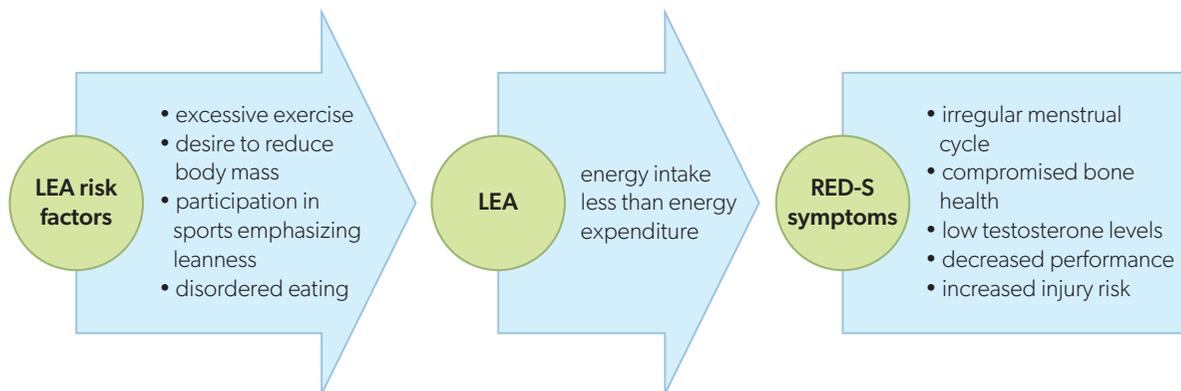
▲ **Figure 16** Energy availability scenarios with potential to lead to LEA

EA can be viewed conceptually as the energy remaining after exercise for normal physiological functioning (such as thermoregulation and cellular growth). The optimal EA for biologically female athletes to allow for healthy physiological functions is thought to be 45 kcal per kilogram of FFM per day. LEA for a biological female athlete has been defined as an EA level below 30 kcal kg⁻¹ of FFM per day. Optimal EA is less clear for biologically male athletes.

RED-S

Over time, LEA caused by a decrease in dietary energy intake and/or increase in exercise energy expenditure can lead to a condition called **relative energy deficiency in sport (RED-S)**. RED-S is a condition in which energy imbalance leads to impaired physiological function of multiple organ systems. Both health and performance consequences of RED-S can be severe.

Impaired physiological function caused by energy deficiency linked with RED-S includes, but is not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis and cardiovascular health. Figure 17 shows some of the risk factors associated with a decrease in dietary energy intake.



▲ **Figure 17** Risk factors for LEA leading to RED-S and consequences for athletes

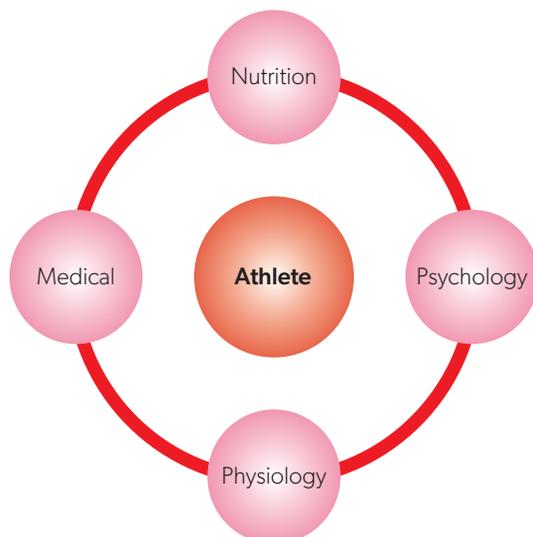
Risk of RED-S for sportspeople

Due to the substantial energy demands associated with sustained physical activity, athletes are more susceptible to experiencing LEA, and therefore RED-S, compared with less physically active individuals. RED-S can impact sportspeople regardless of sex differences, with both short- and long-term threats to athletes' health and performance.

Some researchers have reported that the risk of LEA ranges from 14% to 63% in the athletic community, with athletes participating in sports that are weight sensitive and with an emphasis on leanness at the highest risk of LEA, for example track and field, cross-country running, cycling, wrestling, gymnastics, rowing and synchronized swimming. In "lean" sports a higher power-to-body-mass ratio is thought to contribute to optimal performance. A 2021 study of elite and pre-elite biologically female Australian athletes (age range 15–32 years) from a variety of sports (athletics, rowing, boxing, weightlifting, basketball, triathlon, water polo and netball) found almost 80% of participants had at least 1 symptom of RED-S, while almost 40% had at least 2 symptoms. A 2022 study of United States university competitive cheerleaders (age range 19–21 years) showed that 100% of the cheerleaders had LEA (that is, below $30 \text{ kcal kg}^{-1} \text{ FFM day}^{-1}$), similar to another study involving synchronized swimmers. Another study in 2022 examined a research database of 150 Slovenian competitive athletes. Most (87%) of the athletes had at least 1 symptom of RED-S, and only 9% of biologically female athletes and 18% of biologically male athletes did not have any symptoms of RED-S. From a sport performance perspective 85% showed signs associated with a decrease in athletic performance. Some of the potential performance consequences of RED-S are shown in Figure 17.

Treatment of RED-S

Treatment of RED-S needs to take into account nutrition, psychology, physiology and medical factors with the goal of increasing EA by increasing energy intake or decreasing exercise energy expenditure, or both. From a wider health perspective, there needs to be an increase in awareness of, and education about, RED-S because the promotion of physical activity is a critical part of public health strategy.



▲ **Figure 18** Treatment of RED-S relies on a multidisciplinary approach to educate and support the athlete

Key points

- RED-S is the result of insufficient energy intake and/or excessive energy expenditure over time.
- RED-S leads to suboptimal performance and potentially serious health consequences.
- There is a need to identify athletes at risk for RED-S, irrespective of sex differences. There remains a gap in our understanding of RED-S in biologically male athletes.
- Improved awareness to prevent RED-S must be achieved through educational initiatives for athletes and coaches. There is still much to be learned about the psychological and physiological health risks and long-term performance effects of RED-S.
- Treatment relies on a multidisciplinary approach to educate and support the athlete. Practical guidelines for the treatment and safe return to play for athletes with RED-S need to be further developed to improve athletes' health and performance.



Models

The diagnosis of RED-S has replaced an earlier model known as the female athlete triad (FAT). The limitation of the FAT was that this model excluded anyone who is not female. The RED-S clinical model was first described by the International Olympic Committee (IOC) in 2014 and incorporates the FAT.



Activity 4

1. In which sports are the athletes more susceptible to the risk of developing LEA and the health/performance consequences of RED-S?
2. What might be the first sign of poor bone health due to LEA in cyclists and why?
3. Why might dancers be at higher risk of RED-S?
4. While having an eating disorder increases your risk of developing RED-S, an athlete with RED-S does not necessarily have an eating disorder. Why might this be?

The gut microbiome

The gut is home to trillions of microorganisms that have fundamental roles in many aspects of human biology, including metabolism, nervous and endocrine systems, and immune function.

The **microbiome** refers to the collection of genomes from all the microorganisms in the environment. The word microbiota is used to refer to the microorganisms, including bacteria, viruses, fungi and parasites, that are found within a specific environment, such as the gut, skin or mouth.

ATL Thinking skills

The most surprising revelation of the Human Genome Project has been the relatively small size of the human gene pool compared with the genomes of much simpler organisms. Some types of rice, for example, have about 20,000 more functioning genes than the human gene pool. This has led some to speculate that human physiological and behavioural complexity may depend on the large number of genes found in the human gut microbiome (the community of bacteria, viruses, fungi and other microorganisms that live in the digestive tract). You can find out more about the Human Genome Project on the internet.

Numerous factors such as age, genetics, stress, smoking and especially diet can affect the gut microbiome. Physical activity appears to promote a health-associated microbiota, a higher abundance of health-promoting bacteria and increased microbiome diversity.

The gut is at the core of well-being. This is where digestion and nutrition happen. The gut interacts with your immune functions, communicates with your brain, affects your mood and regulates your energy levels and appetite. The gut is inside you, acting as the primary gateway into your body, in essence “a bit of the outside that is inside you”. The gut microbes help protect you from undesirable visitors. Be aware that some things people ingest, such as alcohol, can damage the gut microbiota. What you eat matters because dietary fibre, polyphenols and fermented food will help take care of your gut microbiota.

- Dietary fibre is a food source for the “good” bacteria in the gut, helping them grow well.
- Polyphenols, found in plant-based foods, promote the growth of “good” gut bacteria and inhibit the growth of harmful bacteria, and they also help to reduce inflammation in the gut.
- Fermented foods help to introduce “good” bacteria to the gut microbiota. Consuming fermented foods is associated with improved digestion and a stronger immune system.

ATL Research skills

Factors such as diet, personal hygiene and medications, including the use of antibiotics, can produce a significant impact on the gut microbiota. The effect of these factors is more relevant early in life, when the gut microbiota has not yet become fully established (Lizumi et al., 2017). Antibiotics are one of the greatest discoveries in medicine and the benefits in the reduction of mortality from infectious diseases are unquestionable. However, alongside their many benefits, the use of antibiotics can also affect the “good bacteria” in the gut. Interestingly, a global rise in the incidence of autoimmune diseases has paralleled the widespread use of antibiotics (Vangoitsenhoven, 2020).

Research ways in which the gut microbiome is important in the development and maturation of the immune system.



▲ **Figure 19** The gut is home to trillions of microorganisms that have fundamental roles in many aspects of human biology

ATL Thinking skills

Alcohol and the gut microbiome

Alcohol is a psychoactive drug with dependence-producing qualities that has been widely used in diverse civilizations and populations for many years. It is a central nervous system (CNS) depressant. Alcohol is also a toxin that can damage the intestinal lining, which can lead to having more harmful bacteria and less beneficial bacteria.

When alcohol is consumed, it is absorbed into the bloodstream through the walls of the stomach and small intestine.

Alcohol is a diuretic, meaning that it increases urine production and can lead to dehydration.

Alcohol can impair muscle function and recovery, cognitive function and motor coordination, and can interfere with sleep quality and duration.

The best way to avoid the negative effects of alcohol on exercise performance is to avoid consuming alcohol before exercise altogether.

According to the WHO, approximately 13% of all deaths among individuals between the ages of 20 and 39 are due to excessive alcohol consumption.

Alcohol can interfere with the absorption of nutrients in the gut, and this will impair the ability of the gut microbiota to function effectively.

Alcohol can negatively affect the immune system (which helps regulate the gut microbiota), and impair the body's ability to control the growth of harmful bacteria in the gut.

Digestion extracts nutrients from the food we eat. Most of these nutrients are absorbed in the small intestine. After several hours, any unabsorbed nutrients and undigested food move into the large intestine. In the large intestine, microorganisms break down the undigested food and release small molecules called metabolites. These include B vitamins and vitamin K (that get absorbed), as well as molecules that act as strong signals to the brain via your:

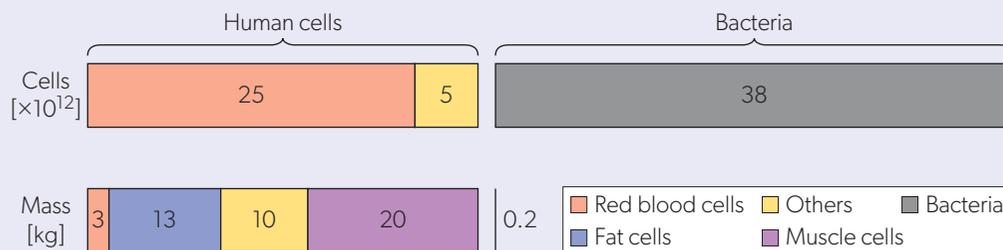
- nervous system
- immune system
- blood circulatory system.

When your gut is nearly empty, a hormonal signal is sent to the brain ("time to eat"). When food is ingested and detected in the stomach and nutrients start to reach the small intestine, satiety hormones are released, signalling to the brain (and liver) "we have enough energy: stop eating". Additionally, the gut sends other signals that impact your health, such as informing your immune system when harmful pathogens are present. It also influences your health in other ways, for example, the balance between cholesterol produced by the liver (transported to the gut via bile) and absorbed from the diet will determine cholesterol levels in the blood. It is your gut microbiota that is responsible for triggering and

modulating many of these signals by stimulating the release of hormones or neurotransmitters, or an immune response, or inflammation, or sending stress signals to the brain.

The human body contains as many microbes as human cells. Some of these bugs are on your skin, others in your lungs or in the urogenital system, but most are in your gut, mainly in the large intestine. The human gut microbiota is a complex system of microorganisms that live all through the gastrointestinal tract. The gut microbiota density varies along the gastrointestinal tract. It is fairly low in the stomach, duodenum and jejunum and increases in the ileum and colon.

ATL Thinking skills



▲ **Figure 20** Distribution of cell number and mass for different cell types in the human body (for a 70 kg adult)

Your microbiome is unique to you—in terms of size, diversity and balance of species—similar to a fingerprint. For example, it includes more than 1,000 unique bacterial species, with more than 95% of them located in the large intestine. Your microbiome carries an enormous amount of genetic material (more than 3 million genes) compared with the human genome (23,000 genes). The gut microbiota can reach up to 1.5 kg in a 70 kg individual.

The gut microbiota has many beneficial functions: microorganisms in the microbiota play a direct role in digestion, for instance, by ensuring the fermentation of substrates and non-digestible food residues, by facilitating nutrient assimilation thanks to a set of enzymes that are not present in human cells, and by participating in the synthesis of some vitamins. They also influence the overall functioning of the gastrointestinal tract and participate in the functioning of the intestinal immune system, which is essential for the intestinal wall barrier function.

Some important roles of the gut microbiome

The gut microbiome extracts and synthesizes nutrients from the food you eat. For example, breaking down dietary fibre to produce essential vitamins such as vitamin K. It also helps absorb minerals such as calcium. It produces (short-chain) fatty acids in the gut that strengthen the gut barrier/wall (possibly reducing the risk of colorectal cancer).

The gut microbiome provides defence. It prevents the overgrowth of pathogens, inhibits the growth of less desirable bacteria and interacts with your immune system to tell friends from foes.

TOK

Can butterflies in the stomach be explained physiologically? What is happening when butterflies in the stomach occur?

**Evidence**

Much of the reported research investigating the microbiome-gut-brain axis has been conducted using animal models, mostly in rodents. Why do we need more human studies on the role of diet in mental health?

Key point

The main function of the gut is to digest food and absorb nutrients. In athletic populations some probiotics can increase absorption of important nutrients.

Key terms

Probiotics Live microorganisms that are considered to be health promoting.

Microbiome The collection of genomes from all the microorganisms in an environment.

Neurotransmitters, such as dopamine and serotonin, are secreted in the gut. These hormones target the area in the brain involved in mood regulation (for example, happiness, feeling good) and cognition (such as memory and concentration). Serotonin also aids gut motility (the speed that foods travel through the gut).

Many factors influence your microbiome, including your genes, your age and previous infections. Some lifestyle factors are within your control, such as sleeping well, regular exercise and what you eat.

Gut-brain axis

The gut-brain axis is a two-way communication system between the gastrointestinal system and the CNS (the brain and spinal cord). This connection is not only anatomical, it extends to include endocrine, humoral, metabolic and immune routes of communication that allow information to be exchanged between the gut and the brain. This link between the gut and the brain allows the brain and the gut to influence mood, cognition and mental health. Therefore, the gut-brain axis, a two-way communication system, plays a key role in both your physical and mental well-being. For example, butterflies in the stomach just before competing (brain to gut), or having a “gut-feeling” that something is just not right (gut to brain).

**Thinking skills****The enteric nervous system**

The enteric nervous system exists in our gastrointestinal tract. It is responsible for controlling the digestive process and communicating with the CNS (the brain and spinal cord) to regulate the movement of food through our intestines and the release of digestive juices.

Gastrointestinal disease, such as irritable bowel syndrome, is associated with alteration of the gut microbiome. The gut microbiome can be affected by diet and stress. An imbalanced gut microbiome has been associated with a wide range of health problems, including digestive issues and mental health problems. The gut microbiome also helps to produce fatty acids and neurotransmitters that are important for brain function. A diet that is high in fibre, whole grains, fruits and vegetables can help promote a healthy gut microbiome. A diet that is high in sugar, processed foods and saturated fat can have a negative impact on cognitive function.

The term **probiotic** is derived from the Latin “pro” (which means “for”) and the Greek word “biotic” (which means “life”). Probiotics are live microorganisms that, when administered in adequate amounts, are considered to be health-promoting microorganisms. The IOC (2018) stated that:

Probiotics are live micro-organisms that when administered orally for several weeks can increase the numbers of beneficial bacteria in the gut. These have been associated with a range of potential benefits to gut health, as well as modulation of immune function.

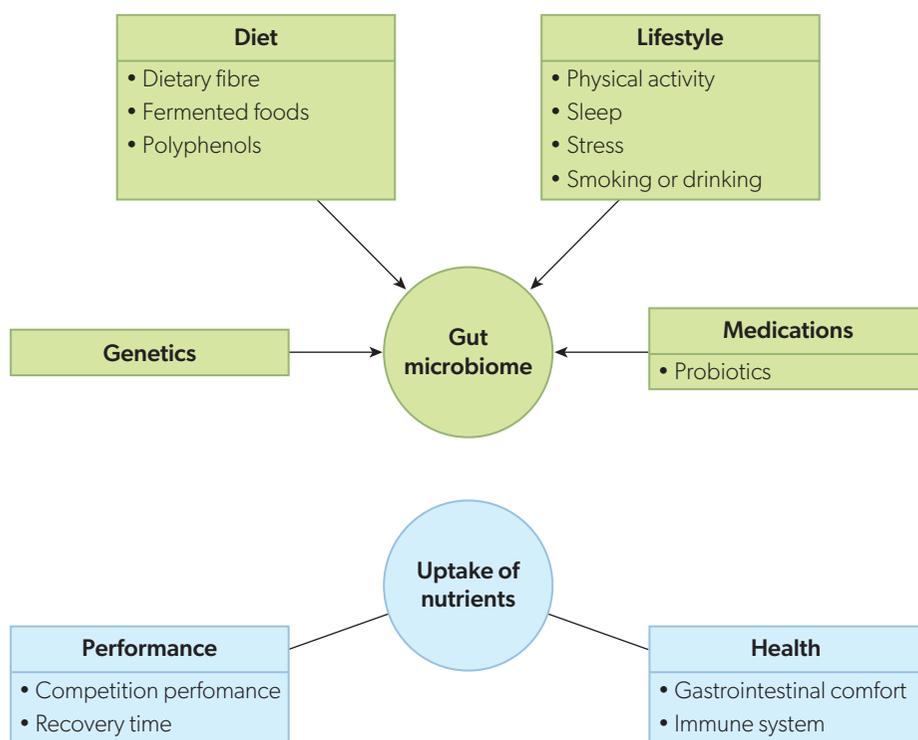
A growing number of dietary supplements containing probiotics are commercially available worldwide, in capsule, tablet, powder and liquid forms, and in specific foods such as yogurt. The amount of probiotic research studies in recreational and competitive athletes is increasing, including investigations

in gastrointestinal health, exercise performance, physical fatigue, recovery from exercise/fatigue, immunity and body composition.

Potential links between gut microbiome, athlete health and sports performance

An undesirable gut microbiota has been linked with changes in the gut wall permeability that allows bacteria to move from one location to another, such as from the gut to the bloodstream, to spread infection and attack the immune system of an athlete. When the immune system does not function properly there is increased risk of upper respiratory tract infections.

Gastrointestinal complaints are associated with RED-S. Studies have found that athletes with RED-S may have a reduced diversity of gut bacteria compared with healthy individuals, and this reduced diversity has been associated with, for example, decreased immune function and a reduced ability to absorb nutrients. One study compared professional rugby players demonstrating greater microbial diversity (a positive indicator of gut health) with control subjects. They found greater microbial diversity in the rugby players compared with the controls, and this positively correlated with higher protein intake (dietary factor) and higher creatine kinase levels (physical activity factor) in the athletes relative to controls. Therefore, maintaining a balanced energy intake and expenditure and a healthy gut microbiome is important for the health of an athlete and their athletic performance. Since then several studies (for example, Mancin et al., 2021, Figure 21) have suggested that gut microbiome modification (in other words, more health-promoting bacteria, increased microbial diversity) in response to exercise may provide insights for improving athletic performance and/or recovery time after training.



▲ **Figure 21** Factors affecting the gut microbiome and how the gut microbiome can influence the health and performance of an individual



Linking question

How does anxiety affect the gut microbiome? (C.4.2)

Consider:

- the body's stress response and changes in gut motility, secretion and permeability
- the immune system, and maintaining the balance of gut bacteria
- changes to diet and lifestyle that can impact the gut microbiome.



Experiments

Why do future studies on the interaction between diet, physical activity and gut microbiota need to take into account confounding variables? For example, by controlling caloric intake, as well as nutrient quality and composition; and by fixing exercise parameters (such as acute or chronic exercise, cardio and/or resistance training, duration and frequency)?

The majority of approaches to sports nutrition involve manipulating macronutrient intake (an external focus) based on type of training and performance goals. However, it may be that a shift to an internal focus, prioritizing the health of the gut microbiome, needs to be considered. We need more research on this topic if the athletic population is to gain a competitive edge and enhance its performance. Studies have shown that macro- and micronutrients influence gut microbiota composition. Poor dietary choices, self-medication and use of supplements may exert a harmful effect on the gut and microbiome. This contributes to a less-effective immune response and potentially disrupts recovery from injury and/or training. A healthy diet can help restore integrity of gut barrier defences and support the immune system. These factors help the athlete to recover from injury, continue training regimens and may even enhance performance in competition. Therefore, dietary strategies for the athletic population must support the athlete to fuel, protect and perform.

Overall, we do not fully understand the mechanisms by which being active promotes a healthy microbiome. But a combination of intrinsic and extrinsic factors is involved. For example, physically active individuals are more likely to be exposed to their environmental biosphere (they spend more time outdoors). They also follow an overall healthy lifestyle and, consequently, have "better" microbiota. Simultaneously, intrinsic adaptations to endurance training (such as decreased blood flow, tissue hypoxia, and increased transit and absorptive capacity) can lead to changes in the gastrointestinal tract.

The current body of literature, although limited, indicates that exercise, dietary factors and body composition promote a more "health-associated" gut microbiota. For example, more health-promoting bacteria, increased microbial diversity, enhanced immunity and improved gut barrier functions compared with sedentary controls. However, there is a need for longer-term studies in different athletic cohorts to examine more fully the impact of diet on the structure and function of the gut microbiota. There is a view that the gut microbiota could be considered a "pivotal" organ for health and sports performance, leading to a new concept: the nutrition-microbiota-physical activity triad.

More longitudinal (and well-designed) research studies are needed to investigate whether microbiome manipulation may be an effective tool for improving health and performance in athletic populations. The question remains: what is the best combination of the three elements to enhance sports performance for individual athletes?

Key points

- The gut is at the core of well-being.
- Physical activity and exercise appear to be able to enrich the gut microbiome.
- Although there has been continual research on probiotic supplementation in the application of sport and exercise, many questions remain concerning mechanisms of action and strain/dose specificity.
- Further probiotics studies on the potential ergogenic effects in the athletic population and elite performers are warranted.



▲ **Figure 22** The gut is at the core of our well-being



Linking question

How can variables be controlled effectively when designing experiments on nutrition for exercise and health? (Inquiry 1)

Consider:

- focusing on one variable at a time
- randomization (the bias issue)
- control group
- sample size and statistical power
- blinding
- standardizing conditions
- monitoring compliance
- controlling confounding factors
- appropriate data analysis.

Practice question

Discuss the recommended macronutrients required to provide sufficient energy for an endurance runner.

(4 marks)

Summary

- An optimal nutritional status is important for development, growth, performance and health.
- A balanced diet is essential to ensure an optimal nutritional status and is defined as a diet that provides the right amount of each of carbohydrate, lipids and proteins, and water (macronutrients).
- A balanced diet also requires vitamins, minerals and trace elements (micronutrients).
- Governments and international organizations provide dietary recommendations for an adequate intake for all nutrients that are essential for the promotion of health. Dietary guidelines help the population to put dietary recommendations and the concept of a “balanced diet” into practice.
- Nutritional requirements vary between population subgroups. For example, an athlete needs more fluids and energy from macronutrients than a non-athlete.
- Carbohydrates and fat are the dominant energy sources in food.
- Carbohydrate is used for energy across a wide range of exercise intensities.
- A limited amount of carbohydrate is stored as glycogen in the liver and muscle.
- Glycogen is used up during exercise; when it runs out exercise is limited or prevented—fatigue occurs.
- Athletes may consume carbohydrates before exercise to increase glycogen stores (carbo-loading), during exercise to provide additional carbohydrate, to spare their muscle glycogen, and after exercise to promote recovery of glycogen stores.
- Glycaemic index (GI) provides a measure of how accessible the carbohydrate content of different foods is; carbohydrate foods with a higher GI are better for rapid post-exercise recovery.
- Proteins in the body are only present with a specific biological function; there is no store of protein unlike fat and carbohydrate.
- Constant turnover of body protein means that humans have a daily requirement of around 0.8 g kg^{-1} body mass per day and this must include essential amino acids.
- The daily requirement for protein is increased in athletes because they oxidize amino acids for energy, muscle repair and hypertrophy.
- Athletes may supplement their diet with nutritional ergogenic aids to increase exercise performance and tolerance.
- Gastrointestinal problems are common in athletes.
- RED-S is a condition in which energy imbalance leads to impaired physiological function of multiple organ systems.
- The gut microbiome influences the health and performance of individuals.

AHL

AHL

Check your understanding

After reading this chapter, you should be able to:

- list the macronutrients and outline their roles
- list key micronutrients and outline their roles
- understand the concept of and current recommendations for a healthy balanced diet
- understand nutritional strategies including the importance of carbohydrates in sustaining energy levels during exercise
- understand gastrointestinal discomfort
- understand that low energy availability (LEA) can lead to the condition of relative energy deficiency in sport (RED-S)
- explain the role of the gut microbiome.

AHL

AHL

Self-study questions

- Outline how the availability of macronutrients can influence health and performance.
- State the functions of fat stored in adipose tissue.
- Discuss the ways in which poor nutrition might impair athletic performance.
- Outline what RED-S is.
- During exercise, explain why the mechanical causes of gastrointestinal problems are related to either impact or posture.
- Describe the role calcium plays in muscle contraction.
- Discuss how the gut microbiome affects the availability and uptake of nutrients.

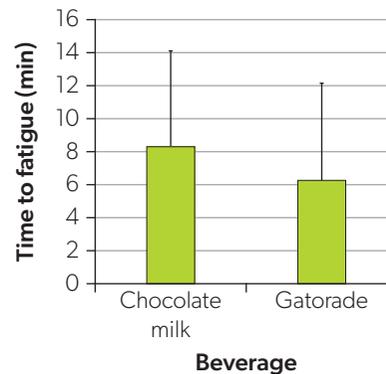
AHL

Data-based question

A study (randomized, cross-over design; two separate days) (Spaccarotella, Andzel, 2011) compared the effectiveness of either a low-fat chocolate milk or a carbohydrate-electrolyte beverage (Gatorade sports drink) on recovery between morning and afternoon training sessions. The beverage (240 ml) was consumed immediately after the morning training session. Table 10 shows the composition of the two beverages.

Nutrient	Low-fat chocolate milk	Gatorade
Energy (kJ)	669	299
Protein (g)	8	0
Fat (g)	3	0
Carbohydrate (g)	27	14
Calcium (mg)	200	0
Sodium (mg)	240	110

▲ Table 10



▲ Figure 23

Immediately following the afternoon training session, the subjects then completed a 20 m shuttle test to fatigue. The mean (\pm SD) time to fatigue for both trials is shown in Figure 23.

- State which beverage contained more protein. (1 mark)
- Identify from Figure 23 which beverage consumption resulted in better performance. (1 mark)
- Using the data in Table 10, give a nutritional explanation for the difference in performance shown in Figure 23. (1 mark)
- What might athletes and coaches learn from these results? (4 marks)

A.2.3

Energy systems

Syllabus understandings

A.2.3.1 The body relies on the phosphagen, glycolytic and oxidative systems for energy production to sustain life and physical activity.

A.2.3.2 Maximal oxygen consumption ($\dot{V}O_{2\max}$) is influenced by an individual's age, sex differences, body composition, lifestyle factors and level of fitness.

AHL

A.2.3.3 The lactate inflection point is the maximum intensity at which the body can metabolize lactate at the same rate as its production.

A.2.3.4 Excess post-exercise oxygen consumption (EPOC) is required for the body to return to homeostasis and is dependent on the oxygen deficit incurred during exercise. EPOC is typically divided into two subsections: fast and slow.

Introduction

The amount and composition of carbohydrates, fat and proteins in the diet determine the availability of energy. Macronutrients that can be stored easily in the body—such as fat in adipose tissue—are metabolized more slowly than proteins for which the body lacks any storage capacity. Therefore, after eating a meal containing all macronutrients, the body will metabolize proteins first, then carbohydrates and then fat.

Not all energy stored in food is available for metabolism in humans. Some components, such as fibre, cannot be digested and absorbed. This energy is lost in faeces. Even if nutrients are digestible there are metabolic pathways whose end products still contain energy. One example is the production of urea and ammonia in the metabolism of protein. These compounds still contain energy that is lost in the urine. Only the metabolizable energy of food is relevant for the energy metabolism of the human body.

Metabolism

Metabolism can be defined as all chemical processes in living organisms required for the maintenance of life. Metabolism consists of two phases: anabolism and catabolism. They are defined as follows.

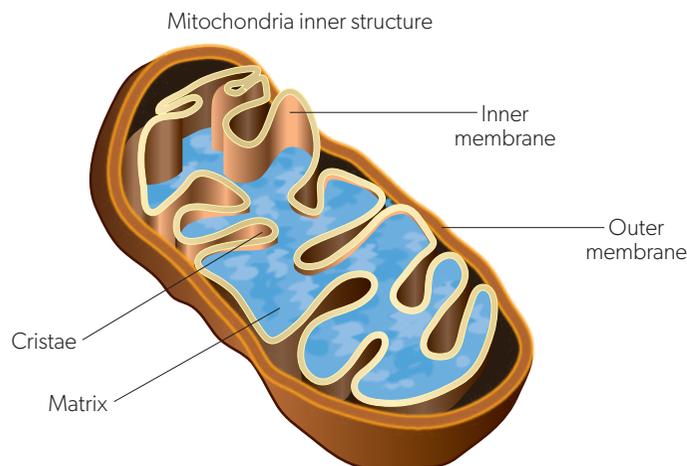
- **Anabolism** The constructive phase of metabolism where smaller molecules are converted to larger molecules. For example, glucose molecules convert to glycogen.
- **Catabolism** The destructive phase of metabolism where larger molecules are converted to smaller molecules. For example, triglycerides convert to glycerol and fatty acids.

The role of mitochondria

All cells in the human body require a source of energy to perform biological work. This includes all the processes involved in growth and maintenance of function. Muscle cells also require a source of energy to produce force during muscle contraction.

Mitochondria are cell components that have an important role in energy provision for cells, and they are the only site in which oxygen is used. With the exception of red blood cells, mitochondria are present in all human cells. The mitochondria of cells accommodate the biochemical processes of **aerobic metabolism** including the **Krebs cycle** and the **electron transport chain**. The Krebs cycle is a series of chemical reactions that produce a large quantity of adenosine triphosphate (ATP).

These processes can produce ATP from all the main food groups of our diet. Although carbohydrates and fats are the principal energy substrates, proteins are also used and contribute around 15% of resting energy metabolism. The structure of a mitochondrion is shown in Figure 1.

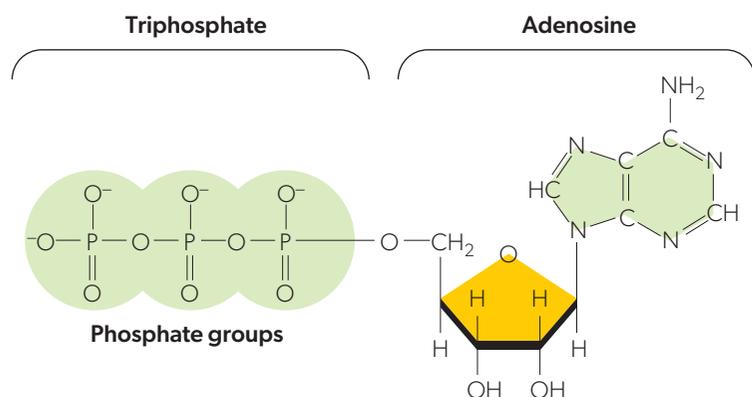


▲ **Figure 1** Ultrastructure of a mitochondrion

The energy currency of the cells—ATP

In cells, catabolic reactions take place that convert biochemical energy from organic molecules into a molecule called ATP. The controlled release of energy in the form of ATP is called **cell respiration**.

Figure 2 shows the structure of an ATP molecule. The bonds between the three inorganic phosphate groups are very energy rich. This energy is released when an ATP molecule is combined with water.

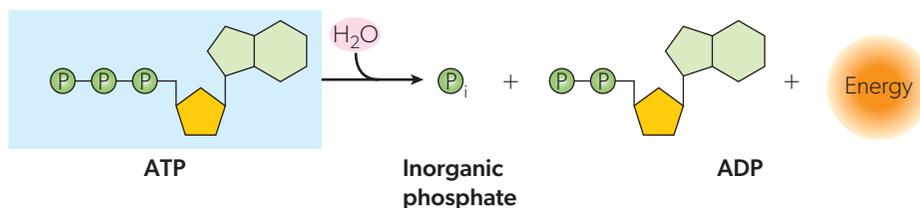


▲ **Figure 2** Chemical structure of ATP

As a result ATP loses the last phosphate group from the chain. This separation releases large amounts of energy (Figure 3). In the reverse process called phosphorylation, ATP can be synthesized by adding a phosphate group to the compound adenosine diphosphate (ADP).

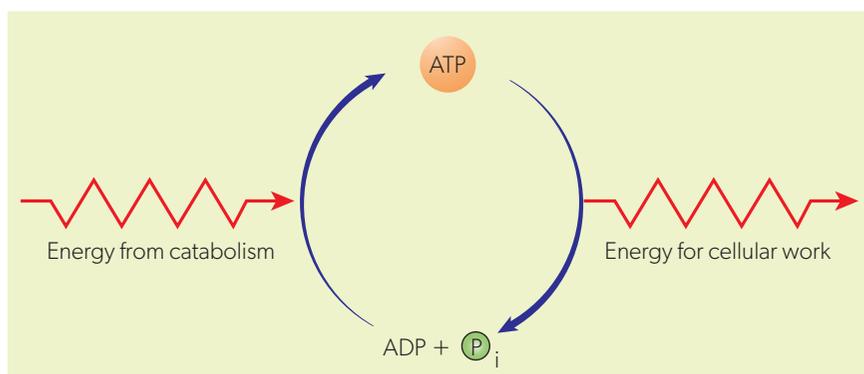
Key term

Cell respiration The controlled release of energy in the form of ATP.



▲ **Figure 3** Energy is released from ATP when a phosphate group splits away

The ATP molecule is at the centre of energy metabolism as it connects anabolic and catabolic reactions. For example, chemical energy ingested as food can be stored in the body as glycogen or fat. However, making use of this available energy means that the chemical energy must be transferred to ATP first. Chemical energy in this form can now be used to drive reactions and processes in the body that require energy (Figure 4). This universal process has meant that ATP is often referred to as the energy currency of the cell.



▲ **Figure 4** Involvement of ATP in energy provision for cells

TOK

The knowledge of energy metabolism and energy systems and how nutrition influences sport performance was primarily investigated in small animals, mainly mice, rats and hamsters.

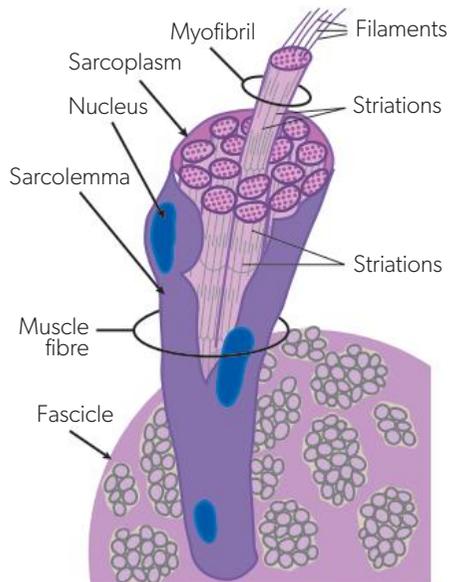
1. Discuss ethical concerns related to research in animals.
2. Justify the relevance of knowledge obtained from experiments with rodents to the human metabolism.

Energy for muscle contraction

One important process in the body that requires lots of energy is muscle contraction. Each muscle fibre making up a muscle is in itself a single elongated cell. All muscle fibres have the biochemical capacity to produce ATP using energy sources such as carbohydrates and fats. When a muscle fibre is stimulated to contract by the nervous system, the contractile protein molecules within it (such as actin and myosin) use ATP to provide the chemical energy to drive the contraction process. Since muscle-driven movement is central to sport and exercise, it is ATP within muscle fibres that provides all the energy to make this possible.

In muscle there is sufficient ATP present to allow just 2 seconds of muscular activity. This means any exercise lasting longer than about 2 seconds must be using ATP from another source. This source of ATP comes from a range of

biochemical pathways within the muscle cell itself called the **energy systems**. This refers to a set of catabolic reactions occurring within all cells whose principal function is generating ATP. In muscle fibres the performance of the energy systems influences the contraction of muscle; this in turn can influence our ability to perform different types of exercise.



▲ Figure 5 A muscle fibre

Carbohydrate metabolism

To release energy from the carbohydrates in our food, they are first digested down to the simple sugars (monosaccharides) glucose, fructose and galactose. These are absorbed into the bloodstream and transported to the liver. In the liver, fructose and galactose are converted to glucose. From there glucose is transported to the other organs.

Breakdown of glucose to pyruvate for energy

The breakdown of glucose takes place in all cells, in a part of the cell called the cytosol. The process is called **glycolysis** and involves many reactions.

Glycolysis leads to the metabolism of glucose to **pyruvate** and the production of energy in the form of ATP. When oxygen is available pyruvate enters the mitochondria where it is oxidized to carbon dioxide and water. Under anaerobic conditions (for example, in brief, high-intensity exercise) pyruvate is converted to lactate. Lactate is either transported back to the liver where glucose is re-formed in a process called **gluconeogenesis**, or oxidized to pyruvate in the muscles.

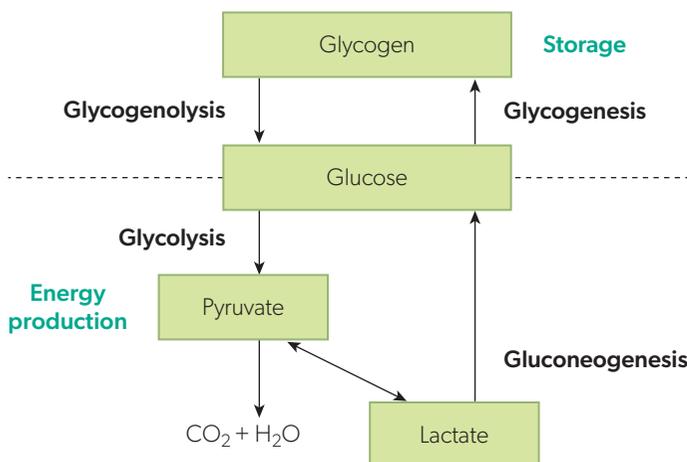
Conversion of glucose to glycogen for storage

In liver and muscle cells glucose is converted to glycogen when the diet provides more glucose than the tissue requires. Glycogen is the storage form of glucose. In a process called **glycogenesis** many glucose molecules are linked together to form glycogen.

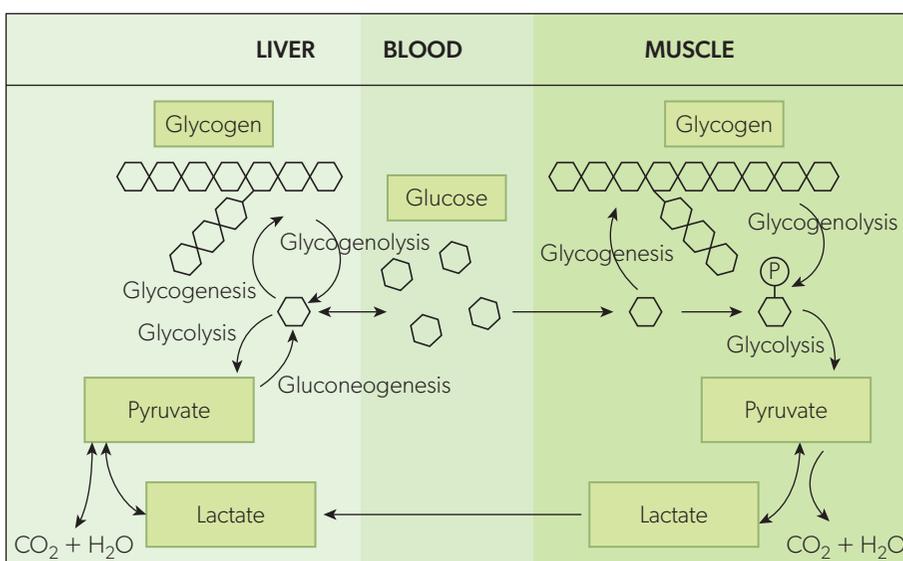
When the body needs more glucose than is ingested, glycogen is broken down into glucose in the liver and glucose-6-phosphate in the muscles. This process is called **glycogenolysis**. The muscle glycogen is only used to deliver an immediate energy source for the muscle, while the liver glycogen provides glucose for all the other organs.

Key point

Glucose is broken down to provide energy. This process is known as glycolysis (the breakdown of glucose to pyruvate). Glucose that is not used immediately is stored as glycogen. This conversion of glucose to glycogen is called glycogenesis. When the energy stored in the glycogen is needed it is turned back into glucose. This process is known as glycogenolysis (the conversion of glycogen to glucose).



▲ Figure 6 Pathways in carbohydrate metabolism



▲ Figure 7 Liver and muscle play an important role in carbohydrate metabolism

Activity 1

Draw your own diagram to show the relationship between:

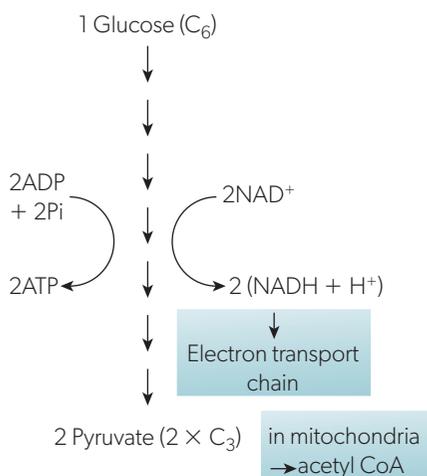
- liver
- muscle
- bloodstream
- food
- glucose
- glycogen
- lactate
- carbon dioxide
- water
- glycolysis (aerobic, anaerobic)
- glycogenolysis
- glycogenesis.

Aerobic (oxidative) energy system

Glucose oxidation

The final product of glycolysis, pyruvate, has a different fate depending upon the metabolic conditions in cells (Figure 8). During less demanding metabolic conditions pyruvate is converted to acetyl coenzyme A (CoA). This compound

enters the Krebs cycle in the mitochondria where chemical reactions that involve oxygen convert it to water and carbon dioxide. During glycolysis and the Krebs cycle hydrogen ions are released. Specific coenzymes bind the hydrogen ions and carry them to the electron transport chain where energy is produced. This energy is needed to form ATP as described in the section The energy currency of the cell—ATP.



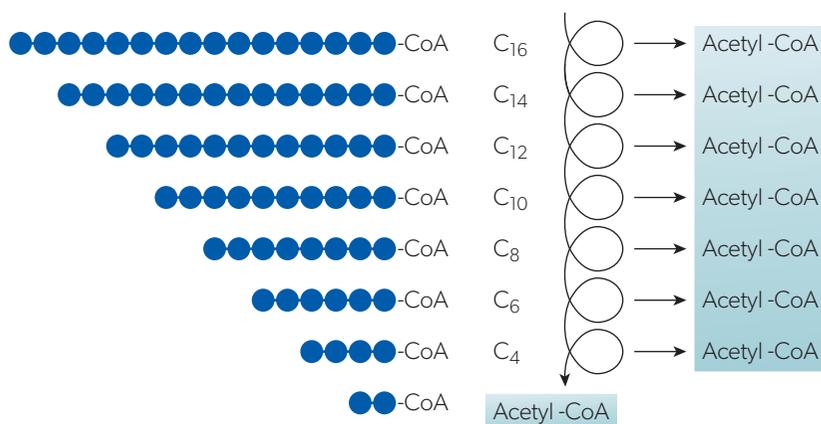
▲ **Figure 8** Aerobic glucose oxidation

Fat oxidation

The energy-yielding process in the metabolism of fat is the **β-oxidation** of fatty acids. β-oxidation occurs in the mitochondria, to which fatty acids are transported with the support of the shuttle enzyme carnitine. The enzymes of β-oxidation are in the matrix of the mitochondria. Fatty acids are gradually broken down to acetyl CoA molecules by shortening the fatty acid chain. This β-oxidation of fatty acids involves a repeat cycle of four reactions, reducing the fatty acid chain by two carbons on each cycle. This already generates energy but more energy is released when the acetyl CoA produced is further metabolized in the Krebs cycle.

Key term

β-oxidation The process of releasing energy from fatty acids.



▲ **Figure 9** β-oxidation of palmitic acid

The oxidation differs slightly depending on the chain length of fatty acids, whether they have double bonds and how many of them they have. Research in both animals and humans has shown that the body prefers to metabolize mono- and polyunsaturated fatty acids over the metabolism of saturated fatty acids. This means that choosing the correct type of fat in the diet can prevent chronic diseases, such as those affecting the arteries of the heart. The reason is that the slower the oxidation of fatty acids, the longer they remain in the bloodstream. Fatty acids contribute to reactions that form cholesterol, which subsequently can be placed in the vessel wall.

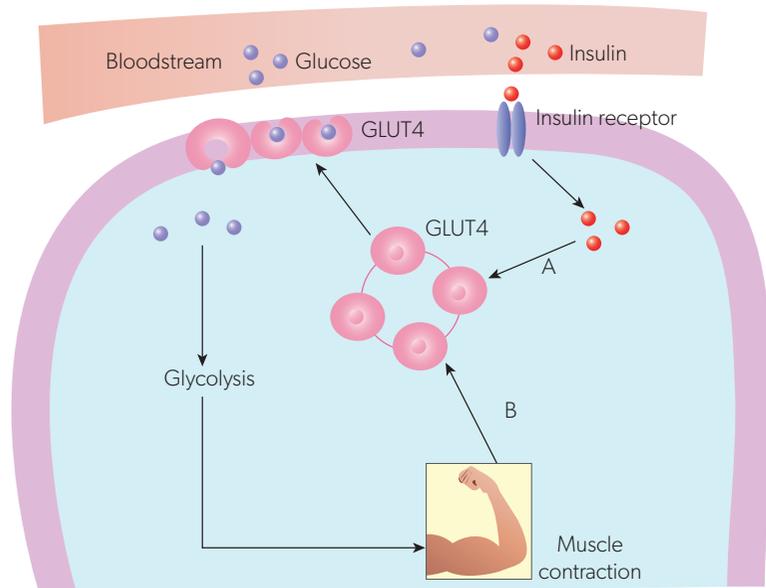
Hormonal regulation of energy metabolism

Energy metabolism is controlled by many hormones. These hormones include insulin, glucagon, epinephrine, cortisol and growth hormones.

After you have eaten a meal, the glucose concentration in the blood rises. This is a signal for the pancreas to secrete insulin. Insulin increases the transport of glucose into the cell, especially into skeletal muscle cells and liver cells (Figure 12). Skeletal muscles need glucose to work properly but glucose cannot just go into muscle cells on its own. The glucose transporter GLUT4 is key for skeletal muscle glucose uptake. That is, GLUT4 helps glucose get into the muscle cells so they can use it for energy. Think of GLUT4 as doors on the surface of your muscle cells. These doors are usually closed, preventing the glucose from entering the cells. To let the glucose inside the muscle cells, your body needs a “key”, which is the hormone insulin. When insulin stimulates the GLUT4 “doors”, the glucose can rush into the muscle cells. Once inside, the glucose can be used by cells to produce energy.

The fast uptake of glucose in the blood inhibits the release of glucose from the liver and muscle stores and promotes the synthesis of glycogen in the liver and muscle. Insulin stimulates glycolysis to lower blood glucose levels after a meal to signal energy availability to all organs. It inhibits gluconeogenesis (the conversion of protein or fat into glucose) and promotes glycogenesis (the conversion of glucose to glycogen). Insulin also inhibits lipolysis in fat stores and the breakdown of proteins (it also promotes the synthesis of proteins).

During a prolonged period with no food intake (fasting) or with exercise, the blood glucose concentration decreases, which causes the secretion of the hormone glucagon. Glucagon is secreted by the pancreas and acts in the opposite way to insulin. It stimulates glycogenolysis and synthesis of glucose, which increases the glucose level in the blood—a sign that glucose is being transported to the organs for the utilization of energy. Glucagon also activates the lipolysis of triglycerides in fat stores that subsequently contributes to the energy supply. A low blood glucose concentration also stimulates epinephrine, which acts like glucagon in the processes of glycogen breakdown and lipolysis.



▲ **Figure 12** Mechanisms of glucose uptake into skeletal muscle. (A) insulin-stimulated glucose uptake, (B) muscle contraction-stimulated glucose uptake. GLUT4: glucose transporter 4



Linking question

How does a lack of ATP affect muscular contraction? (B1.3)

Consider:

- ATP is the primary energy source used by muscle cells during muscular contraction
- muscle cells have a limited amount of stored ATP
- what will happen if ATP synthesis is unable to keep up with the demand for ATP.

ATL Thinking skills

Blood sugar testing using a blood glucose monitor provides an easy, accurate and self-administered method to assess the concentration of glucose in the blood. This is important for people with diabetes where the blood glucose regulation by insulin is impaired. Both a high and a low blood sugar concentration can be harmful.



▲ Figure 13 Using a blood glucose monitor

ATL Research skills

Research on the role of carbohydrates for exercise and particularly endurance performance became the foundation for the dietary practice for many athletes. A high-carbohydrate diet improves endurance performance, and carbohydrate intake during exercise delays fatigue.

1. Investigate the use of sport drinks and energy bars as means for carbohydrate intake during endurance performance.
2. Discuss the development of a multimillion-dollar industry of sports nutrition products that evolved from the knowledge of the effect of carbohydrate on performance and how this industry can influence future research.

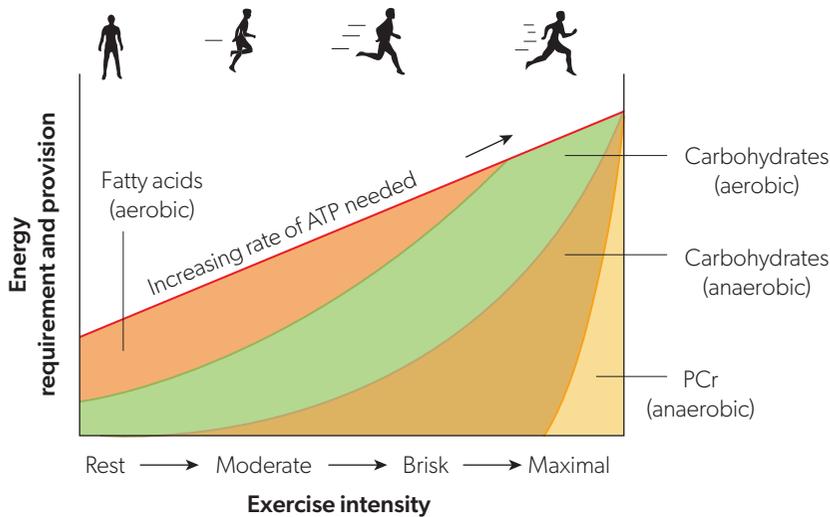
Key points

- When we begin exercise it is the anaerobic systems that dominate energy provision. The pre-existing ATP within the muscle provides energy during the first 2 seconds, then PCr's contribution (via the phosphagen system) fades after the first 20 seconds, after which increasing activation of the glycolytic system dominates energy provision. This too is short-lived and as exercise continues, an increasing activation of the aerobic energy system, known as the **oxidative system**, means that it quickly dominates energy provision.
- Fats can only be used during aerobic activities, not high-intensity, anaerobic activities.

Characteristics of the energy systems and their contributions during exercise

During exercise all fuel sources and the energy systems that use them come into play to meet the demand for ATP. The rate at which the energy systems can synthesize ATP varies, with fat oxidation being the slowest and the phosphagen system being the fastest. Therefore, it makes sense that the faster energy systems dominate when ATP is required at high rates such as those needed to support high-intensity exercise (Figure 14).

In the first moment of muscle contractions, PCr stores will be used to provide energy. During exercise of light to moderate intensity, energy is derived from glucose, initially from anaerobic glycolysis until the aerobic system can convert stored glucose into energy. To maintain the energy supply by glucose, the muscle increases the uptake of glucose from the blood. Muscle contraction stimulates glucose transport from the inner cell storage pool to the cell membrane but in a



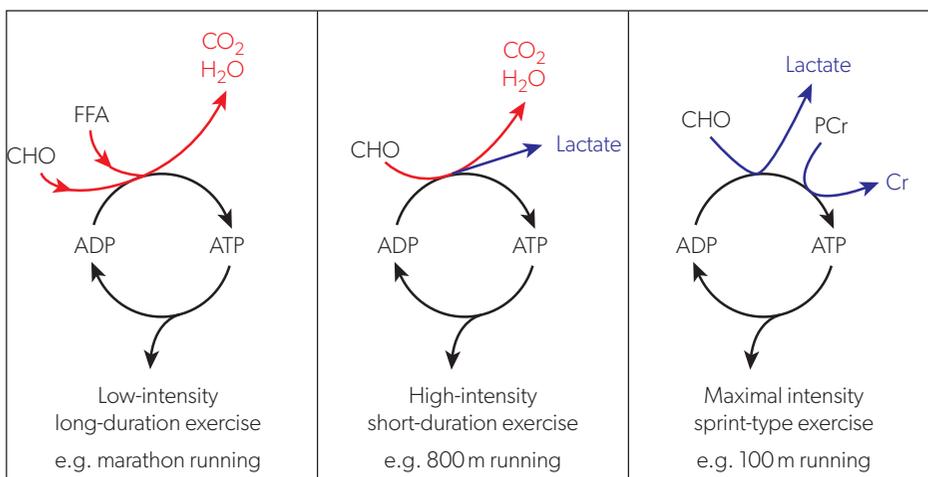
◀ **Figure 14** The relationship between exercise intensity and rate of energy (ATP) demand. Both the overall rate of ATP production and the mechanism of its synthesis change with intensity.

different way to insulin (Figure 12). The insulin-induced glucose transport takes place during phases of no exercise (rest). Exercise lowers the concentration of insulin in the blood and therefore reduces its function in glucose transport.

Glucose (anaerobic and/or aerobic) is important across the full range of exercise intensities. However, fatty acids are only used during lower-intensity exercise. Above about 90% of maximal exercise no free fatty acids are used at all. Conversely, PCr only contributes during brief, high-intensity exercise; it no longer contributes after 20 seconds of all-out exercise.

Of course exercise is never that simple: we rarely maintain a constant pace or rate of work. There may be repeated bursts of high-intensity activity, for example, during team games, in which anaerobic metabolism (glycolytic system and phosphagen system) is used, broken up by periods of lower effort in which recovery can occur. Similarly, during longer, seemingly constant-pace running, speed may change, with bursts of faster running at the start and a sprint for the finish line.

In summary, the contraction of muscle during exercise of any type and level of intensity requires ATP. The high rate of mechanical work required during intense exercise requires a high rate of ATP provision. This can only be achieved by the fast metabolic processes of the glycolytic system and PCr. The slower processes associated with aerobic metabolism are active during longer, slower exercise efforts. Figure 15 illustrates the relative contribution of the energy systems during different types of exercise.



◀ **Figure 15** Relative contributions to ATP synthesis during three different types of exercise effort. The red content represents aerobic metabolism and the blue anaerobic metabolism. CHO: carbohydrates (glucose); FFA: free fatty acids; PCr: creatine phosphate; Cr: creatine.

Activity 2

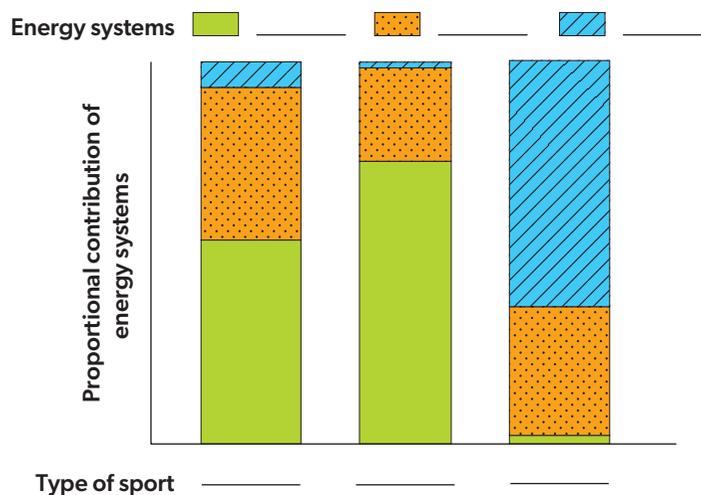
Contribution of the different energy systems during different types of sport

1. Evaluate the dominating energy systems during the sports shown in Figure 16:
 - a. rugby
 - b. Tour de France cycling
 - c. high jump.



▲ Figure 16

2. Label the diagram in Figure 17 according to the type of sport on the x-axis and energy systems (different colour boxes). Choose between the phosphagen, glycolytic and oxidative systems.



▲ Figure 17

Maximal oxygen consumption ($\dot{V}O_2\text{max}$) and endurance

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) is the maximum rate at which an individual can take in and use oxygen. It is a key factor in endurance. $\dot{V}O_2\text{max}$ is the gold standard used to evaluate an individual's cardiovascular-respiratory function. Factors affecting $\dot{V}O_2\text{max}$ can be divided into two categories: central circulatory factors (such as maximal cardiac output) and peripheral factors (such as skeletal muscles). In the majority of healthy individuals, the primary determining factor for $\dot{V}O_2\text{max}$ is the capacity of the cardiovascular system to deliver oxygen. However, there are exceptions to this rule, including for individuals affected by illness.

Absolute and relative $\dot{V}O_2\text{max}$

When comparing $\dot{V}O_2\text{max}$ values between different populations it is crucial to recognize that the values can be expressed in two formats.

- **Absolute** $\dot{V}O_2\text{max}$ is reported in litres per minute (l min^{-1}).
- **Relative** $\dot{V}O_2\text{max}$ is normalized according to body mass in millilitres per minute per kilogram ($\text{ml min}^{-1} \text{kg}^{-1}$), which is rewritten as millilitres per kilogram per minute ($\text{ml kg}^{-1} \text{min}^{-1}$).

For activities that are considered weight bearing it is more appropriate to use the relative $\dot{V}O_2\text{max}$ value as this makes an attempt to account for individual differences in size and mass. This is important as differences in size and mass explain the majority of the variability in absolute $\dot{V}O_2\text{max}$ values between individuals, due to factors such as active muscle mass, heart size and blood volume.

For example, an untrained healthy adult with a body mass of 70 kg may have an absolute $\dot{V}O_2\text{max}$ of 3.0 l min^{-1} , which means a relative $\dot{V}O_2\text{max}$ of $42.9 \text{ ml kg}^{-1} \text{min}^{-1}$ ($3.0 \times 1,000$ to convert litres to ml, then divide by 70 kg). In contrast, a 58 kg hockey player may also have an absolute $\dot{V}O_2\text{max}$ of 3.0 l min^{-1} , yet a relative $\dot{V}O_2\text{max}$ of $51.7 \text{ ml kg}^{-1} \text{min}^{-1}$ reflects their training adaptations that mean they will be able to run at faster speeds and for longer than the untrained adult.

The highest values of $\dot{V}O_2\text{max}$ have been recorded in cross-country skiers (over $90 \text{ ml kg}^{-1} \text{min}^{-1}$). In contrast, for those who are seriously ill the values can be considerably lower, even below $20 \text{ ml kg}^{-1} \text{min}^{-1}$. The general pattern is for relative $\dot{V}O_2\text{max}$ to reflect cardiorespiratory fitness, although it must be recognized that there is still a lot of individual variation and these are population averages (Table 1).

▼ **Table 1** Typical relative $\dot{V}O_2\text{max}$ ranges for 20-year-old adults

Training status	Typical relative $\dot{V}O_2\text{max}$ ($\text{ml kg}^{-1} \text{min}^{-1}$)	
	Biological male	Biological female
untrained but healthy	40–45	35–40
moderately trained	45–55	40–50
professional team sport athletes	50–60	45–55
top endurance athletes	>65	55–60

$\dot{V}O_2\text{max}$ and sex differences

Absolute $\dot{V}O_2\text{max}$ values are typically considerably lower in biological females than males, primarily due to smaller body size. However, even when expressed in relative terms, females typically have lower $\dot{V}O_2\text{max}$ values than males, as shown

Key points

- $\dot{V}O_2\text{max}$ can be improved by training.
- Individual differences and genetic factors have an influence on $\dot{V}O_2\text{max}$.
- One of the key factors determining endurance performance is $\dot{V}O_2\text{max}$.



Patterns and trends

There are many people with a low body mass and a high body fat, and there are many athletes with a high body mass and a low body fat. When considering absolute (l min^{-1}) compared with weight-relative ($\text{ml kg}^{-1} \text{min}^{-1}$) values of $\dot{V}O_2\text{max}$, what conclusions might you draw about how $\dot{V}O_2\text{max}$ is influenced by body composition, and how lifestyle factors can influence $\dot{V}O_2\text{max}$?

in Table 1. Biological females present on average a 15%–25% lower $\dot{V}O_2\text{max}$ than biological males for a given age and fitness status, although among athletes the difference is smaller.

The primary factors that contribute to these typical differences in $\dot{V}O_2\text{max}$ are as follows.

- Cardiac output: biological females typically have a smaller heart compared with biological males (even when normalized by body size), as well as a reduced cardiac filling and lower capacity to pump blood.
- Blood volume: blood oxygen-carrying capacity is typically also lower in absolute and relative units in biological females.
- Haemoglobin concentration: biological males typically have a slightly higher concentration of haemoglobin in the blood.
- Lung capacity: biological females typically have lower lung volume and capacities compared with biological males.
- Body composition: dividing by body mass does not account for the naturally higher percentage of non-oxygen-using body fat in biological females. Differences may reduce when $\dot{V}O_2\text{max}$ is expressed relative to fat-free mass (or active muscle mass).

Sex differences in body size and muscle mass also contribute to typically lower strength, power and anaerobic performance in biological females. Similarly, structural elements of the aerobic energy system are sex specific.

An additional factor affecting endurance is differences in running biomechanics. When the human body stands in a neutral position, the hip joint performs flexion/extension in the sagittal plane (chapter B.1.1). During endurance running, biological females tend to have greater non-sagittal hip (and knee) joint motion. This can be partly explained by anatomical differences, such as a wider pelvis and shorter lower limb length relative to total height.

Interestingly, some studies have also shown that biologically female athletes have a greater proportional area of slow twitch muscle fibres and are more able to use fatty acids (and preserve carbohydrates) during prolonged running. However, other factors (for example, lower blood oxygen-carrying capacity) appear to counterbalance these potential advantages.

$\dot{V}O_2\text{max}$ and age

A further important factor that influences $\dot{V}O_2\text{max}$ is age. Children typically have much lower absolute $\dot{V}O_2\text{max}$ values than adults due to their size. During childhood and adolescence, absolute $\dot{V}O_2\text{max}$ increases according to patterns of growth and maturation, peaking in the early and mid-teens for biological females and early 20s for biological males.

When you consider $\dot{V}O_2\text{max}$ changes with age then how to express the $\dot{V}O_2\text{max}$ values becomes important. Expressing it relative to body weight reveals the effects of weight gain on $\dot{V}O_2\text{max}$ as children become adolescents and mature to adulthood. For weight-bearing activities (for example, activities that involve running) it is more appropriate to use $\text{ml kg}^{-1} \text{min}^{-1}$, whereas for non-weight-bearing exercise, such as cycling, it is acceptable to use either. In sedentary adults, $\dot{V}O_2\text{max}$ generally decreases by about 10% per decade. Trained endurance athletes will begin with a higher $\dot{V}O_2\text{max}$, and if their $\dot{V}O_2\text{max}$

declined at the same rate it would still be higher than that of sedentary individuals of the same chronological age.

In biological females, absolute $\dot{V}O_2$ max peaks in the mid-teens. However, relative $\dot{V}O_2$ max actually tends to decrease from the early teens, partly due to the changes in body composition (more accumulation of body fat and less muscle mass during puberty), potentially in addition to changes in physical activity patterns.

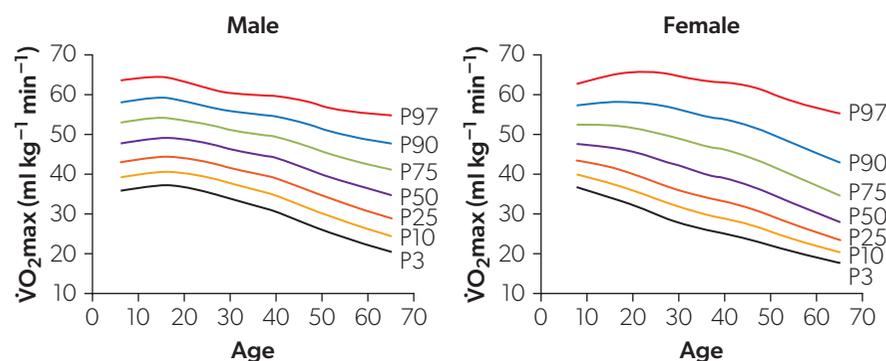
In biological males, however, when the values are normalized to body mass, children and adolescents have very similar values to healthy adults. In other words, relative $\dot{V}O_2$ max is very similar in adults and children. Does this mean that a trained child should be able to run a marathon in the same time as a trained adult? Children, of course, could not achieve such fast times. This illustrates that normalizing $\dot{V}O_2$ max to body mass cannot fully explain differences in actual endurance performance, for a variety of reasons.

From adulthood, regardless of sex differences, the relative $\dot{V}O_2$ max typically declines by approximately 1% each year on average. This reflects a gradual decline in the maximum heart rate that can be achieved, although again changes in physical activity patterns may contribute. So, for a healthy untrained 20-year-old with a $\dot{V}O_2$ max of $45 \text{ ml kg}^{-1} \text{ min}^{-1}$ natural ageing would mean that at 45 and 70 years old the $\dot{V}O_2$ max would be expected to have declined to $35.0 \text{ ml kg}^{-1} \text{ min}^{-1}$ and $27.2 \text{ ml kg}^{-1} \text{ min}^{-1}$, respectively. This implies a steady decline in endurance capacity as we get older, and any illness or injury will speed up this decline. However, very importantly this does not mean that all elderly people have very low $\dot{V}O_2$ max values and limited endurance capacity. Although the size of training response gets lower as we get older, physical exercise can still induce significant improvements in $\dot{V}O_2$ max in the elderly such that a trained 65-year-old may well have a higher $\dot{V}O_2$ max than an untrained and overweight 30-year-old.

Indeed, Masters athletes compete all over the world until the end of their lives. A remarkable example is that of Fauja Singh (Figure 18). Singh completed the Toronto Waterfront marathon in 2011 when he was 100 years old!



▲ Figure 18 Fauja Singh



▲ Figure 19 $\dot{V}O_2$ max according to age and sex. Adapted from van der Steeg, Takken (2021)

How does training increase $\dot{V}O_2$ max?

The training responses following a period of aerobic training support the idea that training can increase $\dot{V}O_2$ max. The increases in $\dot{V}O_2$ max are underpinned, at least in part, by training-induced changes in the heart and cardiovascular system (central adaptations). The increases are helped by some changes within the muscle (peripheral adaptations).



Linking question

How does a person's level of aerobic fitness affect their mental toughness? (C.1.2)

Consider:

- aerobic exercise, improved cognitive function, reduced stress and anxiety, and increased resilience
- aerobic exercise can help individuals develop mental toughness by improving their ability to push through physical discomfort and challenges
- physical challenge, confidence and motivation
- aerobic exercise and a sense of accomplishment and self-efficacy.

Key point

Aerobic training can increase $\dot{V}O_2\text{max}$. The main mechanism is an increased stroke volume, although other adaptations in the cardiovascular and muscular systems also contribute.

The main training response is an increase in stroke volume at submaximal and maximal values. In contrast, the heart rate response becomes lower at submaximal intensities. The maximum heart rate is actually unchanged with training, but reaching it requires the person to work harder compared with before training (their capacity has improved).

The mechanism responsible for the increased stroke volume is mainly an increase in the volume of the left ventricle, meaning that more blood can fill the ventricle ahead of each contraction. As well as some changes in the blood, the muscles also develop more capillaries so that more blood can supply oxygen to the exercising muscles. In terms of oxygen use, there are also some adaptations that occur within the muscle itself to increase the amount of oxygen being extracted from the blood as it passes. Collectively, these central and peripheral adaptations permit an individual to exercise harder as their $\dot{V}O_2\text{max}$ has increased.



Activity 3

Evidence from training studies suggests that at least some of the variation in $\dot{V}O_2\text{max}$ between individuals can be explained by genetic variation. However, there is little doubt that training can have a positive impact on $\dot{V}O_2\text{max}$. This raises a classic question of fitness—is it due to nature (genetics) or nurture (training)? Some very insightful research has compared the training adaptations of identical twins with those of non-identical twins. Interestingly, both sets of twins improved but the responses were more similar in the identical than the non-identical twins, despite identical training programmes and similar initial fitness levels.

- Why does such research imply that genetics must at least play some part?
- Why did using twins in both groups help to answer the nature versus nurture question?

A good way to think of this is that each person may have a “ceiling” $\dot{V}O_2\text{max}$ that is determined by their genes, but this will only become limiting once that person has trained and increased their $\dot{V}O_2\text{max}$ as much as possible. Therefore, people with a low untrained $\dot{V}O_2\text{max}$ cannot blame their genes as they have not reached their genetic ceiling.

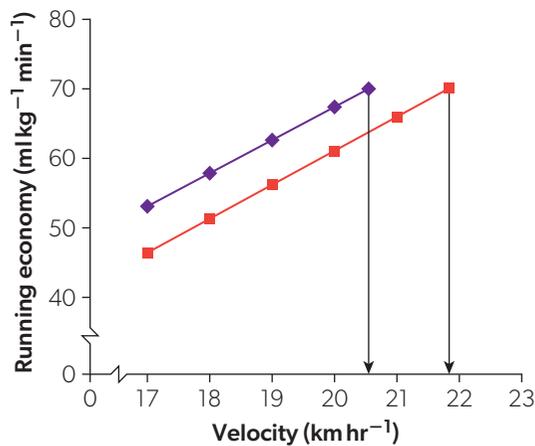
$\dot{V}O_2\text{max}$ and type of exercise

A final factor that can further influence recorded values for $\dot{V}O_2\text{max}$ is the type of exercise that is being performed. Within the same individual the highest rate of oxygen uptake that is recorded will be different dependent on whether the person is running or cycling, for example. As more muscle mass is being used during running (compared with cycling, the upper-body and postural muscles are being used more as this is a weight-bearing activity), it would be expected that a higher $\dot{V}O_2\text{max}$ would be recorded compared with cycling. This is the main reason underpinning why the highest observed values are in cross-country skiers and not runners. Cross-country skiing places even more oxygen demand on the upper-body muscles, in addition to the lower-body and postural muscles that are working hard in both types of exercise.

Running economy

The steady-state oxygen consumption ($\dot{V}O_2$) at a given running velocity is known as **running economy (RE)**. RE reflects the energy demand of running

at a constant submaximal speed. Runners with good RE use less oxygen than runners with poor RE at the same steady-state speed. RE is thought to be a useful predictor of endurance running performance. The RE profiles of two adult runners of equal $\dot{V}O_{2\max}$ are shown in Figure 20.



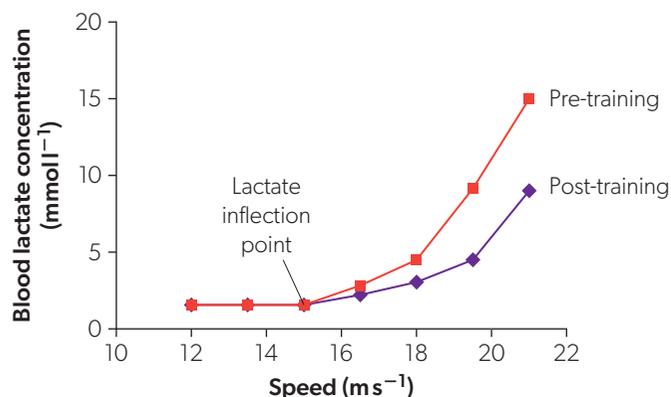
▲ **Figure 20** The running economy profiles of two athletes who have the same $\dot{V}O_{2\max}$

An athlete's RE represents the combined functioning of the metabolic, cardiorespiratory, biomechanical and neuromuscular systems during running. RE can be improved; therefore, it has importance for coaches and athletes.

Lactate inflection point

A threshold, or inflection point, is a level or point at which something begins to change or happen. For example, the pain threshold is the point at which an individual begins to experience pain. There is a historical importance of thresholds to humankind. For example, many historians consider the emergence of agriculture to be a key threshold in shaping the human species and our world.

Lactic acid has played an important role in the traditional theory of muscle fatigue and limitation of endurance exercise performance. It was thought that once exercise intensity exceeds the rate of maximal oxygen consumption ($\dot{V}O_{2\max}$), then an "oxygen debt" occurs and metabolism switches from aerobic to anaerobic, leading to an abrupt increase in blood lactate levels. The **lactate inflection point** (also known as the anaerobic threshold or lactate threshold) is defined as the point at which blood lactate begins to substantially accumulate above resting concentrations during exercise of increasing intensity. For example, Figure 21 shows the relationship between blood lactate and running speed.



▲ **Figure 21** The relationship between running speed and blood lactate concentration

The increase in blood lactate concentration was believed to impair muscle contractility and lead to fatigue and exhaustion. The uncomfortable feelings within muscles working at these near-maximal efforts were believed to be directly associated with this increase in lactic acid production (exceeding lactic acid clearance), as was the delayed-onset muscle soreness that developed during subsequent days. Thus, lactic acid was believed to be little more than a metabolic waste product. However, scientific thought has evolved towards new understandings of the role of lactate in energy metabolism.

Ideas supported by more recent research, such as the critical power (CP) threshold, might predict more closely the tolerable duration of high-intensity exercise that precedes fatigue/exhaustion/cessation of exercise. **Critical power** is a measure of the maximum power output that a person can sustain for a prolonged period of time without becoming fatigued/exhausted. This has led some to suggest:

At present, when it is possible for an individual to undertake high-intensity exhausting exercise, critical power/speed offers, perhaps, the greatest potential to predict athletic performance, clinically assess healthy/patient physiological function and monitor training efficacy.

Poole et al. (2021)

ATL Thinking skills

There is a negative relationship between power output and the time for which it can be sustained. This is a fundamental feature of high-intensity exercise performance.

Your CP is the power that you can maintain for a certain duration. This could be the power that you can sustain for 20 minutes (CP_{20}), 45 minutes (CP_{45}) or 60 minutes (CP_{60}).

CP_{60} is lower in power than CP_{45} , and CP_{45} is lower than CP_{20} . In other words, you can last for a shorter time with a higher power.

In general, exercise such as running, cycling or swimming above your critical power threshold results in a very small endurance. Exercise below your critical power threshold, on the other hand, enables much more endurance.

Traditionally, the CP model has been used to provide insights into physiological responses, fatigue mechanisms and performance during continuous constant power output exercise. However, in recent years, the CP concept has been broadened through its application to intermittent high-intensity exercise. For example, popular team sports (such as football, hockey or basketball) are characterized by frequent bursts of severe-intensity exercise interspersed by lower-intensity recovery periods. The CP model is now used by applied sports scientists to better understand the limitations to performance in such sports, and inform competition tactics and training practices.

Key point

The lactate inflection point is usually expressed as the percentage of maximal oxygen uptake ($\% \dot{V}O_{2\max}$) at which it occurs. In untrained individuals this will occur at a lower percentage of their $\dot{V}O_{2\max}$ (approximately 50%–60% of $\dot{V}O_{2\max}$) compared with elite endurance athletes (around 70%–80% of their $\dot{V}O_{2\max}$); it may be even higher in some elite athletes. Generally, in two athletes with the same $\dot{V}O_{2\max}$, the athlete with the higher lactate inflection point usually has the better endurance performance—but do not forget that other factors can contribute as well, such as running economy.



▲ **Figure 22** Road cycling is an endurance event requiring high power over a sustained period of time



▲ **Figure 23** Basketball is characterized by frequent bursts of severe-intensity exercise interspersed by lower-intensity recovery periods



Linking question

How might exercising in hot, humid conditions for extended periods of time influence the predominant energy system used and the lactate inflection point? (A.1.2)

Consider:

- the three main energy systems used during exercise
- maintaining a safe core temperature
- demand for energy and the depletion of glycogen stores
- oxidative phosphorylation and glycolysis
- exercise intensity and the lactate inflection point
- hydration, nutrition and pacing strategy.



▲ **Figure 24** Taking part in a marathon in hot, humid conditions



Linking question

Is there a relationship between mental toughness and the lactate inflection point? (C.1.2)

Consider:

- ability to tolerate high-intensity exercise
- ability to tolerate discomfort
- ability to regulate emotions
- how genetics, training status and nutrition can influence the lactate inflection point.



▲ Figure 25 Exhausted athlete

Oxygen deficit and excess post-exercise oxygen consumption

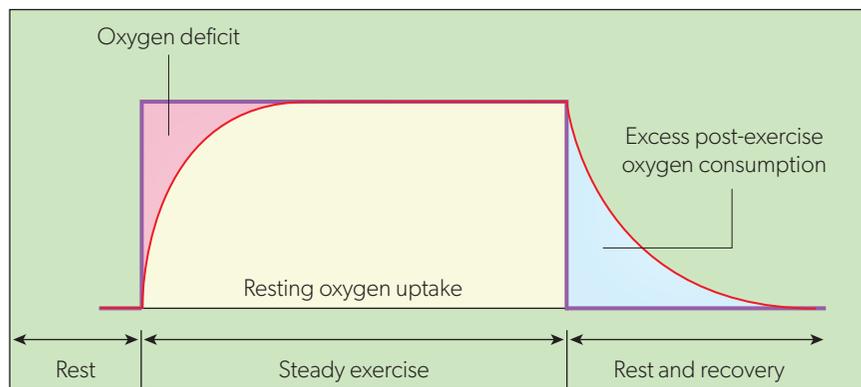
Struggling to complete hard exercise leaves us feeling fatigued afterwards. Even at rest we continue to breathe hard for some time. When exercise begins abruptly, the demand for ATP is immediate. It is initially met with ATP stores, quickly followed by PCr and the glycolytic system. These energy systems are activated more quickly than the aerobic energy system, which takes longer to react.

The body needs oxygen from the moment we begin to exercise. The body gets into an oxygen deficit because oxygen need and oxygen supply do not match in the first moment of exercise. During recovery from exercise, oxygen utilization continues at a rate greater than that needed at rest. This is referred to as **excess post-exercise oxygen consumption (EPOC)**. Part of this is to offset the consequences of anaerobic metabolism during the early phase of exercise. However, additional oxygen demands persist during recovery, for processes such as the restoration of tissue and myoglobin oxygenation, the cost of respiration that remains elevated, and a whole range of other physiological factors that keep metabolism elevated even when exercise has ceased. Post-exercise tissue repair, which is one of the foundations of the training response, has an energy cost too. Figure 26 shows how ATP cost and oxygen use result in an oxygen deficit at the beginning of exercise and EPOC at recovery after exercise.

Traditionally, EPOC has been described as having two components: an initial fast component and a secondary slow component.

The **fast component** of the curve represented oxygen required to rebuild the ATP and PCr used during the initial stages of exercise. As there was insufficient oxygen available, the high energy phosphate bonds were broken to supply the energy needed. During recovery, these bonds would need to be re-formed, via oxidative processes, to replenish the energy stores or repay the oxygen debt. The **slow component** of the curve was thought to result from removal of accumulated lactate from the muscle tissue(s), either from conversion to glycogen or oxidation to CO₂ and H₂O, to provide the energy required to restore glycogen stores.

More recently, researchers have questioned this two-component explanation. EPOC depends on more factors than the replenishing of ATP and PCr, and the clearing of lactate produced by anaerobic metabolism. For example, *during the initial phase of exercise* some oxygen is used from haemoglobin and myoglobin—and that must be replaced during early recovery as well. Additionally, *following exercise*, breathing remains temporarily elevated to help clear the carbon dioxide, and body temperature is elevated, which keeps the metabolic and respiratory rates high and this requires more oxygen.



— ATP cost
— Oxygen use

▲ **Figure 26** Oxygen deficit and EPOC

Key point

Because oxygen needs and oxygen supply differ during the transition from rest to exercise, your body experiences oxygen deficit. During the initial minutes of recovery at the end of exercise, oxygen consumption remains elevated temporarily. There are several reasons for this, including:

- oxygen is required to rebuild the ATP and PCr stores
- during the initial phase of exercise some oxygen is borrowed from haemoglobin and myoglobin, and that oxygen must be replenished
- respiration remains elevated to help “clear out” any excess carbon dioxide that has accumulated in the tissues during exercise
- participation in exercise elevates body temperature and there is an oxygen cost to help cool the body (through increased breathing rate, for example).

Practice questions

1. In basketball, teams have to shoot within 24 seconds of gaining possession of the ball. Outline the two systems used to produce ATP during a short, intense period of possession. (4 marks)
2. On completion of the 200 m individual medley race, a swimmer breathes heavily during their recovery period. Explain the factors that influence the swimmer’s elevated breathing after the race. (5 marks)

Summary

- Our body depends on the supply of energy from food that is converted into ATP in biochemical pathways.
- The metabolism either breaks large molecules down (catabolism) to release energy, or synthesizes larger molecules from smaller ones (anabolism) to store energy.
- Energy from carbohydrates can be stored in the form of glycogen in the liver and skeletal muscles. Energy from fat can be stored in the form of triglycerides in adipose tissue and skeletal muscle.
- Muscle contraction is an important energy-requiring process. Different energy systems are accessed to provide energy in the form of ATP.
- The anaerobic energy systems are the phosphagen system and the glycolytic system. These provide energy quickly for a short time. The aerobic systems are the glucose and fat oxidative systems, which make energy available for a long period after a delayed onset.
- In muscle fibres the performance of the energy systems influences the contraction of muscle; this in turn can influence our ability to perform different types of exercise.
- $\dot{V}O_2$ max has been an international “gold standard” to evaluate cardiovascular-respiratory function.
- $\dot{V}O_2$ max can be improved by training.
- Steady-state oxygen consumption at a given running velocity is known as running economy.
- The lactate inflection point (anaerobic threshold/lactate threshold) is defined as the point at which blood lactate begins to substantially accumulate above resting concentrations during exercise of increasing intensity.
- Critical power is a measure of the maximum power output that a person can sustain for a prolonged period of time without becoming fatigued/exhausted.
- EPOC is the period of recovery from exercise during which oxygen utilization continues at a rate greater than that needed at rest.

AHL

Check your understanding

After reading this chapter, you should be able to:

- understand the metabolism of carbohydrate and fat
- outline the metabolic pathways of carbohydrate and fat metabolism
- explain the role of insulin, glucagon and epinephrine in carbohydrate and fat metabolism
- explain the role of insulin and muscle contraction in glucose uptake during exercise
- reproduce the ultrastructure of a mitochondrion
- define the term cell respiration
- describe metabolic pathways that supply energy
- explain the role of ATP in muscle contraction
- discuss the characteristics of the energy systems and their contribution during exercise
- evaluate the contributions of the energy systems during different types of exercise
- explain running economy
- outline how $\dot{V}O_2$ max can be influenced by age, sex and training status
- discuss the lactate inflection point
- explain the phenomena of oxygen deficit and excess post-exercise oxygen consumption (EPOC).

AHL

Self-study questions

1. State the main energy system used to provide energy at rest.
2. Compare the relative contributions of the pathways for ATP production:
 - a. in short-duration, intense exercise (e.g. 100 m sprint)
 - b. during a 30-minute steady-state, low-intensity jog.
3. Outline what running economy is and its relationship to sport performance.
4. Discuss how an understanding of the lactate inflection point can help a coach plan a training session.
5. Explain the concept of EPOC.

AHL

Data-based question

Using a cross-over randomized design, a study (Schaun et al., 2018) compared the energy expenditure in 11 healthy and physically active females (age range 18–35 years), during and after two water aerobics protocols: high-intensity interval training (HIIT) and moderate continuous training (CONT).

The HIIT consisted of eight 20-second bouts at 130% of the cadence associated with $\dot{V}O_{2\max}$, with 10-second passive rests between bouts, and the CONT was 30 minutes at 70% maximum heart rate. The mean (\pm SD) $\dot{V}O_2$, energy expenditure (EE) during exercise, and EPOC for 30 minutes post-exercise are shown in Table 2.

▼ Table 2

	CONT	HIIT
Mean $\dot{V}O_2$ during exercise ($l\ min^{-1}$)	1.56 (\pm 0.2)	1.98 (\pm 0.2)
Mean EE during exercise ($kcal\ min^{-1}$)	7.6 (\pm 1.1)	10.0 (\pm 1.1)
EPOC during 30-minute rest post-exercise (l)	4.6 (\pm 1.7)	4.2 (\pm 1.0)

1. Identify which protocol had the higher energy expenditure per minute during exercise. (1 mark)
2. Calculate the difference in $\dot{V}O_2$ ($l\ min^{-1}$) during exercise between the two protocols. (1 mark)
3. Explain the difference in the mean and SD values found for EPOC. (3 marks)

A.3

Response

How does our body respond to exercise or training?

This topic examines key factors that can affect the response to a given training programme to achieve optimal performance, including the principle of periodization and other training programme considerations for individual athletes, such as the menstrual cycle. The health benefits of an active lifestyle, the risks of an inactive lifestyle, exercise and the immune system, the relationship between exercise and mental health, and physical activity recommendations for specific populations are all discussed. Finally, the topic considers two important concerns for all athletes: exercise-induced fatigue and recovery. We will see how fatigue is likely to be an integrated, complex and multifaceted occurrence, and consider the key role of recovery in improving performance in both training and competition.

A.3.1 Qualities of training

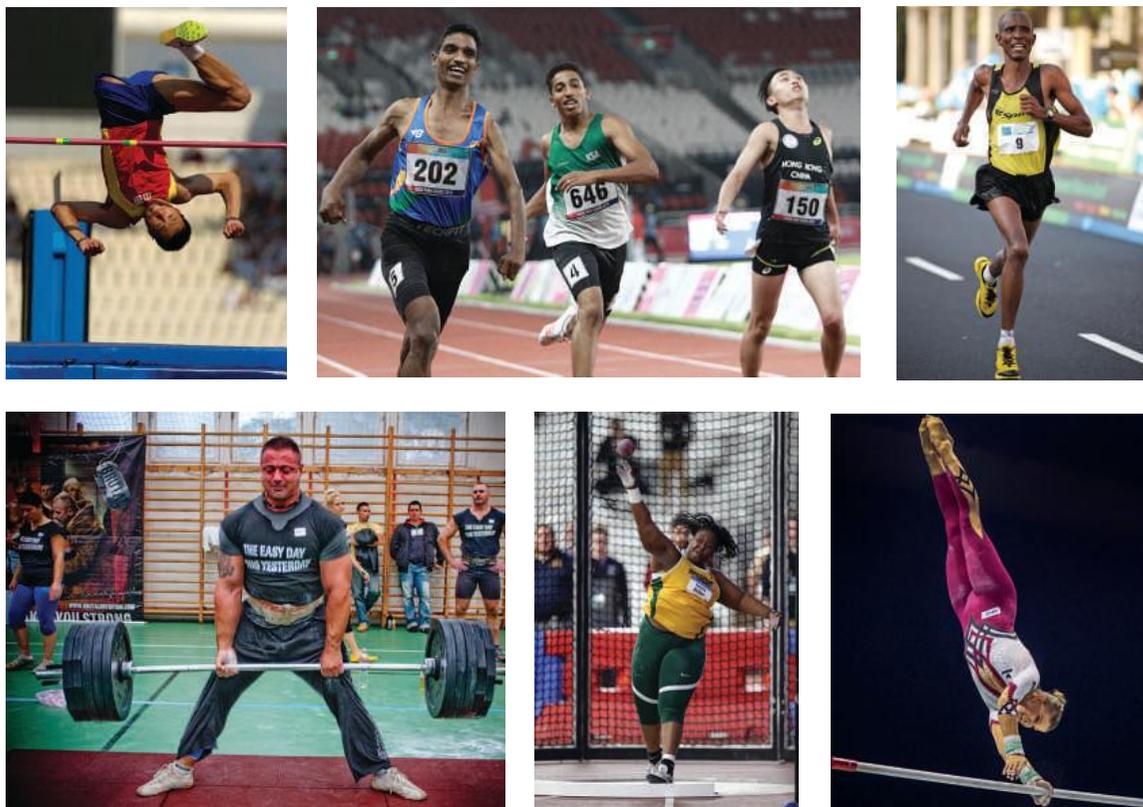
Syllabus understandings

A.3.1.1 The quality of training design and programme design are essential elements in developing a safe and effective programme for improving health or performance.

Introduction

Sport is played by athletes of different shapes, sizes, ages and biological sex (Figure 1). These athletes all have different physical requirements based on the nature and demands of their chosen sport. For example, a javelin thrower requires a large amount of explosive muscle power, but does not need the aerobic endurance that is important to a 5,000 m runner. It may appear, therefore, that across different sports, athletes do not have much in common with one another. However, there is one thing that unites all athletes, regardless of their chosen sport: the need to improve and maximize their physical performance.

Maximizing physical performance is achieved in many ways. For example, appropriate diet, adequate sleep and rest, and reduced stress levels will all help the athlete to improve performance. However, appropriate training is, undoubtedly, one of the most important methods that an athlete can use to maximize physical performance.



▲ Figure 1 Athletes come in all shapes and sizes

Key terms

Training The systematic, repeated performance of structured exercise sessions over a period of time, with the achievement of a specific goal in mind.

Undertraining Not providing the body with enough stimulation for performance to improve, by training too infrequently or at too low an intensity.

Overtraining Training too often or at too high an intensity over a prolonged period of time.

Overreaching Pushing the body beyond its limits for a short period of time to stimulate a training response.

Training

Training is the systematic, repeated performance of structured exercise sessions over a period of time, with the achievement of a specific goal in mind. The type, duration, intensity and frequency of training will vary depending on what this goal is. While training is crucial for improving and maximizing sports performance, unsuitable training prescriptions can actually be detrimental to performance.

Undertraining is a failure to provide adequate stimulation to the body by training too infrequently, for too short a period of time, or at an insufficient intensity that will not generate the physical adaptations that are required for enhanced performance.

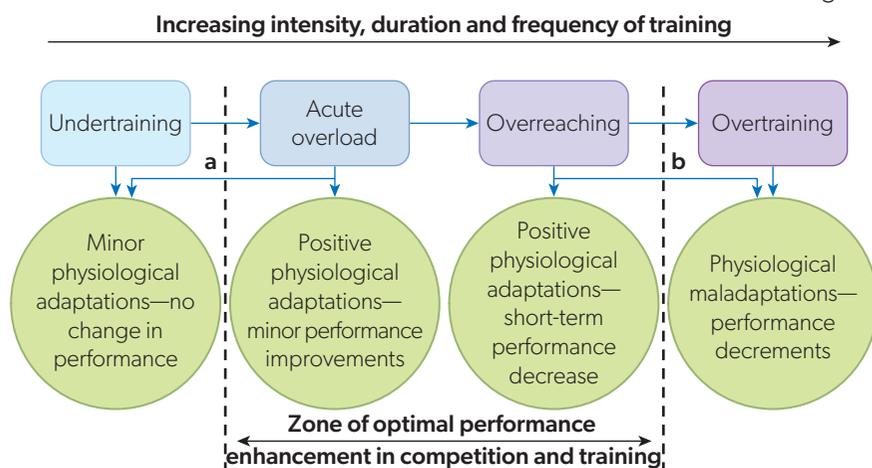
Overtraining occurs if an athlete attempts to do more training than they are able to physically and/or mentally tolerate over a prolonged period. The performance and even the health of the athlete can deteriorate significantly. If this is allowed to continue, it can become a career-threatening problem (further discussed later in this chapter). However, athletes do need to stress their bodies sufficiently for a training response to be generated.

Overreaching is when an athlete places stress on their body that is beyond their current limit of tolerance, but only for a short period of time. A short-term decrease in performance may be observed as a result of overreaching, with full recovery taking from several days to several weeks. Therefore, overreaching can be thought of as transient overtraining.

Coupled with appropriate recovery, overreaching can be a useful tool in maximizing the training response, although the consensus on its efficacy is inconsistent (Brittenham et al., 1998). The distinction between functional- and non-functional overreaching is based on the duration of the symptoms until performance returns to normal levels. Recovery to normal performances should occur within days to weeks in functional overreaching, whereas in non-functional overreaching it may take several weeks to months. Non-functional overreaching and overtraining syndrome (a general breakdown in physiological function) are both characterized by performance decline, high levels of fatigue, and psychological and hormonal disturbances. It is believed that the symptoms of overtraining are more severe than those of non-functional overreaching. The time needed to recover is the most discriminating factor between non-functional overreaching and overtraining syndrome. Fully recovering from non-functional overreaching needs weeks to months, whereas recovering from

overtraining syndrome takes months to years, and the athlete may never reach their best level again. When using the method of overreaching, if appropriate recovery is not provided, overtraining can develop.

The interaction of the different concepts of training discussed above can be viewed as a training continuum. Figure 2 shows the progression of training states from undertraining through to overtraining (boxes), with the associated outcomes for each training state (circles). It also demonstrates the fine degree of difference between developing



▲ Figure 2 A schematic of the training continuum

minor performance enhancements or no enhancements at all (a), and between optimizing physiological adaptations and performance enhancement or reaching a state of overtraining (b).

Training principles

Several training principles apply to all forms of exercise training.

Principle of specificity

Training adaptations are specific to the type of activity being performed and to the volume and intensity of the exercise. For example, to improve swimming endurance, an open-water long-distance (10 km) Olympic swimmer would not focus on fast, high-intensity intermittent sprint running training. To enhance performance for their chosen sport, athletes and coaches need to understand that exercise adaptations are specific to the mode, intensity and duration of training. Therefore, the training programme planned for an athlete must stress the physiological systems that are critical for optimal performance in their sport/ event in order to achieve specific training adaptations and goals.



▲ Figure 3

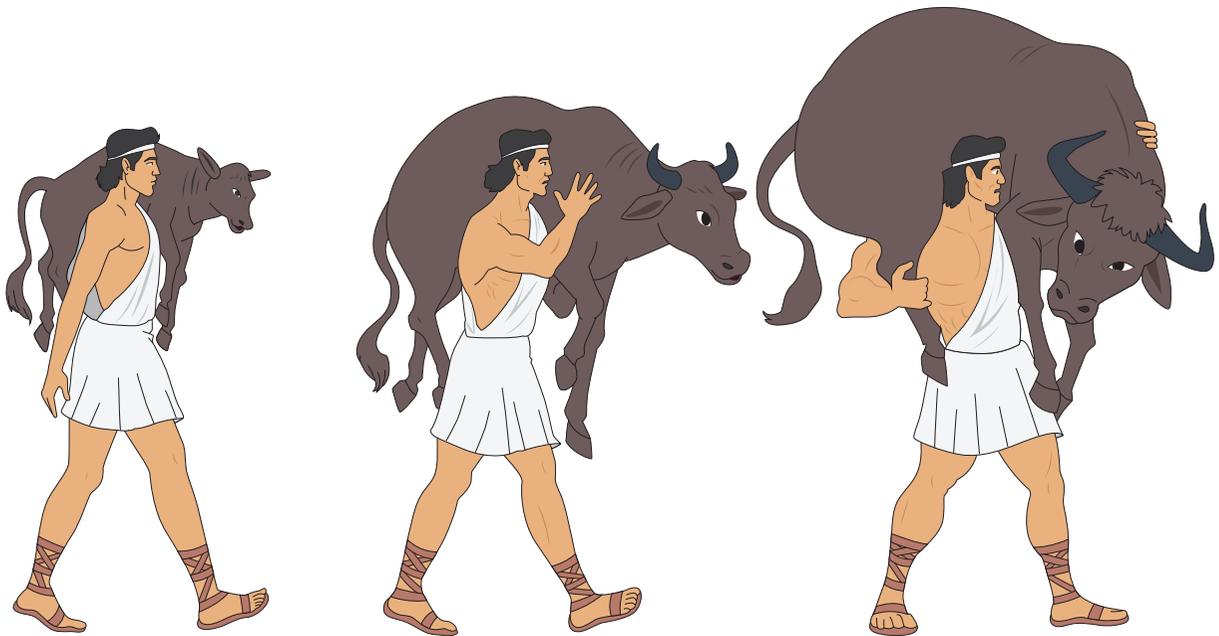
Principle of reversibility (“use it or lose it”)

Any adaptation that takes place as a result of training will be lost if you stop training. When a training stimulus is removed, fitness levels will eventually return towards baseline. Hence, coaches and athletes need to understand that effective training programmes must include a maintenance plan to sustain the physiological adaptations gained from training.

Principle of progressive overload

Systematically increasing the demands on the body is necessary for continued improvement. Here are some examples when undergoing a resistance training programme.

- Rooted in the mythology of Greek wrestler Milo of Croton who hoisted a calf overhead and proceeded to carry it each day as it grew into a full-sized bull, the slow yet steady increase in load is synonymous with increasing the weight or resistance used on a specific exercise.



▲ Figure 4 Progressive overload

- Increase the number of repetitions performed when holding the load constant.
- Increase the number of sets performed for a given exercise.
- Increase the frequency of how many times a week a muscle group is trained.
- Increase training density (the amount of work performed per unit of time). For example, if an individual was previously using 120s rest between all sets, if all variables were held constant, but the rest periods were reduced to 100s, the training density would have increased, as more work was performed per unit of time.

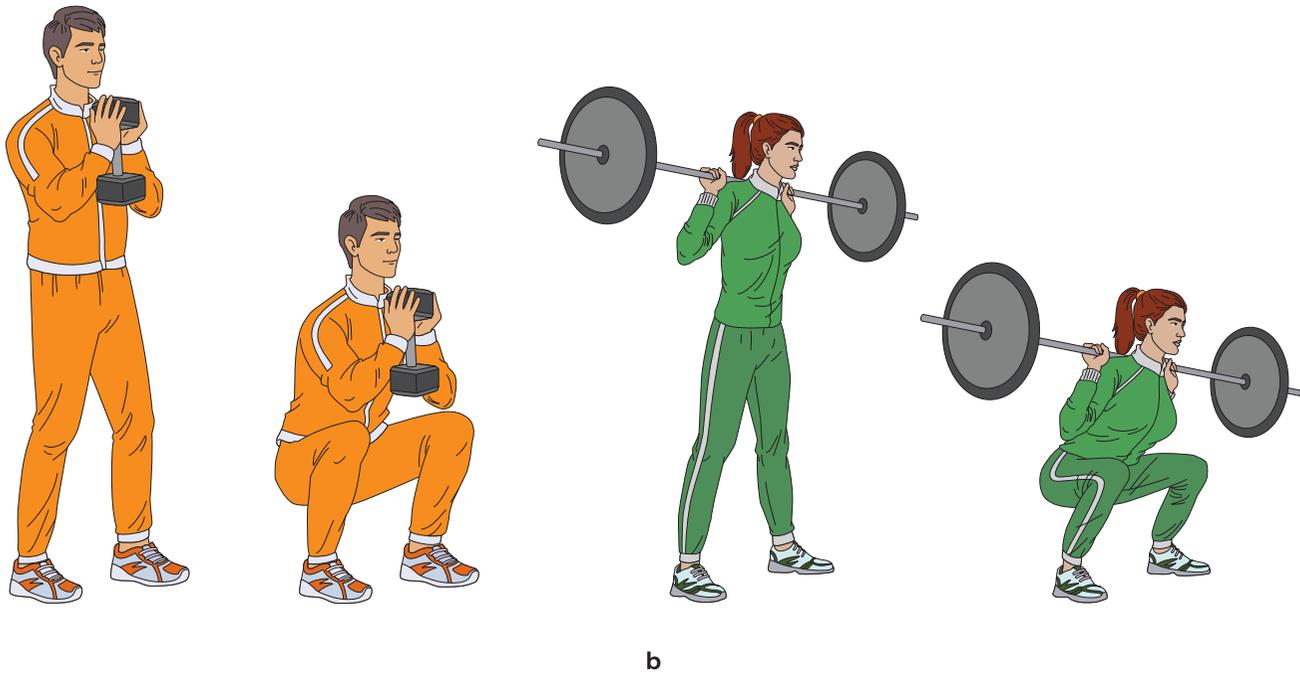
Principle of recovery (rest)

Athletes need adequate time to recover from training (and competition). There are several key aspects of the recovery (rest principle), including: rest between training sessions; getting an adequate amount of sleep; consuming a well-balanced diet (such as nutrition and hydration); engaging in effective recovery strategies (such as ice baths); and periodization (such as planned periods of reduced training intensity/volume). Refer to chapter A.3.3 for more on recovery.

Principle of variety

The principle of variety is the systematic process of changing one or more variables (mode, volume and/or intensity) in the training programme over time to ensure the training stimulus remains challenging and effective.

Additionally, a variety of exercise choices for a given muscle group or movement pattern not only provides options to keep a workout from getting monotonous but also can be a means of progression. For example, the dumbbell goblet squat and barbell back squat are similar lower-body exercises that use the squat movement pattern but lend themselves to markedly different loading strategies and progressions.



▲ **Figure 5** a Dumbbell goblet squat, b barbell back squat

Principle of periodization

Periodization is a structured, organized approach to training revolving around the completion of certain “phases” of training within a given time frame, with the aim of ensuring the athlete is in peak physical condition for the most important events of their sport. In the case of a track athlete, this may involve peaking for several competitions within a single year or season. For a soccer player, it may mean ensuring a high level of performance for the beginning of the season, and attempting to maintain that performance level for the duration of the season.

Structure of a periodized training programme

The exact structure of periodization will depend largely on the specific sport the athlete is involved in, the performance level and experience of the athlete, their performance potential and the sporting calendar they are working to. However, the overall theory of periodization contains broadly similar concepts. Generally, periodization is split into three phases: transition (usually post-season), preparation (pre-season) and competition. These phases are cyclical—one follows the other (Figure 6).



▲ **Figure 6** The cyclical nature of the main phases of periodization

Transition (post-season)

Following a competitive season, athletes will probably be mentally and physically fatigued. This fatigue can take some time to dissipate, therefore, it would be unwise to place an athlete directly into a new training phase. The main goal of the transition phase is to allow the athlete to recover and become refreshed before beginning the new pre-season phase of training. To do this, an effective transition phase should provide opportunities for the athlete to rest and relax, physically and mentally, while maintaining an acceptable level of physical fitness (Bompa, 1999).

The approximate duration of the transition phase is 3–4 weeks, usually no longer than 5 weeks (Bompa, 1999). An inappropriate approach to the transition phase is to encourage the athlete to rest completely with no physical activity undertaken

at all; this will lead to detraining and lack of conditioning, losing gains made in the previous training cycle and placing greater stress on the subsequent cycle in order to regain this lost conditioning. A more effective approach is to encourage the athlete to take part in exercises and activities that are different to their normal training activities and in different environments. This will maintain fitness levels while providing the athlete with active rest and relaxation. For example, a 400-metre runner who normally trains on an athletic track may take part in off-road cycling or swimming in their transition phase.

Preparation (pre-season)

As the name suggests, this periodization phase prepares the athlete with the physical, psychological, technical and tactical tools necessary to maximize their performance in the competitive phase of the season. As a result, it is crucial that this phase is constructed and executed appropriately, as failure here will mean an underprepared athlete entering the competition phase. The preparation phase lasts approximately 3–6 months, depending on factors such as the athlete, whether it is an individual or a team sport and the structure of the sport's competitive season.

Bompa (1999) recommends dividing the preparation phase into two distinct, but related, sub-phases.

- **General preparatory phase** Here, the main focus is on developing the athlete's basic fitness and physical conditioning. This will enable the athlete to tolerate the greater volume and/or intensity of training as the preparatory phase progresses. There will also be some focus on the development of technical and tactical skills.
- **Specific preparatory phase** In this second sub-phase of preparation, focus shifts to preparing the athlete for the competitive season. Training objectives do not differ significantly from the general preparatory phase, but training becomes more specific to the skills and technical requirements of the athlete's specific sport. This phase may involve taking part in competitions of lower importance than those undertaken during the competition season, such as friendly or exhibition competitions. This will provide the athlete and coach with feedback as to the athlete's competition "readiness".

The principle of progressive overload is important during the preparation period. General advice is that increases in training load (for example, time or weight or intensity) should be kept at around 10% or less each week to allow for a gradual adaptation while minimizing risk of injury. To avoid excessive training load or injury it is important to note that everyone's limits are different. What may be a suitably challenging 10% increase for one individual may be too much for another. Individuals need to listen to their body and progress at a rate that feels comfortable, and equally important, physical educators, coaches and athletic trainers need to ensure safety when developing training programmes.

Competition phase

As the name suggests, this is the phase of periodization that takes place during the athlete's competitive season. Clearly, it would not be appropriate for the athlete to be attempting to make large gains in fitness/technique during this phase, as the effort to do this would likely be detrimental to their competitive performance. Therefore, in this phase the goals for the athlete are to maintain general physical condition, continue improving sport-specific skills and

technique, perfect their tactical approach to competition and gain competition experience (Bompa, 1999). To achieve this, the athlete's training volume is reduced, and the focus shifts to working predominantly on breaking down and improving sport-specific skills.



Linking question

How can monitoring inform an athlete's readiness for training?

(C.3, C.4 and Tool 2)

Consider:

- methods of athlete monitoring (such as heart rate, sleep, mood, performance)
- what impacts an athlete's ability to perform at their best
- indicators of athlete "readiness" (measures of fitness, fatigue and recovery status)
- adjusting training plans to avoid overtraining (such as rest, reduce training intensity)
- recovery time/reduce training volume
- using data to support coaches/athletes and help them make informed decisions to support athlete health and performance.

Sub-phases of a periodized training programme

The phases of training discussed above can range from several weeks to several months in duration. Obviously, training must be structured and monitored during these periods, as waiting until the end of the phase to see if the desired training effects have been achieved would be very risky. Coaches can use three sub-phases of training, each of which can be applied within the three phases discussed above, to enable a structured, periodized training programme to occur throughout an athlete's season. These sub-phases are called microcycles, mesocycles and macrocycles. The organization of these sub-phases is shown in Figure 7.

Microcycles

A **microcycle** is a weekly training programme that forms an important foundation of the athlete's longer-term training programme. The microcycle includes all of the athlete's training and recovery sessions in that week. Within a microcycle, each training session will have a specific goal, and each of those goals will contribute to the overall goal of the training phase that the athlete is in. In other words, each microcycle will be specifically structured to achieve the overall goals of the athlete's training phase. Therefore, microcycles are very important to the overall success of an athlete's training programme.

Mesocycles

A **mesocycle** is a specific block of training designed to achieve a specific goal that fits within one of the training phases described in Figure 7. Each of these phases will contain a number of mesocycles; this is another way that the athlete's training is broken down and focused.

An example of a mesocycle is as follows. At some point within a 4-month-long preparation phase of an athlete's training, the coach may want the athlete to

Key terms

Macrocycle An athlete's training programme for an entire year or season.

Mesocycle A block of training composed of several week-long microcycles.

Microcycle A weekly training programme.

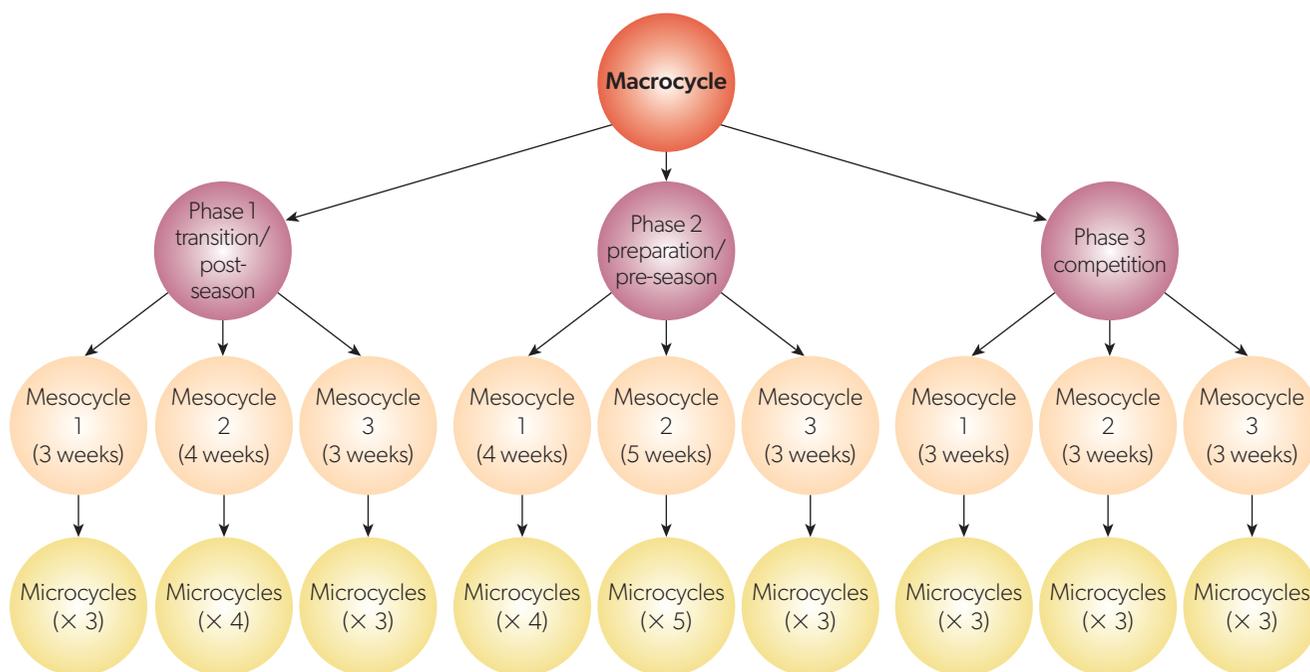
focus on improving their aerobic fitness (endurance). Therefore, the coach would construct a 3-week block of training designed to focus on improving the athlete's endurance. This 3-week block of training is a mesocycle.

Mesocycles are made up of microcycles. In this example, as the mesocycle lasted 3 weeks, it would have consisted of three microcycles (1 week = one microcycle). Mesocycles allow athletes to accomplish specific training goals, which also allow them to achieve the overall goal or goals of the whole training programme.

Macrocycle

Macrocycle is the name for the training programme of an athlete for the entire year or season. The macrocycle includes all of the main phases of training in Figure 7, as well as every mesocycle and microcycle. In this chapter, microcycles and mesocycles are discussed before the macrocycle. However, it is likely that a coach and athlete would initially identify the overall aims of the training programme by planning the macrocycle (usually by starting at the main competition point of the athlete's season and working backwards), and then work out the more specific goals or requirements of the programme (planning mesocycles and microcycles). Of course, the training programme would be flexible and subject to change as time goes on, to account for unforeseen issues like athlete illness and injury that could affect training.

Figure 7 shows the organization of a periodized training programme. The macrocycle incorporates every training phase, mesocycle and microcycle. Each phase of training is made up of several mesocycles. Each mesocycle is subsequently composed of microcycles. As one microcycle is equal to 1 week of training, the number of microcycles will always correspond to the number of weeks that the mesocycle lasts.



▲ **Figure 7** The organization of the macrocycle, mesocycles and microcycles within a periodized training programme

Activity 1

Choose one of the three phases: transition, pre-season or competition. Design your own training in a specific sport, thinking about the goals for each mesocycle and for each microcycle.

TOK

Various concepts of periodization have been researched extensively. However, most research studies have only investigated small, short-duration sections of a periodization training programme, rather than the whole annual programme. The main reason for this is the logistical difficulties in conducting a year-long training study. This means that athletes and coaches are designing and implementing periodized training programmes

without full supporting evidence that they are effective. This is contrary to the predominant research methodology of sports science, where a theory is developed and objectively tested, with the results supporting or refuting the stated theory. Evaluate the relative merits of two primary research approaches—deductive research and inductive research—within sports science research.

Training programme considerations

Baseline values and progress

Measuring baseline values and progress are important components of training programme design. At the beginning of a training programme, the baseline values provide a reference point for an individual's current fitness level. When combined with a needs analysis, baseline values help to meet individual needs and goals (for example, strength, endurance, speed and/or body composition). The baseline values help track progress, and evaluate and provide feedback on the effectiveness of a training programme. Additionally, tracking progress assists with monitoring improvement over time and can serve as a source of motivation. Therefore, baseline measurements enable individuals to modify their training programme to meet their individual needs and match their rate of progress. Importantly, baseline measurements can help identify potential injury risks and/or the need for rest/recovery. They ensure evidence-based, informed decision-making about training intensity, volume and specificity.

Training status

Training to achieve optimal athletic performance requires manipulation of the subtle balance of training stress and recovery at important time points. Otherwise, with too much training load, training-induced fatigue may accumulate, and with too little training load, detraining may happen. Both will result in attenuated exercise performance. Therefore, it is important to recognize training-induced fatigue or the level of recovery/adaptation achieved, and adjust training load to individualize training programmes. In other words, take into account an athlete's current training status and select an appropriate training dose for the individual to allow optimal improvements in fitness and performance. Quantification of training load is generally based on external and internal indicators of effort intensity. External indicators include distance, power output and number of repetitions. Internal indicators include oxygen uptake, heart rate, blood lactate and rate of perceived exertion.

For example, regular resistance training is recommended for maintenance of lean mass, strength and function in healthy adults of all ages. Prescribing resistance training should be based on intensity or per cent maximal strength (percentage of one repetition maximum). If a resistance training programme is prescribed at an intensity that is too low to effectively stimulate muscular adaptations, this can discourage adherence to the training programme. Also, if the resistance training programme is too high-intensity, it can result in increased risk of injury. It is, therefore, important to accurately assess the training status of an individual so that training intensity can be appropriately prescribed.

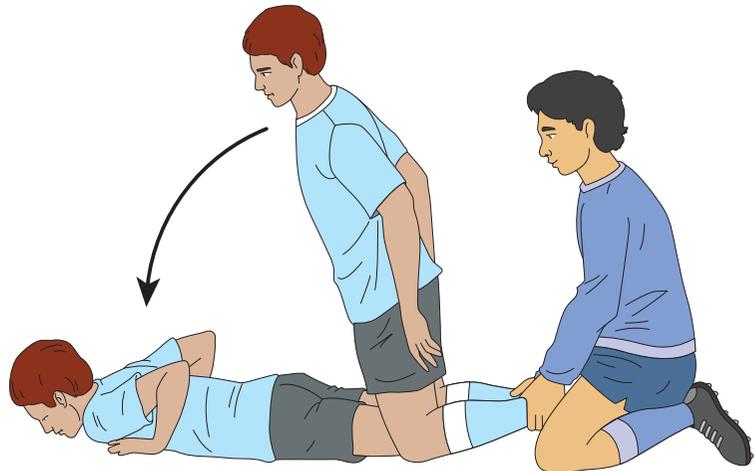


Linking question

How do the training principles of prehabilitation and appropriate warm-up protocols support injury reduction? (B.3.2)

Consider (part A):

Prehabilitation is a proactive exercise-based and educational approach to injury risk reduction. It is used to increase the body's capacity for how much the muscles, tendons and bones can tolerate during sport. It improves a person's strength, reactions and balance mechanisms and incorporates education on load management, such as monitoring the volume of activity the athlete is doing and avoiding oversteering the tissues.



▲ Figure 8 Nordic hamstring exercise

- Injuries are often specific to individual sports and have common mechanisms of injury and risk factors.
- In contact sports such as soccer and rugby where collisions occur and there are sudden changes of direction and velocity, injuries are usually traumatic-type injuries and include anterior cruciate ligament ruptures, hamstring and adductor muscle tears, and lateral ankle ligament sprains.
- In endurance sports such as running, the injuries are generally overuse injuries, such as tendon injuries and stress injuries to bones, related to repetition and overloading these structures.
- There are exercises known that can address the risk factors of specific injuries and can reduce the likelihood of injury. For example, a weak hamstring muscle predisposes an athlete to a hamstring tear. The Nordic hamstring exercise strengthens the hamstring muscle and can reduce the likelihood of hamstring tears (Figure 8).

Consider (part B):

Warm-up protocols can include dynamic stretching, strengthening, balance, skill practice, plyometric and cardio exercises.

- An active warm-up prepares an athlete mentally and physically for their sport and improves performance.
- Athletes who take part in warm-ups that incorporate prehabilitation exercises, particularly strengthening and balance exercises, are less likely to have an injury.
- Prehabilitation exercises can be devised specifically for the type of sport played, or devised with the aim to reduce injuries that most commonly occur in that sport.
- Adherence to and compliance with warm-up programmes are associated with reduced injury. Coaches who implement and support athletes with such programmes are helpful to their success.
- Injury prevention programmes help ensure a previous injury has been fully rehabilitated (previous injury is the main risk factor for injury).



▲ Figure 9 Ice hockey players

For example: a young hockey player, new to this sport, is keen to play their first game. Besides learning the skills of the game, what aspects of the warm-up could be key for them to prepare them for playing hockey regularly, and reducing the likelihood of injury?

Age

Training programmes need to consider age because different age groups have different physiological and psychological needs and limitations. Children, adolescents, young and older adults have different age-appropriate training needs. For example, the course of childhood is marked with progressive enlargement of the lungs, heart and skeletal muscles—all components that determine VO_2max —as well as improvement in endurance performance. Therefore, training programmes should be tailored to the individual's age group to ensure that they are effective (and safe).

Sex differences

Biological males and females have different physiological characteristics and hormonal profiles that can affect their response to a training programme. For example, biological males tend to have higher levels of testosterone, which can lead to greater muscle mass and strength compared with biological females, and this can impact the effect(s) of the training programme.

An interesting and often overlooked area is sex differences in risk of injury. Zech et al. (2022) compared injury rates between female and male players and evaluated sex-specific differences in team-sport injuries. They found male team-sport players have a higher rate of overall, upper extremity, hip/groin, thigh and foot injuries compared with female players. Conversely, female athletes showed a 2.15 times higher rate of anterior cruciate ligament injury than males. No significant sex differences were found for sprains, strains, concussions, ankle sprains or Achilles tendon injuries. This study has provided evidence for sex-specific differences in injury rates in team sports. Refer to chapter B.3.1 for more on this topic.

Menstrual cycle

In elite athletes, training individualization is widely recommended to optimize competitive performance. Consideration of menstrual cycle phases as a parameter in training individualization strategies is necessary. The menstrual cycle is a natural and complex process where large fluctuations in female sex hormones occur as the uterus is prepared for a potential pregnancy.

The main four constantly fluctuating hormones involved are:

- oestrogen
- progesterone
- luteinizing hormone
- follicle-stimulating hormone.

These variations in hormone profiles are used to differentiate between two main distinct phases of the cycle: **follicular** and **luteal** (Figure 10).

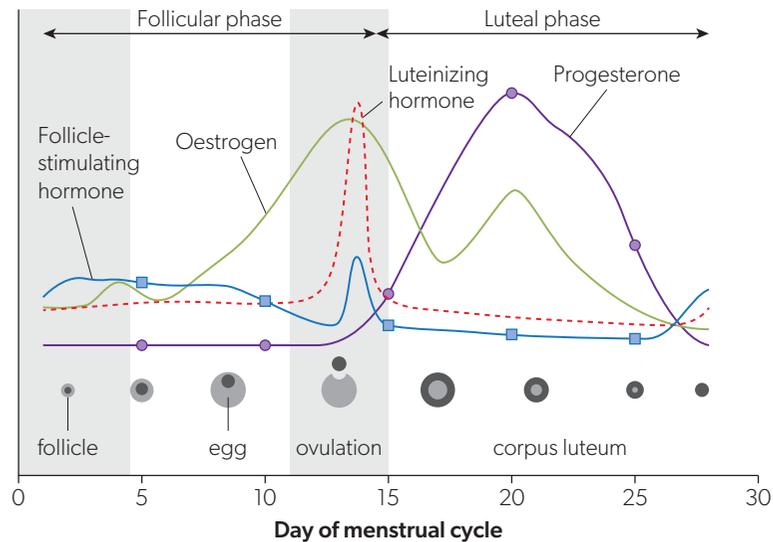
Research has shown that changes in oestrogen and progesterone levels across the menstrual cycle also have a wide range of complex effects on a variety of physiological systems, which may subsequently have an impact on exercise performance. Although in theory the menstrual cycle is a regular cycle covering 24–35 days, there is significant inter-individual variation in the timing of cycle events and hormone concentration, which makes research in this area complicated and highly variable.



Experiments

In 1993, the National Institutes of Health (NIH) in the USA introduced a new policy that all NIH-supported human research studies must ensure the inclusion of women unless “a clear and compelling rationale and justification” is established.

1. Why is it important that human research studies include female participants?
2. Why do you think it was necessary for this policy to be mandated?



▲ **Figure 10** Theoretical pattern of hormone levels during the menstrual cycle

Phases of the menstrual cycle

The menstrual cycle may be divided into four phases regulated by hormonal changes.

Menstruation phase

The cycle begins with the first day of menstruation. During this phase, levels of oestrogen and progesterone are low. The uterus lining is shed and accompanied by bleeding. Key considerations:

- Symptoms of menstruation, which may include abdominal cramps, heavy bleeding and tiredness

Late follicular phase

The late follicular phase is the time between the last day of menstruation and ovulation. During the follicular phase, follicle-stimulating hormone and luteinizing hormone levels increase. Levels of oestrogen rise while levels of progesterone remain low. Key considerations:

- High oestrogen—effect on sparing glycogen
- High oestrogen—increased injury risk due to effects on joints

Ovulation

Eventually, ovulation occurs. Oestrogen peaks just before ovulation and then drops shortly afterwards. Progesterone levels begin to increase. Key considerations:

- High oestrogen—effect on sparing glycogen
- High oestrogen—increased injury risk due to effects on joints

Luteal phase

The luteal phase is the time between ovulation and the start of menstruation. During this phase, progesterone is produced at a higher level. Progesterone helps prepare the endometrium (lining of the uterus) for implantation of the fertilized ovum. Key considerations:

- High progesterone—a thermogenic effect on thermoregulation leading to increased hydration demand
- High progesterone—effects on fuel availability
- Possible premenstrual symptoms, which may include feeling bloated, food cravings and mood fluctuations

Menstrual cycle and glycogen sparing during exercise

High concentrations of oestrogen and progesterone, typical of the luteal phase, have been shown to induce a glycogen-sparing effect, both at rest and during exercise, aligned with inhibition of gluconeogenesis and glycogenolysis. The decrease in plasma glucose and increase in plasma triglyceride concentrations observed (in studies during the 1990s and early 2000s) could be due to, in part, a reduction in glucose formation and an increase in glycogen storage in the liver and muscle tissues. This can lead to more fat metabolism, for example, in oral contraceptive users. Muscle glycogen is important in long-duration sporting events and the main fuel used in high-intensity exercise. As muscle glycogen has limited storage within the body, any sparing of the fuel throughout the event would be beneficial for the athlete.

This glycogen sparing could be also due to the status of the individual before exercise. For example, Campbell et al. (2001) reported that in endurance-trained females, glycogen sparing and increased fat oxidation only occurred when glycogen levels were initially low, highlighting the importance of adequate carbohydrates before exercise in females. However, it is important to note that this study was limited because the levels of glycogen were not measured directly, so the findings should be treated with caution.

More recently, Matsuda et al. (2022) investigated the effects of the menstrual cycle on muscle glycogen and circulating substrates during high-intensity intermittent exercise until exhaustion in 11 female participants with regular menstrual cycles who habitually exercised. High-intensity intermittent exercise until exhaustion was performed on three different testing days—during the early follicular phase, late follicular phase and luteal phase of the menstrual cycle. Evaluation of muscle glycogen concentration (from thigh muscles) and measurement of blood glucose, lactate, free fatty acids and insulin concentrations were done before exercise (Pre) and immediately after exercise (Post). Muscle glycogen concentrations from thigh muscles at Pre and Post were not significantly different between menstrual cycle phases. Muscle glycogen decreases by exercise were significantly greater in the late follicular phase than in the early follicular phase. However, blood glucose, blood lactate, serum free fatty acids, serum insulin concentrations and exercise time until exhaustion in the early follicular phase, late follicular phase and luteal phase were similar. Matsuda et al. concluded that although exercise time does not change according to the menstrual cycle, the menstrual cycle influences muscle glycogen use during high-intensity intermittent exercise until exhaustion in females with habitual exercise activity.

Menstrual cycle and thermoregulation

Human thermoregulation keeps body temperature constant over a wide range of environments and activity levels. During cold exposure, homeostatic responses to restore body temperature increase energy expenditure through both shivering and non-shivering thermogenesis, and increase peripheral insulation

via decreased skin blood flow. During heat exposure and exercise, core body temperature increases; increased sweating and evaporation of sweat are the major avenues of heat loss. In 2016, Charkoudian and Stachenfeld reported that oestrogen tends to promote lower body temperatures whereas progesterone tends to promote higher body temperatures.

Giersch et al. (2020) confirmed an increased internal body temperature during the luteal phase compared with the follicular phase both at pre-exercise and post-exercise. Therefore, hydration demands increase and need to be taken into consideration by both athletes and coaches when planning for activity, particularly during the luteal phase of the menstrual cycle.

Menstrual cycle and optimal performance window

A study (McNamara et al., 2022) explored the perceived effect of the menstrual cycle and associated fluctuations in hormones on the performance of 195 elite Australian biologically female athletes preparing for competition in the 2020/21 Tokyo Olympic Games and/or Paralympic Games. They found two-thirds of the participating athletes reported that their menstrual cycle affects their performance. Interestingly, the athletes were more likely to be affected in training than competing. When asked to choose an optimal window for performance, the highest proportion wished to compete “just after their period”. The authors of the study link this with suggestions that progesterone may have a negative impact on competitiveness, with athletes more likely to select into a competitive environment during the follicular phase, as well as wanting to avoid the inconvenience of bleeding during competition.

Another study (Brown et al., 2020) examined elite athletes' ($n = 17$) experiences of their menstrual cycle from multiple sports (athletics, climbing, gymnastics, judo and weightlifting). Results revealed athletes experiencing a natural menstrual cycle reported physical symptoms (cramps, heavy bleeding, bloating, nausea, low energy, sleep disturbance and gastrointestinal disturbance) alongside mood disturbances and reduced motivation to train.

Another study (Findlay et al., 2020) explored 15 biologically female international rugby players' past and current experiences and perceptions of the menstrual cycle in relation to its impact on sporting performance. Almost all (93%) reported menstrual cycle-related symptoms, with 33% experiencing heavy menstrual bleeding during menstruation; 67% considered these symptoms impaired their performances.

Meignie et al. (2021) reviewed 662 publications that have investigated the link between menstrual cycle phases and performance in elite athletes. Of these, only seven (1%) studies, involving 314 elite athletes, investigated the influence on a performance or physical parameter during at least one menstrual cycle phase. The athletes were from endurance sports (triathlon, swimming), weight-class sports (judo, taekwondo) and ball games (soccer, rugby, netball, handball and volleyball). A variable association between menstrual cycle and a few performance-related outcomes was reported, such as endurance (Yo-Yo intermittent test), ligament stiffness, decision-making skills or competitiveness (desire to compete and training motivation). They concluded different sports performance-related parameters are affected during the menstrual cycle among elite athletes, but the magnitude and the direction of the effects were inconclusive.

Case study

Menstrual cycle tracking for success

In 2020, the soccer team Chelsea F.C. Women announced that they had started using a specialist app to tailor their training programme around players' menstrual cycles to enhance performance and cut down on injuries. The specialist app helps the coaches at Chelsea FC design players' individual plans around the phases of their menstrual cycle, with the belief that factoring in the menstrual cycle to training and nutrition regimes could help control the weight fluctuations that often affect athletes during certain phases of their cycles. This in turn can reduce a player's susceptibility to soft tissue injuries, such as anterior cruciate ligament damage. The app, with the consent of the players, allows the Chelsea F.C. women to input information about their menstrual health and related symptoms, which can then be logged and monitored. Players learn how to track their menstrual cycle across the four phases: menstruation, late follicular, ovulation and luteal. This is because a player can be affected in different ways depending on the phase of their cycle. Understanding more about the subject could also have a significant impact on preventing injuries, as there can be a higher injury risk during phases one and two. This ranges from serious injuries—research has suggested a link between anterior cruciate ligament injuries and hormonal fluctuations—to less severe soft tissue problems, which are more likely to occur during the first half of the menstrual cycle (Brody et al., 2023; Miyazaki, Maeda, 2022).

1. Why are individuals encouraged not to exercise in a fasted state during the luteal phase of the menstrual cycle?



▲ **Figure 11** In 2020, the soccer team Chelsea F.C. Women announced that they had started using a specialist app to tailor their training programme around players' menstrual cycles to enhance performance and cut down on injuries

Menstrual cycle and the athlete population

The need to understand the impact of the menstrual cycle on female athletes is critical for sports performance alongside ensuring optimal health and well-being. However, many studies examining the link between the menstrual cycle and performance in sport are based on cross-sectional test designs generally conducted in laboratory settings or use subjective assessment via questionnaires, and tend not to include elite athletes.

In 2022 a study (Gimunova et al.) reviewed 48 studies on menstrual cycle disorder prevalence in biologically female athletes and concluded that they have a higher prevalence of menstrual disorders in comparison with the general population. Various explanations could be given including high physical demands, inadequate recovery, insufficient nutritional intake over a long period of time and psychological stress.

Brown et al. (2021) examined elite female athletes' experiences of their menstrual cycle, with a focus upon (a) the impact on training and competition performance and (b) the openness of conversations pertaining to the menstrual cycle with coaching and support staff. They found that elite female athletes' experiences varied greatly between individuals. However, many reported physical symptoms as well as mood disturbances and reduced motivation to train associated with phases of the menstrual cycle. In their study, athletes indicated an openness to talk about the menstrual cycle to female support staff, but there was great variation in the comfort athletes felt regarding talking to male sports coaches and support staff.

Activity 2

Exercise can make menstruation lighter and shorter in duration. Athletes training at a high intensity and/or volume may notice a significant impact on their period, in both flow volume and duration.

1. What sports may predispose young athletes to a delay in the start of menstruation?
2. If an athlete who usually menstruates has delayed or missing menstruation, what would this suggest about the athlete's health?
3. Regular menstruation is a sign of hormonal health. Many athletes may use an oral contraceptive pill that means they only menstruate when they take a break from the pill. How do you think this could:
 - a. mask hormonal problems?
 - b. impact bone health?

ATL Research skills

Many cultures stress the importance of the first menstrual cycle as a sign of transition into physical maturity and fertility, and something to be celebrated. Some communities, such as the San Carlos Apache Tribe, mark this event with celebrations—a positive and enabling social force. In the traditions of the Ojibwe people, menstruating tribe members are considered powerful. However, these positive views are not universal. Menstruation is sometimes seen as a nuisance, dirty, taboo and a source of physical and/or psychological problems.

Research attitudes to menstruation within the athlete population and consider reasons for them. Do you find any evidence that attitudes may be changing?



▲ **Figure 12** Retired 3,000m steeplechase runner Pippa Woolven, at the Aviva English Schools Track & Field Championships 2011. Pippa is CEO and founder of Project RED-S. Her experiences of RED-S, including being reassured that it was normal for “someone like her” not to have periods, led her to found Project RED-S. The project's stated aims are awareness, prevention and support.

Individual responses to training

An athlete's adaptive responses to training will depend on the intensity and methods of training utilized (anaerobic and aerobic) as well as inter-individual differences, such as genetics.

Individuals do not all have the same innate ability to respond to a single session of exercise, or the same capacity to adapt to exercise training. It is well-known that genetic influences make an important contribution to individual variation in acute as well as chronic changes that come from a training programme. With the exception of identical (or monozygotic) twins, no two people have exactly the same genetic characteristics. Therefore, it is not surprising that individuals do not have identical responses from participation in a standardized training programme. For example, there can be variations between individuals in growth and development, metabolism, cardiovascular-respiratory regulation, and neural and endocrine regulation. Thus, in response to an exercise intervention it is common for individuals to show a wide range of responses rather than a similar response.

This is seen in the phenomenon of **high responders** (individuals who show exceptionally large responses) and low or **non-responders** (individuals who show exceptionally small or unchanged responses) following a standardized training intervention. This phenomenon may provide helpful insights into mechanisms of training adaptation and methods of training prescription.

However, the reality is more complex. Individuals who show a low training response in one parameter (such as $\dot{V}O_2\text{max}$) do not necessarily show a low training response in other parameters (such as submaximal heart rate). Interestingly, one study found that some individuals with no change in aerobic enzyme activity post-training can be among the highest responders for $\dot{V}O_2\text{max}$. Another study showed that individuals who failed to improve their $\dot{V}O_2\text{max}$ in response to endurance training were able to improve their $\dot{V}O_2\text{max}$ in response to resistance training. This suggests that individual patterns of non-response may vary by training mode. Additionally, the HERITAGE family study reported that individuals who are high responders tend to be clustered in the same families, as are those who are low responders.

ATL Research skills

The HERITAGE family study (**HE**alth, **RI**sks factors, exercise **T**rainning **ANd** **GE**netics) documented the role of the genotype in the cardiovascular, metabolic and hormonal responses to an aerobic exercise training programme (three times per week, 35–55 minutes per day, at 55%–75% of $\dot{V}O_2\text{max}$). This study, involving a large number of participants, tested, exercise-trained in the laboratory with the same programme for 20 weeks, and then retested for physiological, metabolic and hormonal responses. Also, dietary and activity habits and other lifestyle components were monitored prior to, during and after training, and a variety of genetic analyses were undertaken, including heritability studies and major gene effects, for each phenotype and its response to regular exercise.

Was there any evidence of an increased resting metabolic rate after training?

Did they find any increase in exercise economy (such as reduction in submaximal $\dot{V}O_2$ when performing at the same exercise work rate/load)?

Were there high responders (showing large improvement) and low responders (showing little or no improvement) to the 20-week training programme?

Key points

- There is individual variation in response to exercise, with some subjects experiencing larger improvements than others.
- There is often a sub-group of individuals who appear to exhibit either no or a negative response to specific exercise training programmes.



Measurement

Exercise response is often determined by measurement of one (or at most a small number) of all the potential variables that can typically change with exercise. Just because an individual does not improve their $\dot{V}O_2\text{max}$ with an aerobic training programme, or their 1RM with a strength training programme, does not mean that they have not derived a multitude of other benefits from exercise, many of which, such as increased social interaction seen in community exercise settings, are non-physiological in nature.

ATL Thinking skills

The human genome is an instruction booklet on how to make you. It is made up of four subunits, called bases.

- Thymine (T)
- Adenine (A)
- Guanine (G)
- Cytosine (C)

Your human genome is about 3.2 billion letters long. That genome is packed into every cell of your body.

TOK

Both environmental and genetic factors influence sporting performance. When two areas of knowledge are linked, how can we decide which has more relevance?

TOK

Genetic screening has implications for competitive sports and public health in general. Are there areas of scientific knowledge that are morally unacceptable?

Genes and inheritance of characteristics

Chromosomes are mainly made of deoxyribonucleic acid (DNA), sections of which are referred to as **genes**. Genes code for the production of proteins, which are responsible for the development of an individual. All human somatic cells contain 23 pairs of chromosomes and there are thousands of different proteins in each cell. Therefore, there are many genes on each chromosome.

Human characteristics (or phenotype) are determined by genes (the genotype). Some characteristics are expressed developmentally by genes (for example, eye colour, sex), others also respond to environment (for example, height, VO_2 max).

Genes can be switched on or switched off depending on internal or external factors, so that characteristics influencing athletic performance can change during a person's lifetime. Multiple genes determine the measurable heritable characteristics for each individual, so it is highly unlikely that a single or even a few genetic elements are associated with superior athletic performance.

Genetic and environmental factors on performance

Characteristics that are influenced by genetics include height, muscle fibre type, anaerobic threshold, lung capacity and flexibility. Environmental factors that also influence performance include physical training, nutrition, technological aids and climate. Training maximizes the likelihood of obtaining a performance level with a genetically controlled ceiling. Elite athletes can be distinguished from less well performing athletes with respect to both inherited (genetic) characteristics and training histories. It is presently not possible to ascertain the relative contribution of genetics or training to elite sporting performance, and this contribution is likely to differ for different sports.

The implications of genetic screening for sports, exercise and health include:

- the identification of life-threatening conditions such as risk of sudden cardiac death, connective tissue disorder
- the potential to predict susceptibility to injury and so reduce risk/improve safety for an individual athlete
- ethical implications of involuntary exclusion from, or discrimination in, one or more sports
- ethical implications of discrimination beyond sport, for example, in employment
- the possibility of gene doping in the future to improve athletic performance.

**Global impact of science**

There are currently no scientific grounds for the use of genetic testing for athletic performance improvement, sport selection or talent identification. Athletes and coaches should be discouraged from using genetic testing. Gene doping should not be used on athletes. Genetic research to enhance understanding of athlete susceptibility to injury or illness is valid, but there must be careful consideration of ethical concerns, including the provision of adequate informed consent.

Non-responders or stubborn responders?

Regular participation in endurance exercise and resistance training increases cardiorespiratory fitness and muscle strength, respectively. Additionally, regular participation in both forms of exercise reduces the risk of age-related chronic diseases. However, according to a 2023 report by the Organisation for Economic Co-operation and Development/World Health Organization (*Step Up! Tackling the Burden of Insufficient Physical Activity in Europe*), about 45% of adults aged 18–64 years old do not undertake 150 minutes of exercise per week. There is large variability in the magnitude of adaptations for both cardiorespiratory fitness and strength changes after weeks of training. This has led to the term “non-responder”. For example, some studies report that 40%–50% of individuals do not show a meaningful improvement in $\dot{V}O_{2\max}$ from endurance training. However, there is a growing consensus that “non-responders” to training programmes are based more on anecdotal than experimental evidence. Indeed some studies have found that there are no non-responders if training intensity is higher and training frequency is increased. Additionally, extending the length of the training programme appears to reduce the incidence of non-responders. This has led some to suggest that global non-responders to exercise are unlikely to exist. Consequently, some researchers have proposed a term such as “stubborn” responders (rather than non-responders) to describe individuals who do not initially respond to training—the key is finding the exercise stimulus that works for them.

ATL Thinking skills

Inheritance is the influence of ancestors on the phenotypes of their descendants. There are a number of inheritance mechanisms, including the transmission of genetic and epigenetic variation. Epigenetics is how your behaviours and environment can cause changes that affect the way your genes work.



Falsification

The extent to which a non-response to an exercise training programme is “true” or “false” within published research studies currently remains unclear. It is also not known whether this non-response is:

- static (the individual will always be a non-responder to that particular exercise training programme), or
- a temporary reflection of the adaptive capacity of specific individuals at a given time (the individual did not respond to that exercise training programme, but might if the intervention was repeated).

Why might increasing the number of measured variables and increasing training volume, intensity or duration eliminate the prevalence of exercise non-response?

Overtraining

As discussed earlier in this chapter, undertaking a prolonged period of training that exceeds what the athlete can physically and/or mentally tolerate is called overtraining. This process, usually accompanied by insufficient recovery, can

Key point

Elite performance is understood to be the result of both training (and other environmental factors) and genetic factors. However, the extent to which champions are born or made is a question that remains. Training is critical for elite performance, but training by itself cannot produce an elite athlete. Individual performance thresholds are determined by our genetic make-up, and training can be defined as the process by which genetic potential is realized. Therefore, elite sporting performance is the result of the interaction between genetic and training factors (both nature and nurture are involved).

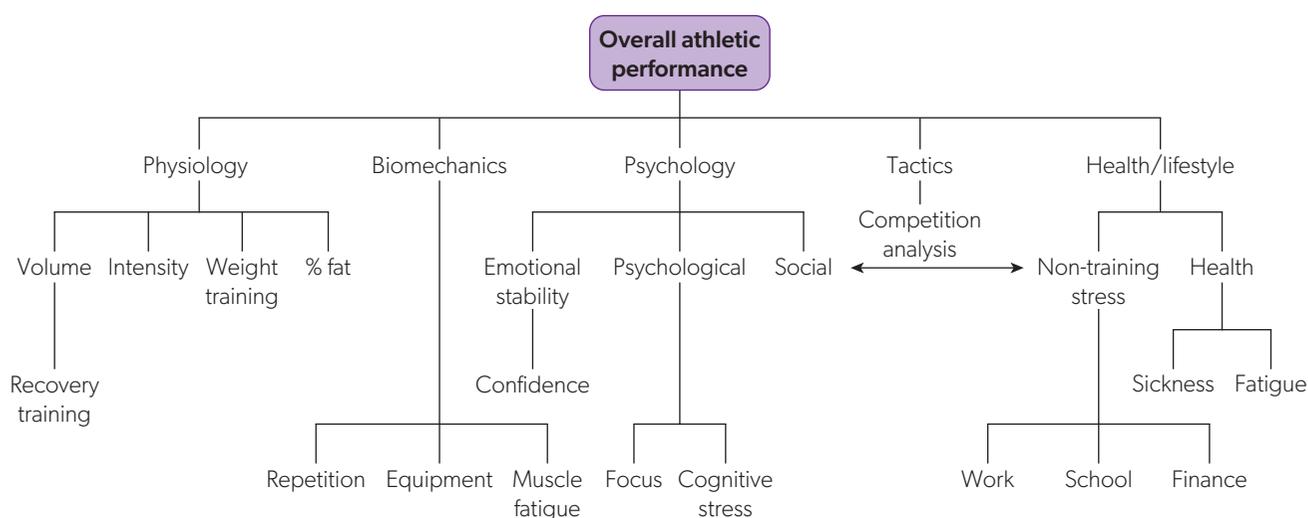
lead to the development of overtraining syndrome (OTS). This is an important differentiation. Overtraining and OTS are not one and the same thing; overtraining is the process, whereas OTS is the eventual outcome of that process.

Athletes suffering from OTS can struggle to train hard or compete at their previous levels, struggle or fail completely to adapt to training and find it increasingly difficult to recover fully from a workout (McArdle et al., 2010). It is also important to note that stressors on the athlete outside of training or competition, such as family concerns or financial worries, can also contribute to the development of OTS (Smith, Norris, 2002).

Key point

Overtraining is the process, whereas OTS is the eventual outcome of that process.

Figure 13 shows the five aspects of performance that impact the overall athletic performance of an athlete. An excess of one or more of these aspects or their constituents could contribute to development of OTS.



▲ **Figure 13** A conceptual model of five aspects of performance that impact the overall athletic performance of an athlete

OTS

OTS is a highly variable condition that can affect athletes differently and induce different symptoms—over 80 have been identified. It can take weeks or months to recover from OTS (Slivka et al., 2010).

ATL Research skills

Similarities in symptoms of RED-S and OTS may result in a misdiagnosis of training-overload. Read the 2021 paper by Stellingwerff et al. for more on this subject.

Symptoms of OTS are often the same as those from a multitude of other illnesses and conditions, meaning that OTS can go undiagnosed for some time. To compound this, no diagnostic tool exists to identify conclusively an athlete as suffering from OTS (Cadejani, 2020). Indeed, OTS is termed a “syndrome of exclusion”, meaning that it is diagnosed only when all other possible causes of an athlete’s symptoms have been ruled out. Potential causes for many symptoms of OTS that must be ruled out include anaemia, magnesium deficiency, viral infections, muscle damage, hormone disorders, eating disorders, depression, allergies, cardiovascular disease and asthma (Purvis et al., 2010). Furthermore, the causative mechanism(s) behind OTS are currently unknown (Armstrong et al., 2022), and the only known “cure” for the condition is prolonged rest from training and competition.

For these reasons, OTS represents one of the most feared conditions for competitive athletes. Despite this, the prevalence of OTS in athletes can be high,

although it appears to be influenced by factors including the performance level of the athlete, the type of sport undertaken, the length of time that the athlete has been competing and the amount of time that the study of OTS was conducted (Cadebiani, 2020). Biological females appear less susceptible to OTS than biological males (Armstrong et al., 2022).

The lack of a clear, defining diagnostic measure of OTS, coupled with the variability of symptoms, makes the scientific study of OTS very difficult. The fact that it is unethical to induce a state of overtraining in athletes increases this difficulty. As a result, most research has used athletes deemed already to be suffering from OTS (which is subject to the inherent difficulties in diagnosis that have been previously described), or has induced a state of overreaching in research subjects as a model for studying OTS.

Sudden, unexplained and persistent performance decrement

The critical, gold-standard criterion for the diagnosis of OTS is a rapid-onset, persistent decrement in the exercise performance of an athlete that is not rectified even when modifications are made to training. This underperformance will persist despite a recovery period lasting from several weeks to months (Cadebiani, 2020). Of course, there are numerous factors other than excessive training demands that could cause a sudden and prolonged performance decrement. These factors must all be excluded prior to a tentative diagnosis of OTS being made. This is why, as discussed earlier, OTS is a condition of exclusion.

Chronic performance decrement is the gold-standard OTS diagnostic tool as it is the only potential marker of OTS present in all diagnosed cases. Unfortunately, detection of performance decrement is too late for any preventative action as OTS has already developed, and therefore underperformance is useless as a predictor or warning sign of the onset of OTS. It is therefore important that future research continues to strive to identify accurate, reliable prediction criteria for OTS to halt the development of the condition before it is too late.

While underperformance can be used as a criterion for the diagnosis of OTS, the obvious question is: what causes the underperformance that is characteristic of OTS? Unfortunately, this is a difficult question to answer as it appears that OTS, as well as being a condition of exclusion, is also a very variable condition that presents differently from athlete to athlete, with the search for a uniform and reliable marker of the condition proving elusive. This may be a factor in why, once OTS has developed, it can prove extremely difficult to eradicate or overcome.

The following sections detail some of the other common potential markers of OTS, which may contribute to the commonly observed underperformance associated with the condition.

Resting heart rate

Primary signs and symptoms of OTS include sleep disturbances (Kenney et al., 2015) and an increase in resting heart rate (Baghaei et al., 2022). While perhaps not a strong direct indicator of OTS, increased resting heart rate may indicate the presence of illness or disease.



Activity 3

Explain why OTS is hard to diagnose.

Key point

The main indicator that an athlete has OTS is a decrease in their performance level. This means OTS is not spotted until it has already developed, making it impossible to predict or prevent.

Chronic muscle soreness

Muscle soreness is a common, normal response to an acute bout of hard exercise, particularly unfamiliar exercise (for example, a session of weightlifting for someone who has not performed resistance training for a long period of time). This type of muscle soreness is termed delayed onset muscle soreness or DOMS. With appropriate recovery, this soreness usually dissipates 24–72 hours after the exercise bout.

DOMS has a number of causes including:

- minute tears in the muscle tissue
- pressure changes that produce fluid retention in the tissues surrounding the muscle
- muscle spasms
- overstretching and tearing of the connective tissue attached to the muscle
- acute inflammation
- a combination of these factors.

This acute muscle damage is widely believed to be a necessary occurrence for adaptations to training, as the response to healing this damage is to adapt the muscle, bone and/or connective tissue to ensure that greater stress is required in order to produce the same degree of damage. In other words, these structures become “stronger”.

Key terms

Cytokines Proteins that regulate the process of inflammation, which is common in all forms of tissue damage and is an important part of the healing process for damaged tissue.

Sleep disturbances Not only fewer hours spent sleeping but also increased movement during sleep that reduces the quality of sleep.

However, some athletes suffering from OTS report muscle soreness that is not alleviated by rest or recovery. This may relate to the common short-term muscle damage discussed above. Trauma to the muscle (which occurs during high-intensity, high-volume and/or unaccustomed exercise) produces proteins that regulate inflammation. Inflammation is common in all forms of tissue damage and is an important part of the healing process. These proteins are called **cytokines**. If tissue-damaging exercise continues without adequate rest and recovery, the local inflammation of the damaged tissues can last for longer than normal. In other words, it can become chronic (Armstrong et al., 2022). In this situation, the circulating cytokines produce even more cytokines and the tissue inflammation becomes systemic—it spreads to other organs and tissues. This systemic inflammation can cause symptoms commonly encountered when a person is unwell, such as reduced appetite, feelings of lethargy or tiredness, **sleep disturbances** and altered mood state (Armstrong et al., 2022).

Later in this chapter, you will see that these symptoms are also potential indicators of OTS. Therefore, this potential cause of chronic muscle soreness in OTS may occur at the early stage of the development of the condition, and may even be a prevalent causative factor of OTS (Cadegiani, 2020). However, chronic muscle soreness is a subjective measurement—the severity of muscle soreness can be perceived differently by different people. The usefulness of it as a measure of OTS is restricted, because a clear reference is difficult to find (Cadegiani, 2020). Also, chronic muscle soreness is not consistently reported in all cases of OTS.

Reduced immune function

Competitive athletes subject themselves to a high level of exercise training stress to enhance their physical performance capacity. The phenomenon of reduced athletic performance following sustained, intense training was first recognized

more than 90 years ago. This training stress, as well as the other stresses of life these athletes encounter, places them at a great risk of developing OTS. The immune system provides a line of defence against invading bacteria, parasites and viruses. Specialized cells (for example, lymphocytes and antibodies) respond collectively to help the immune system protect the body from foreign invaders that might cause illness.

Many studies have shown that excessive training suppresses normal immune function, which can increase the overtrained athlete's vulnerability to infections. Short bouts of exercise at a high intensity can temporarily impair the immune response, and heavy training for several consecutive days can amplify this suppression, which is associated with abnormally low lymphocytes and antibodies. The suppression of the immune system increases the risk of illness such as upper respiratory infection(s) associated with compromises in physical performance capacity (Hackney, Koltun, 2012). The current information regarding the immune system and overreaching confirms that periods of intensified training result in depressed immune cell functions. However, although the immune system changes in response to increased training load, these changes do not distinguish between those athletes who successfully adapt to overreaching and those who maladapt and develop symptoms of OTS (Meeusen et al., 2013). More research is required on the potential influence of overtraining on immune function (Armstrong et al., 2022). We will study the relationship between activity level and immune system function further in chapter A.3.2.

Sleep disturbance

Disturbances to normal sleep patterns are one of the few tools available to diagnose OTS under resting (non-exercising) conditions. Sleep disturbances may be an early indicator of OTS with the term "sleep disturbance" relating not only to an increased amount of time spent in an awake state, but also encompassing increased rates of movement during sleep which can compromise sleep quality. The exact causes of these proposed sleep disturbances with OTS are not clear, and may be due to factors such as increased muscle fatigue and soreness, and altered immune system function and hormone regulation. However, as with many other proposed markers of OTS, sleep disturbances are not consistently observed. Therefore, the usefulness of this as a marker of OTS should be questioned (Baghaei et al., 2022).

Fatigue

OTS is characterized by persistent fatigue. The nature of this fatigue is complex and has been associated with central (alterations in brain chemistry and function) and peripheral mechanisms (such as alterations in circulating hormone levels, changes in muscle energy, and metabolism).

It is extremely difficult to pinpoint the exact cause and nature of fatigue within OTS. Questions about fatigue include the following.

- Is fatigue psychological or physiological?
- Does it stem from chronic fatigue associated with overreaching or OTS, or is it simply tiredness as a result of an isolated training session?
- Is the fatigue a result of another diagnosed or undiagnosed condition?
- Is fatigue per se the issue, or is a loss of vigour a separate and more important concern in OTS?

ATL Thinking skills

Does the immune system become suppressed, leading to OTS, or does an athlete develop OTS, which then results in reduced immune function?

It is also known that conditions such as depression, anaemia, hypoglycaemia and hypothyroidism can all cause fatigue. Furthermore, reductions in athletic performance can be related to protracted upper respiratory tract infections. A thorough investigation of potential underlying health and medical explanations for prolonged underperformance should always be carried out.

Many questions remain about the nature of fatigue during OTS and whether it is directly related to or caused by OTS. Due to the fundamental complexity in understanding human sport and exercise fatigue, using “fatigue” as a “marker” of OTS should be done with caution and as part of a global evaluation of the potential causative factors of OTS on a case-by-case basis.

Decreased appetite

Alterations in brain chemistry can affect a wide array of regulatory functions, one of which is appetite. Increased levels of serotonin in the brain can cause a feeling of sleepiness. Additionally, high serotonin levels can reduce a person’s appetite. Therefore, potential alterations in neurotransmitter and/or hormone levels and function in OTS may contribute to reductions in appetite. However, as with other markers of OTS discussed above, alterations in appetite levels are not consistently observed in individuals believed to be suffering from OTS.

The implications of decreased appetite in an overtrained state are important: it could mean that an exercising individual becomes energy deficient (that is, they do not consume sufficient calories to replenish those they use during exercise). This would be particularly relevant to carbohydrate availability, as carbohydrates are the body’s main fuel source during exercise. If this energy-deficient state were to continue, the body would be forced to generate its energy by other means, for example by an increased use of amino acids as fuel. This may lead to increased production of serotonin, which could elicit appetite dysregulation and sensations of fatigue as already discussed. Therefore, prolonged periods of exercise in the presence of an inadequate diet could exacerbate the overtraining state or contribute to the initiation of OTS. However, this does require further study.

It is clear that OTS is a concern for any athlete. Once the condition has developed, it can be debilitating to the athlete’s health and performance. Furthermore, the somewhat mysterious nature of the condition means that once it has developed, it cannot be easily dealt with or “cured”. Therefore, the focus of an athlete and their coach and support team must surely be to optimize the athlete’s training and competition performance while avoiding the development of OTS altogether. One of the ways in which they can accomplish this is to plan appropriately the athlete’s training load.

Key point

One of the difficulties in diagnosing OTS is that not all the symptoms are experienced by all athletes suffering from OTS, and many of the symptoms can be put down to other causes.

ATL Thinking skills

If you were planning to study OTS further, which of the symptoms would you choose to investigate? How might you go about this?

Practice question

Explain how a macrocycle training structure can avoid overtraining and injury. (4 marks)

Case study

Diagnosing OTS

Amari is a 23-year-old triathlete. Six months ago they moved up to national-level competition, and they are hoping to represent their country at the European championships next year. Before moving up to national level, Amari was a competitive triathlete for six years and won numerous local and regional competitions. Amari is generally healthy, although they suffer from mild asthma and have a tendency to develop anaemia, for which they regularly take iron supplement tablets.

Since moving up to the national level, Amari has a new coach. The new coach has redesigned Amari's training programme, as they believed the old programme would not have allowed Amari to reach their goal of competing at the European championships. The new training programme is more intense, and has notably increased the volume of training compared with that Amari used to do. The coach is also entering Amari into more competitions, as they believe this will give Amari an advantage in the future.

One month into this new training regime, Amari suffered a close family bereavement. Two months into the new training regime, Amari's coach noticed that their performance in training was decreasing. Amari was finding it more difficult to do the same amount of training.

The coach also noticed a difference in Amari's mood: they became less motivated and willing to train, and began to exhibit angry mood swings. Their performance in competitions also worsened: their average finishing position fell from 4th to 11th.

Amari reported feeling tired and sluggish; they would wake up in the morning still feeling exhausted, and for the rest of the day would feel like they wanted to go to sleep. Amari's appetite decreased and they lost several kilograms in weight.

Amari's coach is concerned and believes that Amari is at risk of having to stop training altogether. They think that Amari may be suffering from OTS.

1. How would you respond to Amari's coach asking you: "Does Amari have OTS?" Justify your answer to the question.
2. What information would you get from Amari and their coach in order to be more confident in your diagnosis of whether or not Amari has OTS? Think about possible physical and medical tests or measurements, personal information from conversations etc. that you could use to get this information.
3. Based on your answers to the first two questions, do you think that Amari is suffering from OTS? Justify your response.
4. What would you recommend Amari and their coach do to try to solve the problem?

TOK

As discussed in the above section, knowledge of OTS is limited in part by ethical restrictions, namely the inability to induce OTS in research participants. The scientific study of OTS is beneficial for athletes as it enables the development of strategies to combat and prevent the syndrome. Therefore, the restriction on inducing a state of overtraining appears to be a conflict of interest.

1. Investigate the ethical implications of inducing OTS in research studies designed to understand and combat this syndrome.
2. Using the results of your investigations, provide a consensus statement on whether or not you believe it would be appropriate to enable the inducement of OTS in research studies. Justify your statement.

Summary

- Training is the systematic, repeated performance of structured exercise sessions with a specific goal in mind.
- Appropriately structured training is crucial for optimizing an athlete's physical performance.
- Many types of training are available for the athlete to choose from, based on individual sporting goals and requirements.
- Several training principles apply to all forms of exercise training: specificity, progressive overload (frequency, intensity and duration), recovery (rest principle), variety, reversibility and periodization.
- The athlete's annual training plan (macrocycle) is broken down into key phases, each of which has its own more specific sub-phases (mesocycles and microcycles).
- The exact structure of a periodized training programme will depend on the specific sport, performance level and experience of the athlete, their performance potential and the sporting calendar.
- Training programme considerations to achieve optimal athletic performance include training status, age, sex differences and hormonal changes during the menstrual cycle.
- It is common for individuals to show a wide range of responses from participation in a training programme.
- Both environmental and genetic factors influence sporting performance.
- There is a growing consensus that "non-responders" to training programmes are based more on anecdotal than experimental evidence.
- Failure to structure training appropriately can lead to undertraining or, more seriously, overtraining.
- Prolonged, excessive training can lead to development of overtraining syndrome (OTS).
- OTS is characterized by persistent underperformance and failure to adapt to training, therefore it is a serious condition for any athlete.
- Once developed, the only potential method of alleviating OTS is to drastically reduce, or completely stop, training and competition.
- OTS can be avoided by the use of periodization to plan and structure training loads appropriately.

Check your understanding

After reading this chapter, you should be able to:

- define the terms training, undertraining, overreaching and overtraining
- outline training principles of specificity, progressive overload, recovery, variety, reversibility and periodization
- describe the key components of a periodized training programme and how they fit together
- explain the impact of frequency, intensity and duration of training on the athlete's training response
- describe some of the common methods of training
- outline some training programme considerations
- discuss the overtraining syndrome, its impact on an athlete, how it may occur, the tools used for its diagnosis and the issues associated with those tools
- discuss genetics, responders and non-responders.

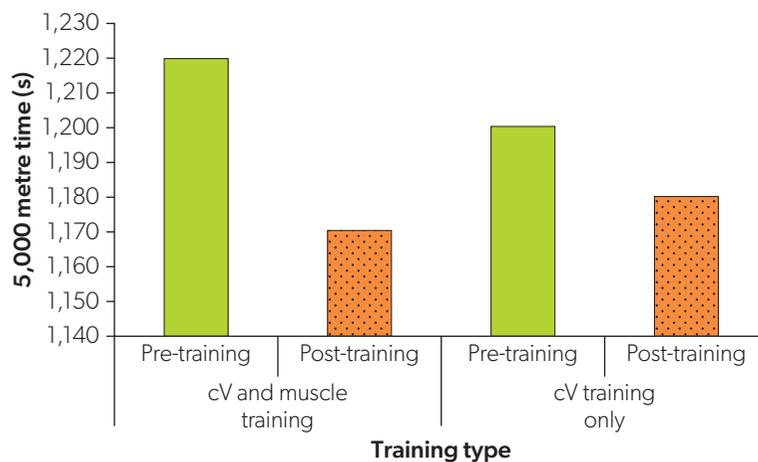
Self-study questions

1. Distinguish between functional overreaching, non-functional overreaching and overtraining syndrome.
2. Outline the primary symptoms of overtraining syndrome.
3. Describe the structure of a periodized training programme.
4. Explain how the menstrual cycle influences athletic performance.
5. List four causes of delayed onset muscle soreness.

Data-based question

A study was conducted comparing the effects of two different 4-week training programmes on 5,000 m running performance. One group was prescribed cardiovascular (cV) training, and one group was prescribed cV training plus inspiratory muscle training. All participants completed a 5,000 m run as fast as possible before and after the training programme.

The results of the study are described in the graph (Figure 14).



▲ Figure 14

1. Compare the pre-training running performance of the two groups. (2 marks)
2. Identify which training programme improved 5,000 m running performance more. (1 mark)
3. Discuss whether it would have been beneficial to the above data to include an additional control group who completed a 5,000 m run before and after the 4-week period, but did not perform any structured training. (3 marks)
4. Evaluate the benefits of using multiple types of training to enhance sporting performance. (3 marks)

A.3.2

Benefits to health of being active

Syllabus understandings

A.3.2.1 An active lifestyle supports physical well-being.

A.3.2.2 Prescribing exercise for health and sporting performance needs careful consideration and planning.

AHL

Introduction

In the 1850s, average life expectancy was less than 50 years in most countries. Over the last 150 years, average life expectancy has increased dramatically due to improvements in living standards resulting from the industrial and technological revolutions that have taken place in recent centuries. However, one negative consequence of these revolutions is that modern-day life requires low levels of physical activity. The findings of many studies (for example, Sabe et al., 2022) indicate that a physically active lifestyle is essential for optimal health.

According to the World Health Organization (WHO), “health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.” Thus, health is not defined solely by the absence of sickness, and optimal health involves the ability to pursue life with physical and mental vigour.

This chapter will explore the ways in which physical activity can assist in lowering the risk of disease as well as aid in the treatment of disease.

Benefits of an active lifestyle

Both moderate- and vigorous-intensity physical activity improve health. Regular physical activity can:

- help prevent and manage non-communicable diseases such as heart disease, stroke, type 2 diabetes and several cancers
- help maintain healthy body weight and reduce risk of obesity
- improve mental health, quality of life and well-being
- improve cognitive functioning
- improve sleep quality and reduce symptoms of depression and anxiety
- improve balance and, in older people, help prevent falls
- support bone health.

Globally, for levels of physical activity the WHO estimates that:

- a quarter of the world’s adult population are insufficiently active
- levels of inactivity are twice as high in high-income countries compared with low-income countries
- about four in five adolescents aged 11–17 years are not meeting WHO recommendations of physical activity per day.

Key point

The recommended level of physical activity varies for different ages and for specific groups, such as older people or those who are pregnant.



▲ **Figure 1** The health benefits for body and mind from physical activity

Exercise and the immune system

The human body is under constant threat from viruses, bacteria and parasites. Our immune system provides us with several layers of defence with the sole goal of protecting the body and eliminating any foreign substances. The different layers of the immune system work in harmony, not dissimilar to a finely tuned orchestra, where different cells and messengers interact to ensure essential processes are carried out.

Pathogens are microorganisms known to cause disease within our bodies. When they attempt to enter the body, they are faced with a very aggressive and localized response from the immune system. This is the body's first line of defence with the sole aim of preventing entry into the body, thereby reducing the risk of disease.

There is a general consensus that regular bouts of short-lasting (up to 45 minutes) moderate- to vigorous-intensity exercise are beneficial for the normal functioning

ATL Research skills

How does inflammation play a crucial role in the immune response?

of your immune system and likely help lower the risk of respiratory infection/illness (and some cancers), whereas repeated bouts of long-lasting (>2 hours) arduous-intensity exercise can be immunosuppressive.

Stress and the immune system

The human body is a finely tuned piece of machinery that has the ability to respond to environmental threats or stressors. A key part of this, known as the “fight-or-flight” response, is how we are able to recognize a threat and either run away or stay and fight it. Immune responses to stressful stimuli could be heightened at such times since there is a greater risk than normal of injury. The process of evolution was designed to enhance our survival rather than be harmful, where wound healing is an important function. Short-term stress has been hypothesized to help prepare the body for the incoming threat by activating the cardiovascular, musculoskeletal, neuroendocrine and immune systems. For example, preparing a zebra to flee from a stalking lion.



▲ Figure 2 The “fight-or-flight” response

In today’s modern society we encounter few predators that place us in this situation. However, alterations to our immune system in response to stressful stimuli that disrupt homeostasis are often reported during various situations including exercise, public speaking and sleep deprivation. The biological stress response is the only way that a stressor can influence the body—the main mediators of this are norepinephrine and epinephrine, released from the sympathetic nervous system, and cortisol released from the hypothalamic-pituitary axis. Virtually every cell within the human body has a receptor for these substances. Acute stress lasts for minutes to hours in comparison with chronic stress that persists for several hours a day

over weeks/months. The intensity of stress an individual experiences can be indicated by changes in heart rate, blood pressure and stress hormones. For the immune system to adequately protect the host during stressful episodes, a rapid recruitment of **leukocytes** (white blood cells) is required. As the stress response continues, blood leukocytes receive signals to move towards the skin, intestines, lungs, liver and lymph nodes resulting in a reduction in the number of leukocytes in the blood. This pattern of leukocyte redistribution is hypothesized to enhance immune function as the cells migrate to sites where they can protect the body from invaders.

Studies have identified prominent risk factors to athletes’ immune system health, including:

- intensified training (especially in the winter)
- long-haul travel
- low energy availability or poor nutrition

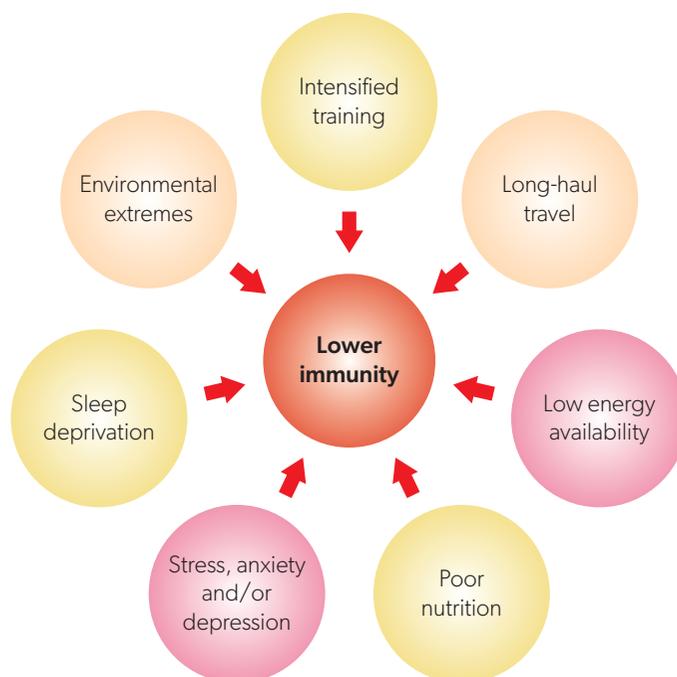
Key points

The immune system:

- is integral to the body’s defence against infection
- influences other physiological systems and processes, including tissue repair, metabolism, thermoregulation, sleep, fatigue and mental health.

- high levels of psychological stress, anxiety and/or depression
- sleep deprivation
- environmental extremes.

Factors that can lower immunity in the athletic population are shown in Figure 3. Upper respiratory tract infections (URTIs) are quite common in several sport activities among athletes who undergo heavy training. Elite athletes are commonly considered prone to respiratory infections, and URTIs are the most common acute illnesses in elite athletes. However, causes of URTIs are still poorly understood. Although numerous studies on exercise and the immune system have proposed that intense exercise may increase susceptibility to respiratory infections, data to support that view are sparse. This is because there are no high-quality long-term studies on the occurrence of URTIs in athletes (Ruuskanen et al., 2022). Cichella et al. (2021) provided evidence that the ingestion of carbohydrates, vitamins C, D and E, probiotics, and even certain fats can reduce URTIs in athletes. Current thinking suggests possible countermeasures to URTIs include correct nutrition, sleep hygiene, proper organization of training loads and the use of techniques to reduce stress.



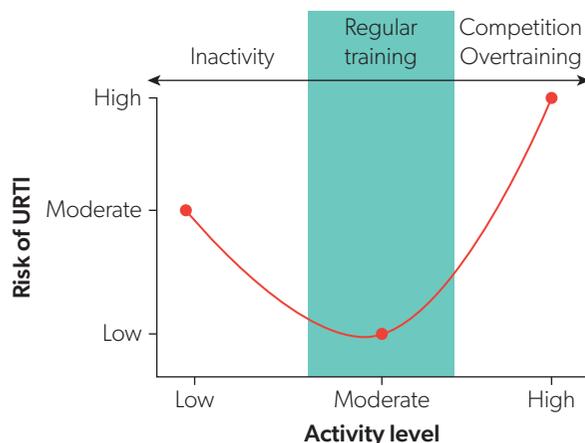
▲ **Figure 3** Key factors that can lower immunity in the athlete

Models for the relationship between activity level and immune system function

The J-curve hypothesis and open-window hypothesis provide theoretical frameworks to explain why exercise can exert apparently both enhancing and suppressive effects on the immune system and alter susceptibility to illness.

The J-shaped model (Figure 4) illustrates the proposed relationship between exercise intensity/volume and susceptibility to URTIs. URTIs are the most reported illness in athletic populations and can influence both performance and training.

The model illustrates that moderate physical activity decreases the risk of infection when compared with sedentary lifestyles. However, prolonged, intense, strenuous exercise can increase the risk of infection.

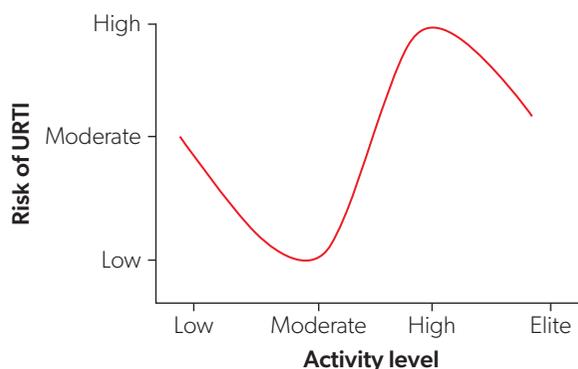


▲ **Figure 4** The J-shaped curve of the relationship between risk of upper respiratory tract infection (URTI) and exercise volume (adapted from Nieman, 1994)

During periods of intensified endurance training such as marathon training, up to 40% of athletes reported at least one episode of URTI 2 months before the event. Interestingly, in one study, where variables such as age and perceived levels of stress were controlled for, it was reported that runners who ran more than 60 miles a week were twice as likely to experience URTIs when compared with counterparts that completed 20 miles a week, suggesting that a relationship also exists between training volume and illness susceptibility. The relationship between training volume and illness rate is not limited to runners, with studies reporting this relationship in various other sports including swimming, football, tennis and rugby union.

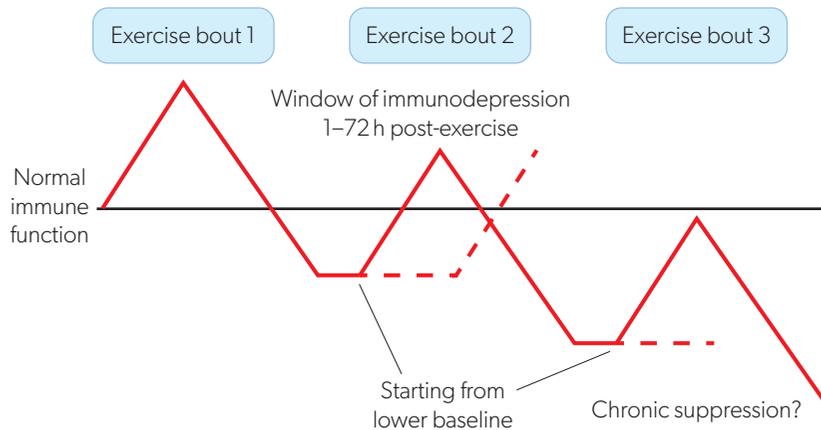
However, when elite athlete populations are considered, the relationship between exercise load and risk of infection appears to be S-shaped, where elite athletes can perform high intensities of exercise with no increase in URTI rate (Figure 5).

▶ **Figure 5** The S-shaped curve illustrating how elite athletes may perform high intensities of exercise with no increase in URTI rate (Malm, 2006)



Many elite athletes perform intensified training at key times in the season, and this can often lead to a period of planned overreaching during which time there is a decline in performance. When adequate recovery is provided, performance improvement happens. If recovery is not adequate after this phase or between successive bouts of exercise, immunodepression may occur, leaving the athlete more susceptible to infection. This is commonly referred to as the open window (Figure 6). The open window model

proposes that when strenuous exercise/training is performed over multiple days in close succession, a decline in immunity is experienced. We will study recovery in more detail in chapter A.3.3.



▲ **Figure 6** The open window theory, showing the effects of multiple bouts of exercise on the immune system (adapted from Simpson et al., 2015)

Some recommendations to maintain immune health in athletes include:

- manipulate training volume and/or intensity to manage training load
- keep the size of increments in volume and intensity to 5%–10% per week; particularly during winter
- undertake easy/moderate training sessions after each high-intensity session
- plan an easier recovery/adaptation week every second or third week of the training cycle
- monitor and manage all forms of stress—psychosocial and physical
- monitor life demands (for example, using the daily analysis of life demands for athletes (DALDA) questionnaire)
- monitor mood, stress and anxiety
- aim for >7 h sleep each night
- optimize **sleep hygiene** routine in the hour before bedtime (for example, go “screen-free”)
- ensure darkness at bedtime
- carefully manage training load and recovery when training in heat or altitude environments
- take extra precautions to avoid prolonged periods of breathing large volumes of cold, dry air (for example, when training and competing in the winter)
- consider short-lasting exposure to environmental extremes, which may enhance immunity and reduce sickness (for example, 30-second hot-to-cold showers)
- match energy intake to expenditure
- eat a well-balanced diet, including >50% daily energy intake as carbohydrate.

Key term

Sleep hygiene Strategies, such as regular going to bed and wake-up times, a routine prior to going to bed (that is, a period of relaxation without electronic device use), and a cool, quiet and dark bedroom environment, that appear to promote good sleep (efficiency, latency, onset and total sleep time).

Key point

Among various nutritional interventions that have been studied to counteract immunodepression during exercise recovery, carbohydrate supplementation has proven the most effective.

ATL Research skills

The DALDA is a self-report inventory of life-stress and symptoms of stress. It can be used to determine the nature of an athlete's response to training, particularly their capacity to tolerate future training loads. The DALDA has 34 questions in two parts.

Part A: Nine questions about sources of everyday stress, such as "have you had any arguments with your parents?" and "is the climate too hot?"

Part B: Twenty-five questions about symptoms of stress, such as "do you have sore joints and/or pains in your muscles?" and "are you getting enough sleep?"

Athletes answer each question with a single response:

- better than normal
- about normal, or
- worse than normal.

Experiments

Is the reliance on self-reported measures of upper respiratory illness symptoms a limitation of studies investigating whether exercise can increase susceptibility to infection?

Experiments

Studies on the effects of exercise on the immune system are associated with a number of experimental confounders including differences in cardiovascular responses, carbohydrate availability and hormonal response, which may differ from one bout of exercise to the next. Does this mean that research on this topic needs more or less controlled studies?

Activity 1

Over the last two to three centuries society has changed in many ways due to the effects of increased mechanization. Fewer and fewer occupations involve physical activity and humans now travel using cars, trains, buses and planes.

Think of the various ways in which mechanization and automation have removed physical activity from daily lives. How many examples can you think of?

Risks of an inactive lifestyle

One of the earliest studies to suggest that exercise is important for health was conducted by Jerry Morris who examined the prevalence of heart disease in bus drivers and bus conductors working on double-decker buses in London. Morris discovered that the bus conductors experienced roughly half the number of heart attacks and sudden deaths due to heart attack compared with the drivers, and he suggested that this was due to differences in the amount of occupational or working activity performed. It was estimated that the bus conductors climbed 600 stairs per day and they did this for 11 out of every 14 days, for 50 weeks per year, often for decades. In contrast, the sedentary drivers sat for 90% of their shift.

Many studies (for example, Ahmadi et al., 2022) have since confirmed a link between high levels of physical activity and a lower risk of heart disease, and these findings have been extended to other conditions and diseases also. This has led to the term **hypokinetic disease** meaning a disease associated with

a sedentary (inactive) lifestyle. A variety of hypokinetic diseases have been identified including **cardiovascular disease (CVD)**, some forms of cancer, obesity, type 2 diabetes, osteoporosis and mental ill-health.

Although the term hypokinetic disease is useful for emphasizing a central role for exercise in the maintenance of health, it is important to be aware that health is affected by a variety of factors beyond exercise including genetic predisposition, diet, smoking, alcohol consumption, and other social and environmental factors, hence it would be an oversimplification to suggest that the sole cause of hypokinetic diseases is a lack of exercise.

The prevalence of a particular disease (or disease risk factor) may be calculated by dividing the total number of people with that disease (or disease risk factor) by the total number of people in a sample group or population. It is used as an estimate of how common a particular disease (or disease risk factor) is in a population. It is contrasted with the term incidence, which is an estimate of the number of new cases of a disease or disease risk factor. Many studies (for example, Schwendinger, Pocco, 2020) have observed a lower prevalence/incidence of disease in active/fit people than in inactive/unfit people.

Key terms

Hypokinetic disease A disease associated with a sedentary or inactive lifestyle.

Cardiovascular disease (CVD) A group of disorders of the heart and blood vessels.



Experiments

Much of the evidence linking physical inactivity to an increased risk of disease comes from a branch of medical science known as **epidemiology**. Epidemiology studies the occurrence, transmission and control of epidemic (widespread) diseases and it usually involves studying large groups numbering tens of thousands, hundreds of thousands or even millions of individuals. Such studies are known as population-based studies.

Some epidemiological studies have examined physical fitness, which may be considered an outcome of the volume and intensity of physical activity. In such studies the type of physical fitness most often examined is cardiovascular fitness. Many of these studies have found that people classified as physically fit are less likely to suffer from disease than people classified as physically unfit.

Case study

Fitness and mortality risk

A study of men living in California, USA, investigated the association between physical fitness and all-cause mortality risk (the risk of death from any cause). This study used a maximal treadmill test to quantify exercise capacity in metabolic equivalent of tasks or METs, which provides an indication of cardiovascular fitness.

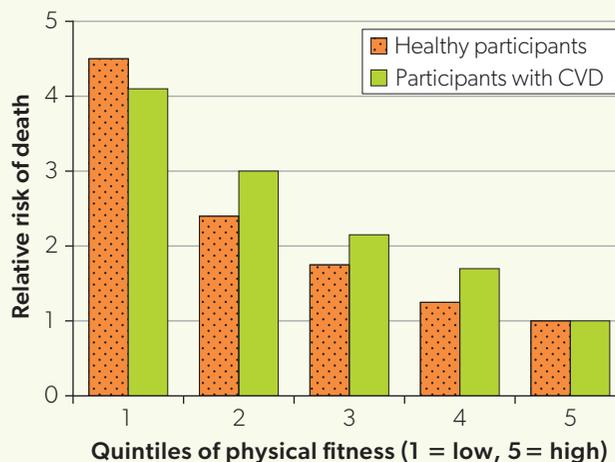
Fitness was assessed in the men at baseline and they were then observed for an average of 6 years after this (known as the follow-up period). At baseline 3,679 of the men were diagnosed with CVD whereas 2,534 of the men did not have CVD. During the follow-up





period 1,256 of the men died, and within each group of men (those who had and those who did not have CVD) those with the lowest levels of fitness at baseline were approximately four times more likely to die during follow-up than those with the highest levels of fitness at baseline.

These findings suggest that high levels of fitness may lower the risk of death during a given period both in healthy men and in men who have pre-existing CVD.



▲ Figure 7

Activity 2

Physical activity is difficult to quantify accurately. A variety of methods are available to measure physical activity. Some are very cheap and others are more expensive. These methods include:

- physical activity questionnaires
- pedometers
- accelerometers
- direct calorimetry
- indirect calorimetry
- doubly labelled water.

Find out about the methodology used for each of these techniques and create a table listing the advantages and disadvantages of each.

Key term

Hypertension A long-term condition of high blood pressure.

Key point

Three major forms of CVD are hypertension, coronary heart disease (CHD) and stroke. CHD and stroke account for a large percentage of deaths in high-income countries.



Measurement

The abbreviation MET stands for **metabolic equivalent of task** and it is a measure of the energy expenditure of physical activity. For reference purposes 1 MET represents the oxygen consumption/energy expenditure at rest, equal to 3.5 millilitres of oxygen per kilogram of body mass per minute ($3.5 \text{ ml O}_2 \text{ kg}^{-1} \text{ min}^{-1}$) or $4.184 \text{ kJ kg}^{-1} \text{ hr}^{-1}$ ($1 \text{ kcal kg}^{-1} \text{ hr}^{-1}$).

The MET unit can be used to describe the intensity of exercise by expressing oxygen consumption/energy expenditure during exercise as a ratio of that at rest. Hence a person running at 10 METs would be consuming $35 \text{ ml O}_2 \text{ kg}^{-1} \text{ min}^{-1}$ and expending $41.84 \text{ kJ kg}^{-1} \text{ hr}^{-1}$.

METs are often used as a method of classifying physical activities in epidemiological studies. Moderate-intensity activities are defined as those requiring three to six METs, whereas vigorous-intensity activities are defined as those requiring greater than six METs. Examples of moderate-intensity activities are brisk walking and slow cycling, while examples of vigorous-intensity activities are jogging, playing soccer and skipping.

CVD

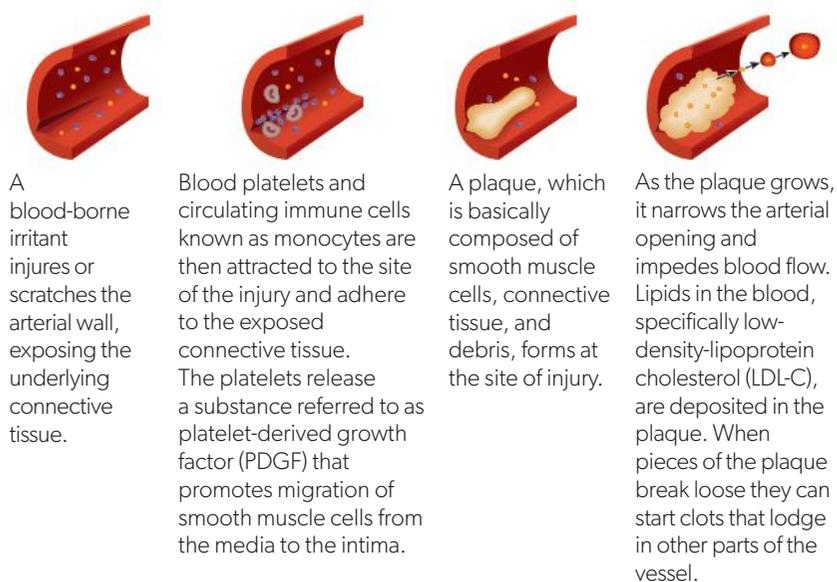
CVD is the term given to a group of disorders of the heart and blood vessels. These disorders include **hypertension** (high blood pressure), coronary heart disease (CHD), which is also known as ischaemic heart disease, and stroke.

According to the WHO CHD is the leading cause of death worldwide and was responsible for 8.89 million deaths in 2019 (16% of all deaths worldwide). Stroke was the second leading cause of death globally in 2019, responsible for 6.19 million deaths (11% of all deaths worldwide).

A major cause of CHD and stroke is atherosclerosis, which is a hardening of the arteries due to the accumulation of fat, cholesterol and other substances in the walls of the arteries forming hard structures called plaques. Atherosclerosis leads to a narrowing of arteries and eventually these can become blocked by a blood clot (thrombus). Pieces of plaque can also break off, blocking arteries. If a blockage occurs in the coronary circulation (the blood vessels supplying the heart) then this will lead to a heart attack (also known as a myocardial infarction). If the blockage occurs in a blood vessel in the brain then the result is a stroke.

Activity 3

Find out the leading causes of death in your country. How many people in your country die each year from CHD and stroke and what percentage of total deaths is due to these two diseases?



▲ Figure 8 Atherosclerosis

There are various risk factors for CVD and these may be divided into modifiable and non-modifiable risk factors. Modifiable risk factors are those that may be influenced by lifestyle. Physical inactivity is a major modifiable risk factor for CVD. Many epidemiological studies have demonstrated an association between high levels of exercise and a lower risk of CHD.

Exercise may lower the risk of CHD by a variety of mechanisms.

- Exercise may have direct effects on the heart, increasing the size of the coronary arteries and making them less likely to get blocked.
- Exercise also improves endothelial function, which means that arteries are able to vasodilate (open up) on demand to increase blood supply, reducing the chances of ischaemia.
- Exercise may also reduce the risk of CHD by having a positive effect on other heart disease risk factors, for example, helping to prevent obesity, diabetes, hypertension and high blood cholesterol, thus reducing the risk of blood clots forming.

- One major positive effect of exercise is helping to maintain high levels of protective high-density lipoprotein cholesterol (HDL-cholesterol). This lipoprotein is thought to play an important role in removing excess cholesterol from the body in a process termed “reverse cholesterol transport”. Cholesterol is insoluble and is therefore carried within the bloodstream in lipoproteins. Two major lipoproteins are low-density lipoprotein (LDL) and high-density lipoprotein (HDL). These lipoproteins have different relationships with CVD. High levels of LDL-cholesterol increase the risk of CVD, whereas high levels of HDL-cholesterol appear to protect from CVD. One important effect of exercise is that it raises HDL-cholesterol concentrations.

▼ **Table 1** Risk factors for coronary heart disease

Modifiable risk factors	Non-modifiable risk factors
cigarette smoking	age
high blood pressure	sex
high blood cholesterol	ethnicity
obesity	family history
diabetes	
physical inactivity	

Risk factors can sometimes cluster together. A clustering of three or more risk factors together is sometimes referred to as the metabolic syndrome. Major components of the metabolic syndrome include dyslipidemia (high triglyceride (blood fat) concentrations and low levels of HDL-cholesterol), impaired glucose

ATL Thinking skills

Animal experiments are useful for exploring the mechanisms by which exercise can lower the risk of CHD. One example is a study conducted in monkeys. This study involved a sedentary group on an atherogenic (likely to cause atherosclerosis) diet and an exercising group also on an atherogenic diet. The exercising group ran on a treadmill for 1 hour three times each week over a 2-year period.

At the end of the study both groups were found to have elevated total cholesterol concentrations but the exercising monkeys had higher levels of HDL-cholesterol. In addition, the degree of coronary artery narrowing caused by the atherogenic diet was much lower in the exercising monkeys than the sedentary monkeys. The authors concluded that “the benefits derived from such moderate exercise for one hour three times per week in the presence of hypercholesterolemia (high blood cholesterol) were less atherosclerosis in wider coronary arteries supplying a larger heart that functioned at a slower rate” (Kramsch et al., 1981, p. 1488).

Animal experiments may be useful for exploring mechanisms that are difficult to assess in humans. However, the findings may not be directly applicable (humans may not respond in the same way as animals). There are also ethical issues relating to animal experimentation.

Think about the advantages and disadvantages of animal experimentation and draw up a list of reasons for and against animal testing.

regulation or diabetes, obesity (particularly visceral/abdominal obesity—fat within and around the abdomen) and hypertension. This clustering of risk factors greatly increases the risk of CVD.

Physical activity can lower the risk of CVD (referred to as primary prevention). It also aids treatment of CVD, and helps prevent a recurrence of CVD events such as a heart attack (termed secondary prevention).

In the past, people who suffered a heart attack and survived were told to rest for many weeks afterwards. But today, people are encouraged to exercise soon after having a heart attack if possible. Studies suggest that heart attack patients who exercise regularly have a lower risk of death in the following years than those who remain sedentary.

Exercise also benefits people suffering from other forms of CVD, such as hypertension, peripheral vascular disease (narrowing of peripheral arteries) and heart failure (inability of the heart to pump sufficient blood around the body for all of the body's requirements).

Obesity

Obesity is an excess of body fat to the point where health is endangered. Obesity is commonly defined using the body mass index (BMI) which is calculated by dividing a person's weight in kilograms by their height in metres squared: kg m^{-2} .

However, BMI values can be misleading in some cases—such as weightlifters, bodybuilders, rugby players and American football players who may have high BMI values due to a large muscle mass rather than body fat.

Very accurate assessments of body fat can be gained using sophisticated imaging techniques, including dual-energy X-ray absorptiometry (DXA), magnetic resonance imaging (MRI) and computed tomography (CT), but these methods are costly and time-consuming and, in the case of DXA and CT scanning, the methods involve exposure to low doses of radiation.

▼ **Table 2** Classification of overweight and obesity by body mass index and associated disease risk. Note that a BMI below 18.5 is also associated with an increased risk of disease.

	BMI (kg m^{-2})	Associated effect on risk of disease
underweight	<18.5	increased
normal	18.5–24.9	not increased
overweight	25.0–29.9	increased
obesity (class I)	30.0–34.9	high
obesity (class II)	35.0–39.9	very high
extreme obesity (class III)	≥ 40.0	extremely high

There is concern about obesity worldwide because the prevalence of obesity has increased in most countries over the last few decades; in some countries one-quarter or more of the adult population are obese. Obesity increases the risks of many diseases and conditions, most notably type 2 diabetes but also CVD, osteoarthritis and some forms of cancer.

Key term

Obesity An excess of body fat that endangers health.

ATL Thinking skills

Some obese people live long, healthy lives and are unaffected by type 2 diabetes, heart disease and cancer. Some obese people do not show any evidence of defective metabolism—they may have normal levels of blood glucose and cholesterol. The term “benign obesity” has been used to describe such individuals. So, do you think that obesity should be classified as a disease?

Energy balance

According to the energy balance equation, body mass is determined by energy intake and energy expenditure as follows:

- energy intake > energy expenditure = weight gain
- energy intake < energy expenditure = weight loss
- energy intake = energy expenditure = stable body weight

Underlying this apparently simple equation is a complex set of factors that affect energy intake and expenditure.

Energy intake and energy expenditure also influence each other.

- A reduction in energy intake will eventually lead to a reduction in metabolic rate and hence energy expenditure.
- An increase in energy intake will eventually lead to weight gain and an increase in metabolic rate to support a larger body mass.

A variety of hormones influence appetite, including the appetite-stimulating hormone ghrelin and the appetite-suppressing hormone leptin. Many environmental factors also influence food intake, including the availability and affordability of palatable (tasty) food.

Physical activity can assist in the prevention and management of obesity by increasing the energy expenditure side of the energy balance equation. Exercise helps by reducing both subcutaneous fat (fat underneath the skin) and abdominal visceral fat (fat within the abdomen). The American College of Sports Medicine recommends between 150 and 250 minutes of exercise each week (approximately 20–35 minutes of exercise each day) for preventing obesity. Some organizations recommend higher levels of exercise for preventing obesity (45–60 minutes each day, or 5–7 hours each week). Even greater amounts of exercise may be required for weight loss. People who are successful at losing weight and maintaining weight loss frequently report high levels of exercise and moderate food intake.

Studies have also demonstrated that there are individual differences in the weight loss response to exercise. In other words, some people lose more weight than others. It is difficult to predict which individuals will lose most weight. This may be partly due to individual differences in appetite and food intake responses to exercise. While most people do not appear to overeat after exercise, this may happen in some cases.



Linking question

How might dietary intake impact perceived exertion and mental health? (A.3.2)

Consider:

- low energy availability
- perceived exertion during exercise
- mood disturbances/anxiety/depression
- macronutrient balance, blood glucose levels during exercise and reduced feelings of fatigue
- muscle repair and recovery after exercise
- impact of micronutrient deficiencies on perceived exertion, fatigue and increased risk of depression and anxiety
- hydration status, cognitive function, perceived exertion, fatigue and mood disturbances.

Case study

The ob gene

Obesity is caused by a combination of genetic predisposition and environmental factors. In most cases genetic predisposition for obesity is polygenic (involving many different genes) but some rare monogenic (single gene) causes have been discovered.

An example is a defect in the ob gene that prevents fat cells from secreting the hormone leptin. Leptin suppresses appetite by acting on the hypothalamus (the appetite-regulating centre in the brain). As fat cells increase in size they secrete more leptin in an effort to suppress appetite (and increase energy expenditure) to prevent further weight gain. People who are leptin deficient report being constantly hungry and they develop obesity early in life. This can be treated with injections of leptin (Figure 9).

Most obese people are not deficient in leptin; most obese people have high leptin levels but appear to be insensitive to it.



▲ **Figure 9** Visible effect of the ob gene in mice

Type 2 diabetes

Diabetes is a disease characterized by elevated blood glucose concentrations, a condition known as hyperglycaemia. In untreated diabetics, blood glucose concentrations may be elevated to 10, 20 or even 50 mmol l⁻¹ in comparison with values of around 5 mmol l⁻¹ in healthy people.

There are two main forms of diabetes, namely type 1 and type 2 diabetes.

- Type 1 diabetics do not produce insulin—type 1 diabetes is caused by an autoimmune destruction of the beta cells in the islets of Langerhans within the pancreas. These cells produce insulin, which plays an important role in moving glucose from the blood into the liver, muscle and adipose tissue cells (where glucose provides a useful store of energy in the form of glycogen).
- Type 2 diabetics are insensitive to insulin—type 2 diabetes is also characterized by hyperglycaemia, but this is due to insensitivity or resistance to the effects of insulin (known as insulin resistance) rather than a lack of insulin. People with type 2 diabetes often have high insulin values (hyperinsulinemia) and high glucose values.

If left untreated both forms of diabetes cause severe hyperglycaemia, ill health and premature death.

The worldwide prevalence of diabetes has increased in recent years and is at approximately 10% now. Most of these cases are type 2 diabetes. The major risk factors for type 2 diabetes are obesity (relating to overconsumption of food and physical inactivity) and family history. There is a particularly high prevalence of type 2 diabetes in certain ethnic groups. A well-documented example is that of the Pima Indians living in southern Arizona. Sun et al. (2022) provided global, regional and country-level estimates of diabetes prevalence. The highest comparative prevalence of diabetes was in the Middle East & North Africa region (18.1%), while the lowest world comparative prevalence was in the Africa region (5.3%). The largest number of people with diabetes (206 million) was found in the Western Pacific region. The regions forecast to experience the largest relative growth in the number of people with diabetes were the Africa and the Middle East & North Africa regions. The regions with the smallest expected relative growth in the number of people with diabetes were the Europe, North America & Caribbean, and Western Pacific regions.

Diabetes is a cause for concern because it is associated with a variety of health risks and premature mortality. The major health risks of diabetes are:

- cerebrovascular disease (stroke)
- retinopathy (a common cause of blindness)
- coronary heart disease
- nephropathy (damage to the kidneys)
- peripheral vascular disease
- neuropathy (damage to the nerves)
- diabetic foot (resulting in ulceration and amputation).

In recent decades, cases of type 2 diabetes have emerged in children. Before this, type 2 diabetes was considered to be an adult-onset disease.

The emergence of type 2 diabetes in children is thought to be related to environmental factors (poor diet and low levels of physical activity).

Many observational studies have demonstrated that active people are less likely to develop type 2 diabetes than inactive people. Intervention studies have also shown that a healthy diet and physical activity lower the risk of developing type 2 diabetes. Physical inactivity is an important risk factor for type 2 diabetes, even in those with a family history of diabetes; those who are more active are less likely to develop type 2 diabetes than their inactive counterparts (although both groups are at greater risk than those without a family history of diabetes).

One of the main benefits of exercise is that it enhances insulin sensitivity and glucose tolerance. This effect can be seen after a single bout of exercise but frequent exercise is necessary for continued benefit. In contrast, periods of inactivity reduce insulin sensitivity and glucose tolerance as shown by bed rest studies. The enhanced insulin sensitivity achieved through exercise assists in maintaining healthy blood glucose concentrations by moving excess glucose out of the bloodstream. By preserving and/or increasing muscle mass, exercise also maintains a large storage area for glucose in the form of muscle glycogen. In addition to its role in lowering the risk of type 2 diabetes, exercising (and maintaining high levels of fitness) also benefits those afflicted with type 2 diabetes by reducing the risk of CVD and all-cause mortality.

Bone health

Bone is a dynamic tissue with high levels of metabolic activity. It acts as a support structure for the body as well as providing a reservoir for minerals, particularly calcium. The term bone health relates to the structure and density of bones.

Optimal bone health provides both strength and lightness so that moving the body around does not expend too much energy. The main determinant of bone strength is **bone mineral density (BMD)**, which increases during growth, reaching a peak at between 25 and 45 years of age and decreasing gradually thereafter. Peak bone mass is lower in biological females than biological males, and the decrease in bone mass with age accelerates sharply from the menopause to about 10% per decade, levelling off to about 3% per decade after the age of 75. Some lose as much as 30% of bone mass by the age of 70.

Sufficient calcium intake is critical to our health, and if we do not consume enough calcium, it is removed from its storage sites in the body, especially the bones. This weakens the bones and can lead to osteoporosis. Osteoporosis is a severe loss of bone mass with deterioration of the microarchitecture of bone, leading to increased risk of bone fracture, and is a common problem in older people, especially postmenopausal females. Genetic factors and poor nutrition and exercise habits contribute to the development of osteoporosis, while decreased oestrogen concentrations after menopause appear to be responsible for the greater rate of bone loss in females (Kenney et al., 2015).

Decreases in BMD lead to lower bone strength, making the bones more fragile and more likely to fracture. If BMD becomes too low this leads to the disorder osteoporosis (literally meaning “porous bones”). Osteoporotic fractures lead to disability, loss of independence and impairment of quality of life. They can also lead to the development of secondary complications as a result of long-term hospitalization. Those most at risk of developing osteoporosis are biological females, people over 60 years old and people with a family history of

Key point

Low bone mineral density can lead to **osteoporosis**, which leaves a person more vulnerable to fracturing bones. Those most at risk are older biological females.

osteoporosis. Other factors that increase the risk of osteoporosis include having a low BMI, a low calcium intake, cigarette smoking, experiencing early menopause and physical inactivity (although excessive exercise in those who limit their food intake and maintain a low body mass can increase the risk of osteoporosis—refer to chapter A.2.2 on RED-S).

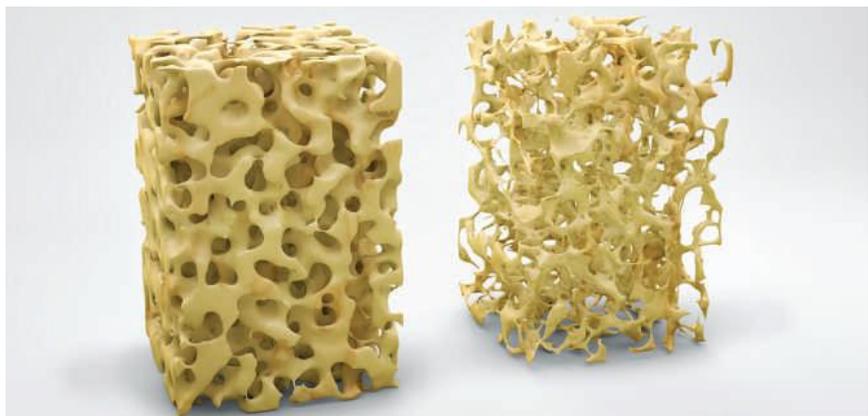
ATL Thinking skills

Osteoporosis statistics

- Osteoporosis is estimated to affect 500 million people worldwide, affecting approximately 21% of biological females over 50 years old and 6% of biological males over the same age range.
- 1 in 3 biological females over 50 will experience osteoporotic fractures, as will 1 in 5 biological males.
- By 2050, the worldwide incidence of hip fracture is projected to increase by 310% in biological males and 240% in biological females, compared with rates in 1990.
- It is estimated that the lifetime risk of experiencing an osteoporotic fracture requiring clinical attention is around 40%.

The WHO defines osteoporosis as when BMD is 2.5 standard deviations below the mean for a young adult. BMD is assessed by DXA and CT.

Osteopenia (low BMD but not reaching the threshold for diagnosis of osteoporosis) is diagnosed when BMD is between 1 and 2.5 standard deviations below the mean. Figure 10 shows healthy bone structure (left) and bone affected by osteoporosis (right).



▲ **Figure 10** Effects of osteoporosis

Weight-bearing physical activity is essential for bone health. Two main factors influence whether or not a person develops osteoporosis: their peak bone mass as a young adult and the rate of bone loss with ageing.

Exercise can influence both of these factors. Childhood is a crucial time for optimizing bone health through exercise. Some commentators have suggested that osteoporosis is a paediatric disease, implying that if bone mass is not optimized in childhood then osteoporosis is far more likely to occur in later life.

Aside from its role in increasing BMD early in life, weight-bearing exercise can also help to reduce the rate of bone loss from middle age onwards. Any weight-bearing exercise may be helpful but improvements in BMD are site specific (relating to the specific bones being stressed by exercise) and resistance training is more effective than endurance exercise.

Optimization of bone health in later life is particularly important for biological females. Biological females with a physically active lifestyle, including walking for exercise, have a lower risk of osteoporotic fracture of the hip than those who are sedentary. Moreover, many fractures are caused by falls, and exercise can decrease the risk of falling by improving balance, strength and possibly coordination.

Activity 4

Osteoporosis: a paediatric disease with geriatric consequences

Childhood and the early adult years are important for bone growth and strength. Puberty is especially important for building stronger and bigger bones. Bones increase in density and strength until around the age of 30, when we reach peak bone mass.

1. How could nutrition impact the growth and strength of bones in teenagers and young adults?
2. How might years of poor bone health as a young adult (below 30 years old) affect that person as an older adult (above 50 years old)? Consider particularly how their peak bone mass may be affected.
3. How might bone density be influenced by sex differences after the age of 30?

ATL Thinking skills

Road cyclists are at risk of poor bone health because:

- road cycling does not provide an osteogenic stimulus as it is non-load bearing/non-impact exercise
- a low body weight confers a performance advantage by providing a higher power-to-weight ratio (watts per kilo) that helps overcome gravity and propel the rider up inclines.

Vertebral fractures resulting from poor bone density may require surgery and substantial time away from training. In cyclists, the lumbar spine is most often affected by RED-S. The type of bone in lumbar vertebrae is particularly sensitive to hormones and nutrition.



▲ Figure 11

ATL Research skills

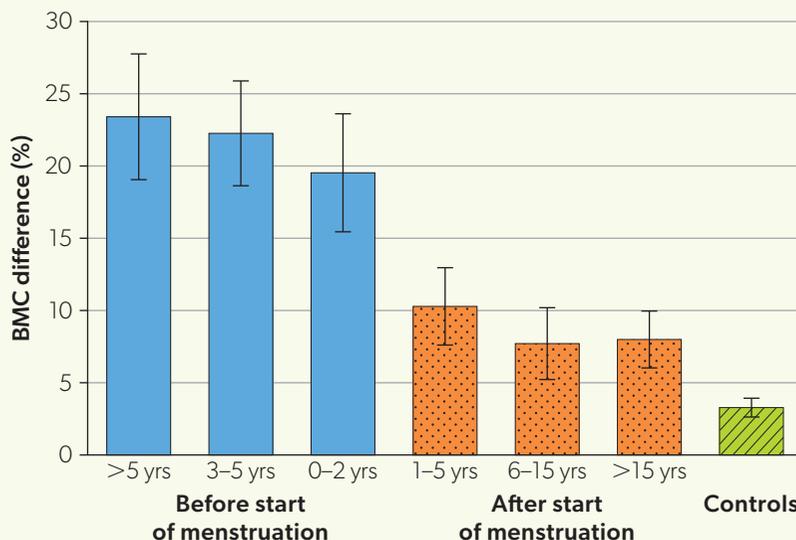
Bone mineral density (BMD) is associated with many factors, including heredity, ethnic group, geographic region, environment, nutrition and lifestyle. For example, one study of older biological females found that BMD values measured at the hip were 21%–31% higher among Tobago Afro-Caribbean participants and 13%–23% higher among African American participants than among US Caucasian participants. BMD values were 4%–5% lower among Hong Kong Chinese participants and 4%–7% lower among South Korean participants. The researchers concluded that differences in body weight partially explained the lower values for the Asian participants.

Find out what the typical BMD values are in your country.

Case study

Benefits for bone mineral content

Childhood and adolescence are key periods for the development of BMD. This is clearly demonstrated by a study of the differences in bone mineral content (BMC) between the playing and non-playing arms of biologically female tennis and squash players (mean age 28 years). The difference between arms was two to four times greater in players who started playing before or at the start of menstruation than in those who started playing more than 15 years after the start of menstruation. This suggests that physical activity before and around the time of puberty is particularly effective for increasing BMD.



▲ Figure 12

Exercise and mental health

So far this chapter has focused on the effects of exercise on physical health. However, there is also evidence to suggest that exercise benefits psychological well-being and mental health.

Much of this evidence comes from cross-sectional and observational studies, but some comes from intervention studies. A variety of aspects are associated with psychological well-being. Possibly the most frequently measured aspect is mood.

Mood refers to a set of feelings experienced on a day-to-day basis. Particular mood states may last for hours, days, weeks or even months. The term “mood” is distinct from the term “emotion” in that mood tends to be a longer-lasting state. Emotions are feelings generated in response to specific events and last for minutes or hours, but not longer. Mood states are generally positive or negative in nature. Examples of positive mood states are happiness and vigour while examples of negative mood states are anger, anxiety, depression and fatigue.

Studies suggest that regular exercise and physical activity:

- is associated with positive mood (enhanced feelings of happiness and energy, and decreased feelings of tension, fatigue and anger)
- enhances self-esteem (due to changes in self-perceptions)



▲ Figure 13 Studies suggest that regular exercise and physical activity is associated with positive mood

- enhances sleep quality (enabling people to fall asleep more quickly and to sleep more deeply and for longer)
- has positive effects on experiences of menstruation, pregnancy and menopause.

Such findings may apply both to healthy individuals and to those with disease and disability.

One key mood state linked to psychological well-being is depression. Here, a distinction may be drawn between:

- non-clinical depression (short-lived depression, of a few hours to a few days), and
- clinical depression (longer-term depression, lasting months or years, which interferes with personal and professional life, and may be considered a mental illness).

Clinical depression is a common disorder affecting about 121 million people globally. It is one of the leading causes of disability worldwide. High levels of physical activity are consistently related to lower levels of depression in population-based surveys, and meta-analyses of studies that have used exercise as a treatment for depression generally show a large **effect size**.

Less clear is the role of exercise in treating anxiety, defined as excessive worry over prolonged periods causing distress and interfering with everyday life. While exercise appears to have a small to moderate effect on reducing non-clinical (short-lived) levels of anxiety, there is insufficient evidence to make firm conclusions about the role of exercise in preventing and treating clinical anxiety disorders.

Depression is a common mental disorder that presents with depressed mood, loss of interest or pleasure, feelings of guilt or low self-worth, disturbed sleep or appetite, low energy, and poor concentration. These problems can become chronic or recurrent and lead to substantial impairments in an individual's ability to take care of his or her everyday responsibilities. At its worst, depression can lead to suicide, a tragic fatality associated with the loss of about 850 000 lives every year.

World Health Organization

How does exercise improve psychological well-being?

A variety of mechanisms have been proposed to explain how exercise enhances psychological well-being. These mechanisms may be broadly divided into physiological, biochemical/metabolic and psychological. No single theory explains the process fully, and the effects of exercise are likely to operate through interacting mechanisms.

The following possible mechanisms link physical activity to psychological well-being (Biddle, Mutrie, 2008).

- Changes associated with an increase in core body temperature during and after exercise—the thermogenic hypothesis.
- Increases in cerebral blood flow and oxygen supply to the brain as a consequence of frequent exercise.
- Increases in endorphin production during and after exercise—the endorphin hypothesis. Endorphins may be considered an endogenous (produced within the body) form of morphine; they function as neurotransmitters and are able to induce pain relief and feelings of well-being.

Key term

Effect size An objective and standardized measure of the magnitude of observed effect; we can compare effect sizes across different studies that have measured different variables, or have used different scales of measurement.

- Changes in central serotonergic systems from exercise—the serotonin hypothesis. Serotonin is a neurotransmitter that contributes to feelings of well-being and happiness. A deficiency in serotonin may be a contributing factor to anxiety and depression.
- Increases in the neurotransmitter norepinephrine, also known as noradrenaline. This may lead to a heightened sense of alertness and heightened vigour.
- A “feel better” effect from exercise. This may enhance body image and feelings of self-worth and self-esteem from mastering new tasks. This in turn may provide a sense of personal control and serve as a distraction from negative or stressful aspects of life. Exercise may also make people feel better due to the positive social interactions it can facilitate.

Prescription of exercise

Moving more and sitting less have benefits for everyone, regardless of age, sex, race, ethnicity or current fitness level. Physical inactivity, sedentary behaviour and low levels of fitness are all modifiable risk factors. Therefore, every individual should be encouraged to be physically active while limiting their time in sedentary activities to achieve optimal health benefits.

Appropriate progression of exercise intensity

When we exercise, our bodies need to adapt and get stronger over time. Just like when you are learning something new, you start with the basics and then slowly build up to more difficult things. As discussed in chapter A.3.1, the principles of specificity and progressive overload need to be taken into account.

If you suddenly do intense exercises without giving your body time to adjust, it can put a lot of stress on your muscles, bones and joints. Consider the example of playing video games. You start on the easiest level and as the game becomes more challenging you progress to higher levels. When you start exercising, it is important to begin at a comfortable level that matches your current fitness. As your body adapts to the exercises, you can gradually increase the intensity, just like moving up one level at a time in the video game. This allows your muscles, bones and joints to get stronger and gradually adapt to the demands of the exercises. If you jump ahead too quickly and increase the intensity too fast, it is like trying to beat a really tough level in the game before you are prepared to do so. It can lead to overuse injuries, strains or even fractures because your body is not prepared for that level of intensity. Therefore, listen to your body and do not push yourself too hard, too quickly. Slowly increasing the intensity of your exercises over time will help you stay healthy, strong, and avoid getting injured. Just like in a video game, the key is to level up gradually and enjoy the journey!

Recommendations for specific target groups

Current evidence suggests that individuals who remain active throughout childhood and adolescence significantly reduce the risk of developing obesity in young adulthood. Physical activity also protects against depressive symptoms across all ages. The current WHO physical activity guidelines for specific groups

are shown below. Further details can be found by searching online for *WHO guidelines on physical activity and sedentary behaviour*.

Children and adolescents aged 5–17 years

- Children and adolescents should do at least an average of 60 minutes per day of moderate-to-vigorous intensity, mostly aerobic, physical activity.
- Vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone, should be incorporated at least 3 days a week.
- Children and adolescents should limit the amount of time spent being sedentary, particularly the amount of recreational screen time.

Adults 18–64 years of age

- All adults should undertake regular physical activity.
- Adults should do at least 150–300 minutes of moderate-intensity aerobic physical activity, or at least 75–150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity throughout the week for substantial health benefits.
- Adults should also do muscle strengthening activities at moderate or greater intensity that involve all major muscle groups on two or more days a week, as these provide additional health benefits. Adults should limit the amount of time spent being sedentary.
- Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits.
- To help reduce the detrimental effects of high levels of sedentary behaviour on health, adults should aim to do more than the recommended levels of moderate- to vigorous-intensity physical activity.

Adults 65 years and older

- All older adults should undertake regular physical activity.
- Older adults should do at least 150–300 minutes of moderate-intensity aerobic physical activity, or at least 75–150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity during the week for major health benefits.
- For additional health benefits older adults should do muscle strengthening activities at moderate or greater intensity that involve all major muscle groups on two or more days a week.
- They may also increase moderate-intensity aerobic physical activity to more than 300 minutes, or do more than 150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity during the week.
- As part of their weekly physical activity, to enhance functional capacity and to prevent falls, older adults should do varied multicomponent physical activity that emphasizes functional balance and strength training at moderate or greater intensity on three or more days a week.
- Older adults should also limit the amount of time spent being sedentary.

Adults and older adults with chronic conditions (aged 18 years and older)

- Adults and older adults with chronic conditions (cancer, hypertension, type 2 diabetes and HIV) should do at least 150–300 minutes of moderate-intensity aerobic physical activity, or at least 75–150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity throughout the week for substantial health benefits.
- For additional health benefits, they should also do muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups on two or more days a week.
- To enhance functional capacity and to prevent falls, they should do varied multicomponent physical activity that emphasizes functional balance and strength training at moderate or greater intensity, on three or more days a week.
- When not contraindicated, adults and older adults with these chronic conditions may increase moderate-intensity aerobic physical activity to more than 300 minutes, or do more than 150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity throughout the week for additional health benefits.

Children and adolescents (aged 5–17 years) living with disability

- This age group living with disability should do at least an average of 60 minutes per day of moderate- to vigorous-intensity, mostly aerobic, physical activity, during the week, including at least three sessions per week of vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone.

Adults (aged 18 years and older) living with disability

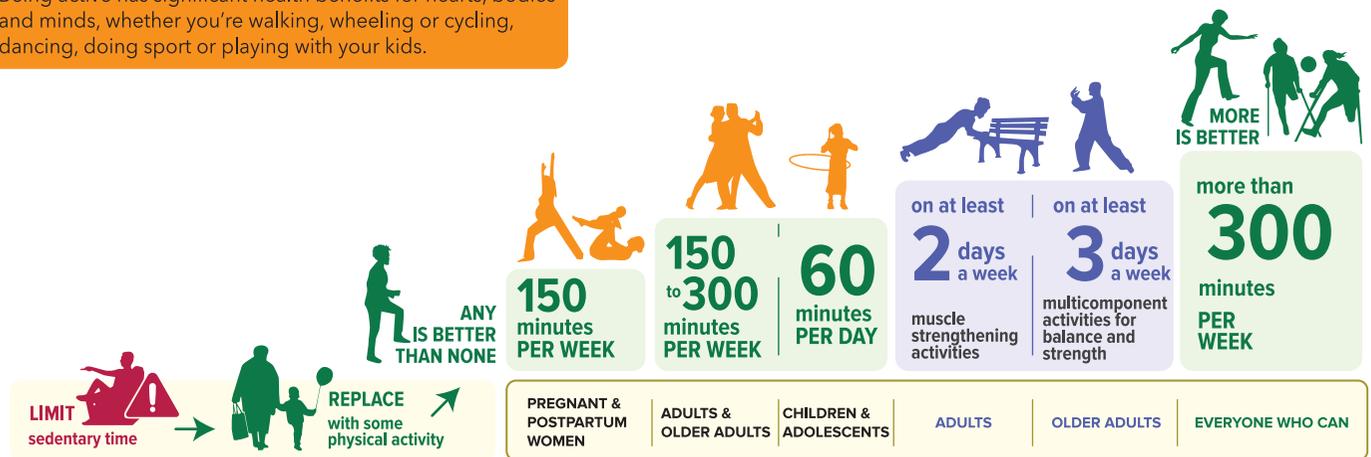
- Adults living with disability should do at least 150–300 minutes of moderate-intensity aerobic physical activity; or at least 75–150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity, during the week for major health benefits.
- For additional health benefits, adults living with disability should also do muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups, on two or more days a week.
- They may increase moderate-intensity aerobic physical activity to more than 300 minutes, or do more than 150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity activity throughout the week.
- To enhance functional capacity and to prevent falls, older adults should do varied multicomponent physical activity that emphasizes functional balance and strength training at moderate or greater intensity, on three or more days a week.

Exercising while pregnant

Pregnancy is a good time to start exercising because, for example, it is associated with an increased motivation to maintain or start a healthy lifestyle. Also, there is likely to be an increased frequency of medical appointments, which should contribute to safer exercise monitoring. It is important to highlight that before recommending an exercise programme, a thorough clinical evaluation should be conducted. Exercise can help prevent pregnancy-related disorders, such as excessive weight gain, anxiety and depression. Exercise in pregnancy is safe for both mother and fetus. Exercise type and intensity should be adapted to the

EVERY MOVE COUNTS

Being active has significant health benefits for hearts, bodies and minds, whether you're walking, wheeling or cycling, dancing, doing sport or playing with your kids.



▲ Figure 14 WHO guidelines on physical activity and sedentary behaviour. Source: World Health Organization

individual's previous fitness level, medical history and characteristics of the ongoing pregnancy. Quality of life is defined as a multidimensional concept that refers to an individual's negative or positive subjective assessment of life, including physical and mental health perceptions. Research suggests that exercise during pregnancy, such as group-based exercise, yoga, aerobic and resistance exercise, is associated with significant benefits related to improvements in quality of life.

ATL Research skills

Strategies for enhancing adherence to exercise may be broadly divided into one of four categories:

- environmental approaches—for example, prompts, contracts, provision of footpaths
- reinforcement approaches—for example, rewards and feedback
- goal-setting approaches—for example, a target race time or distance to cover
- social support approaches—for example, involving family and friends.

Find out more about each of these approaches and the advantages and disadvantages of each for enhancing long-term exercise adherence.

Activity 5

1. For which groups are activities that strengthen bone a part of the recommendations? Explain why.
2. For which groups is functional balance training a part of the recommendations? Explain why.

Recommendations for exercise during pregnancy and postpartum

It is recommended that during pregnancy and **postpartum** (following childbirth), all individuals who do not have any medical conditions or reasons that would prevent them from participating in a particular activity, should engage in regular physical activity. This should include at least 150 minutes of moderate-intensity aerobic physical activity per week for major health benefits. For additional health benefits, include a variety of aerobic and muscle-strengthening activities and gentle stretching. In addition, those who engaged regularly in vigorous-intensity aerobic activity before pregnancy, or who were physically active, can continue these activities during pregnancy and the postpartum period. Pregnant and postpartum individuals should limit the amount of time spent being sedentary.



▲ **Figure 15** Aerobic physical activity and muscle-strengthening activity are recommended during pregnancy and postpartum

Key point

Exercise helps us to maintain functional and mental capacities as we age and reduces the risk of disease in later life, preserving our independence.

Exercise for older people

A major risk factor for many of the disorders discussed thus far is age, and as people are living longer than ever before, the prevalence of many of these disorders could increase in the coming years. Exercise has an important role to play in minimizing age-related deterioration in functional capacities and therefore the risk of disease in later life.

The role of exercise in preserving bone mass has already been addressed—but exercise does far more than this. Regular exercise helps preserve maximum oxygen uptake, muscular strength, muscular endurance, flexibility, balance and possibly coordination.

Such benefits have been demonstrated even in adults in their 90s. The preservation of functional capacities is crucial for older adults so that they can maintain their independence. Tasks which young people take for granted can become a real challenge for older adults. These tasks include unscrewing the lids from jars, putting socks on, kneeling down to tie a shoelace, climbing in and out of a bath, climbing flights of stairs, getting out of an armchair, crossing the road in the time allotted at a pedestrian crossing, and stepping onto and off buses and trains.

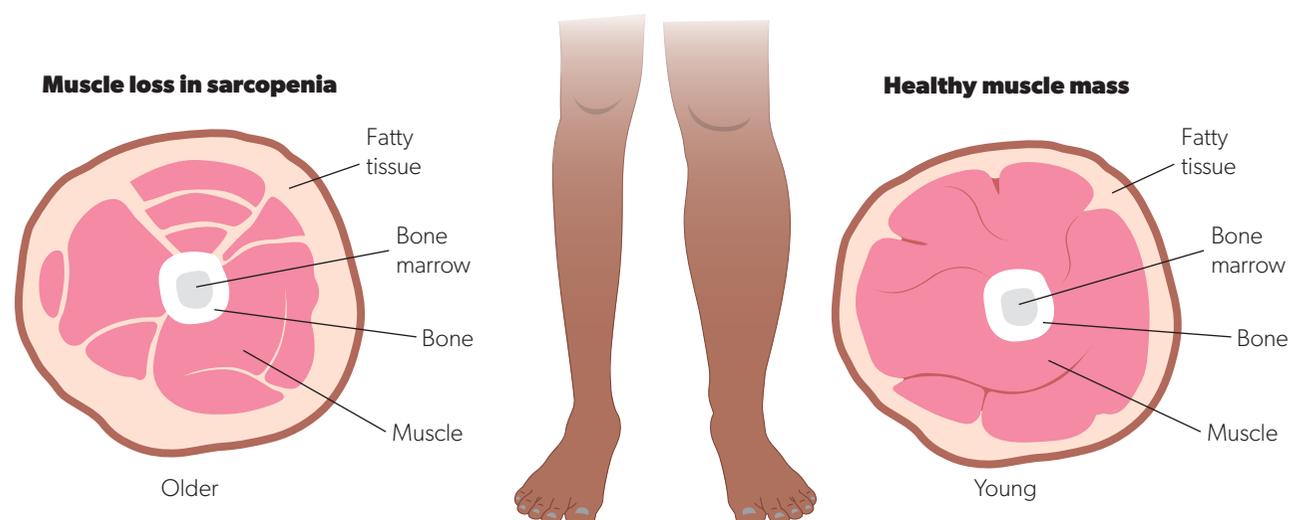
Regular exercise helps to preserve mobility, reduces the risk of disability and maintains the capacity to perform a large variety of tasks essential for independent living.

Recent research also shows that exercise plays an important role in helping to preserve mental function and reduce the risk of Alzheimer's disease and other forms of dementia. Several observational studies have shown that those who exercise more in middle and old age are less likely to experience cognitive impairment than their less active peers. Observational studies have also demonstrated a lower risk of dementia in active compared with inactive older adults.

Another, very recent, piece of research showed a link between physical activity levels and grey matter volume (grey matter is the region of the brain responsible for information processing and cognitive function). And a recent longitudinal training study showed that exercise can increase the size of the hippocampus and improve memory in older adults.

Exercise post-menopause

Menopause is the permanent cessation of menstruation and is defined as occurring 12 months after the final menstrual period, in most cases occurring naturally between the ages of 45 and 55 years. It is preceded by a 2- to 10-year period during which the ovaries gradually produce less oestrogen and progesterone, and menopause occurs when the ovaries stop releasing eggs. The decreases in oestrogen and progesterone levels are often associated with a variety of symptoms and conditions, such as hot flushes, which are experienced by most people during menopause. Musculoskeletal, metabolic and cardiovascular complications have also been reported after menopause. It has been estimated that up to 75% of individuals exhibit symptoms such as hot flushes and mood changes during menopause. A decline in muscle mass and strength, known as **sarcopenia**, often occurs along with the menopause and may be partly caused by the decrease in oestrogen that characterizes menopause. Low physical activity is another factor for sarcopenia.



▲ **Figure 16** Sarcopenia refers to the loss of muscle mass and strength that often accompanies the ageing process, possibly caused by the decrease in oestrogen in post-menopausal individuals

Menopause also starts a critical period of change in bone mass and strength. This can lead to osteopenia, and then osteoporosis, and increase susceptibility to fractures. Declines in BMD and bone loss over the menopause transition are well documented. These musculoskeletal complications post-menopause lead to higher incidences of falls and fractures and frailty. Menopause is often associated with changes in weight and body composition such as an increase in abdominal fat. The prevalence of metabolic syndrome also increases with menopause. Metabolic syndrome is a term that has been used to link coronary artery disease, high blood pressure, type 2 diabetes and upper-body obesity to insulin resistance and high levels of insulin in the blood.

While the menopausal transition is associated with decreases in muscle mass, habitual participation in exercise (such as moderate-to-vigorous-intensity aerobic exercise) can help maintain skeletal muscle mass. However, to increase, rather than just preserve muscle mass and strength, resistance training is recommended. Training programmes should consist of resistance and aerobic exercise to prevent sarcopenia, osteoporosis, metabolic syndrome, and maintain/improve quality of life (physical mobility, pain, sleep, energy, social isolation and emotional status).

There is evidence that active menopausal and post-menopausal individuals have higher health-related quality of life scores than their sedentary counterparts. Regular exercise, such as Nordic walking, can reduce total body fat, waist circumference and body mass index. Resistance exercise can increase hip and femur bone mineral density (as well as muscle mass and strength), reducing the risk of hip injuries and frailty post-menopause. Exercise can also improve mood, insomnia and depression. However, to date, there are few rigorous, well-controlled randomized clinical trials of exercise for menopausal symptoms and further study is needed.



▲ **Figure 17** A training programme consisting of both resistance and aerobic exercise is recommended during and after menopause



Activity 6

Find out if there are any specific physical activity guidelines for your country.



Linking question

How might exercise be part of a coping strategy for a pregnant or menopausal sportsperson? (C.4.2)

Consider:

- if exercise can help to manage some of the physical and emotional changes that occur during pregnancy, such as fatigue and weight gain
- if, during pregnancy, exercise can help improve sleep and reduce stress
- if exercise can help to manage some of the symptoms of menopause (such as mood swings)
- which exercises are age and fitness status appropriate
- safety considerations before starting an exercise programme
- which exercises to avoid during pregnancy.

Considerations to avoid injury risk

Although there are a variety of benefits to physical activity it is important to acknowledge and be aware of the potential hazards of exercise. These include the risk of accident and injury while exercising and playing sport, the risk of overtraining in those who perform excessive amounts of exercise, and the risk that exercise may trigger a heart attack.

Practice question

Discuss the impact of exercise on bone density.

(3 marks)

Summary

- An active lifestyle contributes to the maintenance of health.
- Modern-day life is characterized by low levels of physical activity, thus increasing the risk of hypokinetic disorders.
- Major hypokinetic disorders include CVD, obesity, type 2 diabetes and osteoporosis.
- Regular exercise can lower the risk of hypokinetic disorders although other factors also play a role in these disorders.
- Exercise lowers the risk of CVD through direct effects on the heart and circulation as well as through indirect effects on other CVD risk factors.
- Exercise increases the energy expenditure side of the energy balance equation and assists in preventing obesity.
- Exercise lowers the risk of type 2 diabetes by helping to maintain healthy body fat levels and by enhancing insulin sensitivity and glucose tolerance.
- Exercise contributes to the preservation of bone mass, reducing the risk of osteoporosis and bone fractures in later life, particularly in biological females.
- Exercise makes an important contribution to healthy ageing by preserving physical and mental function and, as a result, the ability to live independently and pursue life to the full.
- Exercise is important as a therapy for a variety of diseases and conditions.
- Exercise preserves psychological well-being by enhancing mood and helping to combat anxiety and depression.
- Every individual (children, adolescents, adults, older adults, pregnant and following childbirth, during and post-menopause, children and adults living with disability) should be encouraged to be physically active while limiting their time in sedentary activities to achieve optimal health.

AHL

Check your understanding

After reading this chapter, you should be able to:

- explain that an active lifestyle contributes to the maintenance of health
- evaluate the role of exercise for assisting in disease management
- identify the main forms of CVD
- examine the role of exercise in lowering the risk of CVD
- explain the energy balance equation and discuss the causes of obesity
- assess the role of exercise in preventing obesity
- explain the causes and consequences of type 2 diabetes
- examine the role of exercise in lowering the risk of type 2 diabetes
- discuss how physical activity can affect muscular and immune system function
- define the terms bone health and osteoporosis
- assess the effects of exercise on bone health
- examine the relationship between exercise and mental health
- discuss exercising during and after pregnancy
- discuss exercise for older and post-menopausal sportspeople.

AHL

Self-study questions

1. Identify and define three major forms of CVD.
2. Identify the major risk factors for CVD.
3. Explain the energy balance equation.
4. List the health risks of diabetes.
5. Explain how exercise reduces the risk of type 2 diabetes.
6. Explain the term "osteoporosis".
7. Discuss the role of exercise for bone health.
8. Explain the role of exercise in psychological well-being.
9. Explain the role of exercise in healthy ageing.
10. Give a brief summary of the WHO physical activity guidelines for health.
11. Which of the following are recommended by the WHO for pregnant individuals who do not have any medical conditions or reasons that would prevent them from participating in a particular activity?
 - A Do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week.
 - B Incorporate a variety of aerobic and muscle-strengthening activities.
 - C Limit the amount of time being sedentary.
12. Which of the following are potential effects of physical activity carried out by pregnant and postpartum individuals?
 - A Reduced chance of high blood pressure during pregnancy.
 - B Reduced chance of developing diabetes during pregnancy.
 - C Reduced chance of excessive weight gain during pregnancy.
 - D Reduced chance of delivery complications during or immediately after childbirth.
 - E Reduced chance of depression after childbirth.

AHL

AHL



Data-based questions

1. Below is a list of various activities and their associated MET values. For each activity calculate the oxygen consumption in litres per minute ($l \text{ min}^{-1}$) and energy expenditure in kilojoules per hour (kJ hr^{-1}) during 60 minutes of exercise for:
 - a. an individual weighing 70 kg (1 mark)
 - b. an individual weighing 90 kg. (1 mark)
2. Outline what you observe about the relationship between body mass, oxygen consumption and energy expenditure. (2 marks)
3. Identify **two** limitations of the MET system of classifying exercise intensity. (2 marks)

Activity	MET value
Basketball, competitive	8
Basketball, recreational	6
Mountain bike racing	16
Running at 19 km hr^{-1}	19
Soccer, competitive	10
Swimming, front crawl, vigorous effort	10
Walking at 6.4 km hr^{-1} on a level firm surface	5

A.3.3 Fatigue and recovery

Syllabus understandings

A.3.3.1 Fatigue can originate at different levels of the motor or energy pathway, possibly combining a variety of sources.

A.3.3.2 Recovery from exercise.

Introduction

Why do we fatigue during exercise? And how important is it that we can recover fully?

Common sensations we associate with fatigue include breathlessness, sore muscles, tired limbs and an overwhelming desire to stop and rest. There are many reasons why we fatigue during exercise and sport. Fatigue is a wide-ranging and complex topic.

Equally, recovery is important for optimal performance during sport and exercise—particularly to a high-performing athlete trying to reduce the effects of fatigue and enhance their performance.

Coaches and athletes know that adequate recovery is necessary to be able to compete or train again at an appropriate level. So it is important to know and understand how recovery interventions affect fatigue, muscle injury and performance.

This chapter will address why and how humans fatigue during sport and exercise, and look at some common recovery techniques used by athletes.



▲ Figure 1 An athlete suffering from fatigue

What is fatigue?

Human **fatigue** has been studied for more than a century. In that time there have been huge strides in technology and wider knowledge that have given us a clearer and deeper understanding of human physiology. The long history

of fatigue research and technological advances may lead you to assume that we have reached a clear, universally accepted definition of fatigue in sport. Unfortunately, this is not the case! If anything, the long history of research has increased the number of existing “definitions” of fatigue in sport (Table 1).

▼ **Table 1** Some of the definitions of fatigue in sport that have been used in the scientific literature

The moment when a participant is unable to maintain the required muscle contraction or performed workload.
Extreme tiredness after exertion; reduction in efficiency of a muscle, organ, etc. after prolonged activity.
The failure to maintain the required or expected force.
Fatigue produced by failure to generate output from the motor cortex.
A loss of maximal force-generating capacity.
A reversible state of force depression, including a lower rate of rise of force and a slower relaxation.
Any exercise-induced reduction in the ability of a muscle to generate force or power; it has peripheral and central causes.
Failure to continue working at a given intensity.
Any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained.
A progressive reduction in voluntary activation of muscle during exercise.

The presence of multiple definitions of fatigue in sport is one of the main challenges in understanding fatigue. If researchers are using different definitions of fatigue, it is more difficult to combine the research to get clear answers. Therefore, the scientific investigation of fatigue is muddled as there has not been a single definition on which to gauge and compare study results.

There are three main reasons why there are so many definitions of fatigue.

- Fatigue is a very broad term that applies to pretty much all forms of sport, exercise, occupational and leisure activities, and clinical and health contexts. Researchers in these fields have defined fatigue as it relates to their specific area of focus (this is termed “fragmentation of fatigue”), leading to multiple definitions.
- Fatigue can manifest via changes/impairments in any of the processes involved in muscle contraction, from the initiation of the motor command in the brain through to the actual contractile processes in muscle fibres. To try to narrow down the potential “locations” of fatigue in different contexts, a lot of research has isolated specific structures and processes in the chain of muscle contraction and studied their influence on fatigue. The problem here is that the body does not function in an isolated manner, so studying it in this way will give an incomplete, or even wrong, view of fatigue.
- There is a huge range of factors that can influence how fatigue manifests in a given situation. For example, exercise intensity, exercise duration, active muscle mass, type of exercise, training status, diet, muscle fibre type, presence/absence of competition, environmental conditions and health status all influence fatigue processes (and there are many more!). Moreover, many of these factors interact with one another.

Key point

Fatigue is a broad term that applies to many different contexts, can be influenced by changes/impairments in any of the processes involved in muscle contraction, and is influenced by a huge range of internal and external factors.

Key point

Fatigue and exhaustion are not the same thing. Fatigue is an inability to continue exercising at the same/desired intensity; exhaustion is a complete inability to continue exercising at all.

You may also come across situations where the terms “fatigue” and “exhaustion” are used as though they mean the same thing. They don’t! Take the example of a person trying to set a personal best time in a 10 km running race. To set a personal best they must maintain an average speed of 14 km h⁻¹. However, 7 km into the run they find they are no longer able to maintain that pace, but if they slow down to 13 km h⁻¹ they can continue running. This person is experiencing fatigue, but not exhaustion. Fatigue is an inability to continue exercising at the same/desired intensity, but an ability to continue at a lower intensity; exhaustion is a complete inability to continue exercising at all.

Traditionally, fatigue has been broadly categorized into two “types”: peripheral fatigue and central fatigue. These terms stem from the locations in which fatigue is thought to manifest.

- **Peripheral fatigue** is the term for fatigue caused by factors that reside outside of the central nervous system (CNS), distal to the neuromuscular junction.
- **Central fatigue** is the term for fatigue caused by factors that reside within the CNS (brain, spinal cord and motor neurons).

We have already discussed how it is not very appropriate to exclusively narrow fatigue processes down to specific regions of the chain of muscle contraction. Perhaps this in part explains why the ability of either peripheral or central fatigue to explain fatigue independently and consistently in all sport and exercise scenarios is highly questionable. It is likely that peripheral and central fatigue processes overlap and influence one another, as reflected in more recent recommendations from fatigue researchers that we re-conceptualize fatigue, moving away from “peripheral” and “central” to viewing fatigue in a more holistic sense.

The “new” view of fatigue takes the position that fragmentation of fatigue research has led to the absence of a universal fatigue definition, which has subsequently limited our ability to understand fatigue more effectively in sport. Within the new view, fatigue is no longer modified by adjectives such as “peripheral” or “central”. Instead, fatigue is defined as:

a disabling symptom in which physical and cognitive function is limited by interactions between performance fatiguability and perceived fatiguability

(Enoka, Duchateau, 2016)

The word “symptom” is an interesting one. If you look in a dictionary, you will find “symptom” defined as “any feeling of illness or physical or mental change that is caused by a particular disease”. Fatigue certainly causes physical and/or mental changes, but what about the word “disease”? Do you think that either sport or exercise is a disease? At first glance, your answer would surely be “no”. However, if you look up “disease” in a dictionary you find: “A disorder of...function...especially one that produces specific symptoms...and is not simply a direct result of physical injury”. Sport and exercise can cause disordered function (if only temporarily), and this disordered function produces symptoms (such as muscle soreness, elevated body temperature, hyperventilation and reduced motivation). Finally, the disordered function and symptoms associated with fatigue do not have to be due to physical injury. So, it seems that exercise can be thought of as a disease, or perhaps more specifically a process that (in a positive way) places the body in a state of dis-ease (not at ease; a disruption to homeostasis). While this definition of fatigue as a symptom has not yet become the sole definition used in research investigating fatigue in sport, it is the closest the field has come to a unified definition and may be an important step towards making the fatigue literature more coherent.

The causes of fatigue in sport are many and remain highly debated, meaning that a conclusive summary is not possible. However, the following sections provide an overview of some of the commonly cited potential causes of fatigue in sport.

TOK

When we research fatigue, we need a sound theoretical framework of fatigue on which to base that research. This means that we should be able to define what we mean by fatigue in a way that makes sense to others, and have sound, objective rationales for all the protocols we use and the measurements we make. However, this has not always been the case in fatigue research; in fact, researchers are still debating the best way to frame what fatigue is.

Is this debate on the framework of fatigue necessary? Is it helping the area to move forwards, or holding it back? Do you see clear differences in the frameworks of fatigue proposed by different researchers, or are these frameworks largely the same, but just explained in a different way?

Imbalance in pH and fatigue

Metabolic acidosis is a reduction in the normal pH of a fluid or tissue caused by the production of acidic substances. Metabolic acidosis is probably one of the most controversial potential causes of fatigue in sport.

Does human energy metabolism produce lactate or lactic acid?

Research from way back in the 1900s suggests that lactic acid is produced in human skeletal muscles during exercise. The accumulation of lactic acid reduces intramuscular pH and causes fatigue.

If lactic acid is produced in energy metabolism, it could make its environment more acidic by releasing a hydrogen ion (H^+ , also known as a proton) into the environment. A H^+ ion is a hydrogen atom that has donated its single electron. The structure of a hydrogen atom is a nucleus containing a single proton, and a single electron “spinning” around that nucleus. If the hydrogen atom loses its electron, all that remains is a single proton. That is why H^+ ions are also referred to as protons. The plus sign in H^+ means that the ion is now positively charged (a cation). Hydrogen ions are acidic (an acid is any substance that donates protons), and therefore make the solution they are placed in (water, blood or intracellular fluid) more acidic.

Two main hypotheses were posed for how lactic acid production may cause fatigue. Firstly, reduced muscle pH may impair muscle contraction via a decline in muscle force production and contraction velocity. Intramuscular acidosis was thought to do this by reducing sarcoplasmic reticulum (SR) calcium (Ca^{2+}) release and Ca^{2+} sensitivity. Secondly, intramuscular acidosis could cause fatigue by inhibiting some of the key steps of glycolysis. The problem with these hypotheses is that as our ability to study energy metabolism has improved, it has become clear that we do not actually produce lactic acid in energy metabolism; we produce **lactate**.

Why is the distinction between lactate and lactic acid important?

As already mentioned, lactic acid has the potential to make its environment more acidic. However, lactate does not have a proton to release, therefore it does not make its environment acidic (refer to ATL box for more information).

Key point

Fatigue has recently been defined as a symptom of the dis-ease associated with sport and exercise. This more global, unified definition has the potential to make fatigue research more coherent.

Key term

Fatigue A disabling symptom in which physical and cognitive function is limited by interactions between performance fatiguability and perceived fatiguability.

Key point

The human body produces lactate (not lactic acid) in energy metabolism.

Lactate is constantly produced in energy metabolism, even when we are at rest, and is produced in higher concentrations when we exercise at a high intensity. However, this is a good thing, for at least two reasons.

Firstly, lactate production can actually reduce acidosis within skeletal muscle, potentially enhancing or at least maintaining function and improving sport performance. The traditional interpretation that lactate accumulation is the cause of fatigue is incorrect, and a classic example of mistaking correlation for causation. Larger amounts of lactate are detected during periods of high-intensity work when some performance decrement may also be seen; however, lactate production is high due to its role in buffering, or consuming, H^+ (which is produced in higher amounts with increasing exercise intensity) and is not itself directly impairing performance.

Key point

Rather than being performance limiting, lactate production confers many benefits to sports performance.

Secondly, lactate is actually an important fuel source during and after sport (approximately 75% of all lactate produced is used as muscle fuel). There is no convincing evidence that lactate directly contributes to uncomfortable muscular sensations typically felt during/after sport (soreness, burning etc.), or to performance decrement. The recent literature places the contribution of lactate to performance decrement at no more than about 5%. So, if lactate is not the source of increased acidosis and fatigue in sport, what is?

ATL Thinking skills

We produce lactate in energy metabolism, not lactic acid. This distinction is crucial for understanding fatigue. Table 2 outlines some misconceptions, to give you an insight into why the difference between lactate and lactic acid is so important.

▼ Table 2 Misconceptions about lactate and lactic acid

Misconception	Counterview
✗ Lactic acid and lactate are the same substance.	✓ Lactic acid contains a H^+ ion that can split from lactic acid and increase acidity of the surrounding tissue/fluid. Lactate does not contain a H^+ ion that can dissociate; therefore, it does not directly make its environment more acidic.
✗ Lactic acid is produced during sport.	✓ Hardly any lactic acid is present in the body. During sport, two separate ions are produced: lactate and H^+ .
✗ Lactate is the cause of muscle burn and muscle fatigue, as well as the muscle soreness sometimes felt in the hours or days following sport.	<p>✓ There is no evidence for lactate contributing to the burning sensation sometimes experienced during sport. Lactate actually extends sport performance via its roles as a H^+ buffer and metabolic fuel.</p> <p>✓ Lactate produced during sport is metabolized within the first hour of recovery. Therefore, it cannot contribute to muscle soreness several hours or days following sport.</p>
✗ Lactate is a waste product.	✓ Lactate is a H^+ buffer and important source of fuel during sport across a range of intensities and durations.

While the body does not produce lactic acid, it does produce lactate and H^+ . While we know that H^+ is produced in the body, there is still a lot of debate as to exactly how and where H^+ production takes place. As previously discussed, production and particularly accumulation of H^+ will make body tissues more acidic, which may pose a problem in terms of fatigue.

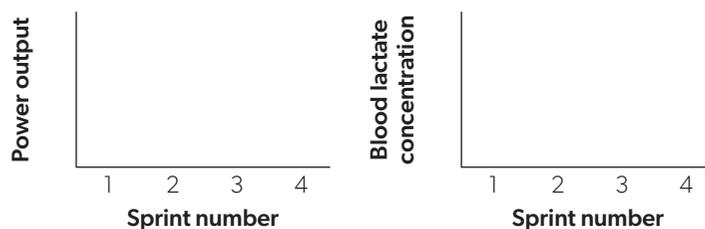
Activity 1

The two athletes in Figure 2 completed four, 30-second sprints against a high resistance on a cycle ergometer. Each sprint was separated by 3 minutes of light cycling. The average power for each 30-second sprint, and the blood lactate concentration at the end of each sprint, were measured.



▲ Figure 2

1. Copy the two sets of axes (Figure 3). Sketch two lines on each set of axes (one for each athlete) to show how you would expect the power output and blood lactate concentrations for each sprint to look.



▲ Figure 3

2. Briefly explain why you sketched the graphs the way you did. Focus particularly on any differences in how the power output and blood lactate concentration change across the sprints between the two athletes.

Availability of calcium and fatigue

The release of calcium ions (Ca^{2+}) inside muscle cells is critical for optimal muscle contraction. Any disruption in Ca^{2+} release and the subsequent functional roles of Ca^{2+} will impair muscle contraction. However, recent research suggests that intramuscular acidity has less of an impact on intramuscular Ca^{2+} than previously thought. In combination with other metabolites produced during sport, particularly of a high-intensity nature, H^+ accumulation may impair Ca^{2+} function by reducing the Ca^{2+} sensitivity of the contractile filaments actin and myosin. This would mean that more Ca^{2+} would be required to activate the myofilaments and allow optimal muscle contraction.

Key point

Availability of calcium ions is critical for optimal muscle contraction. However, acidosis seems to have less of an impact on calcium function than previously thought.

Activity 2

We tend to focus on an athlete's training or competition demands when we think about what may cause fatigue. However, there are many outside factors that could contribute to an athlete's experience of fatigue when they train or compete.

Can you think of any?



▲ **Figure 4** Many outside factors can contribute to an athlete's experience of fatigue

Sodium and potassium

Sodium (Na) and potassium (K) are electrolytes, meaning that they carry small electrical charges that enable electricity to be conducted through the solution in which they are placed. The ionic forms of Na and K are abbreviated as Na^+ and K^+ . The + sign indicates a positively charged ion, known as a cation. Most Na^+ stores are found in the blood and the fluid around cells. Most K^+ stores are within the nervous system, skeletal muscle and bone with a small amount in blood plasma. Sodium and K^+ have independent roles that, when not functioning optimally, may contribute to fatigue. However, mostly they work closely together to accomplish processes that, when impaired, may also cause fatigue.

Na^+ and K^+ both help to regulate total body water content and fluid movement into and out of cells and tissues. Both electrolytes can move into and out of some cells, and the relative concentration of them across a membrane will cause water to move via osmosis from the side with the lower electrolyte concentration to the side with the higher electrolyte concentration. Disruption in the availability of Na^+ and K^+ could, therefore, impair water balance across cells. This is most commonly seen via the loss of Na^+ , resulting in suboptimal plasma Na^+ concentration, called hyponatremia, which was covered in chapter A.2.1.

There are multiple causes of hyponatremia, including:

- high sweat Na^+ concentration (particularly when coupled with high sweat rates during intense or prolonged exercise, which is exacerbated if it takes place in high ambient temperature and/or humidity)
- hormonal dysfunction that affects body Na^+ maintenance
- use of medications that affect body Na^+ handling.

However, the greatest risk factor for hyponatremia is an excessive increase in body water content.

Increases in body water content can occur due to protein breakdown, the role of specific hormones such as vasopressin and impairments in renal function. However, the most important driver of excessive body water content in healthy people taking part in sport and exercise is excessive fluid intake, particularly the excessive intake of hypotonic fluids such as water. Excessive intake of such fluids essentially dilutes Na^+ concentration, leading to hyponatremia. The extent of hyponatremia can be exacerbated if excessive fluid intake is coupled with high rates of Na^+ loss in sweat.

Hyponatremia occurs in up to 51% of athletes participating in endurance sport and exercise events, as well as rowers, open-water swimmers and rugby players. Symptoms can range from weakness, dizziness, headache and vomiting to brain and lung swelling (due to fluid accumulation), seizures and death. So, while hyponatremia can contribute to impaired sport and exercise performance, it can have much more serious consequences. Dehydration is often considered in sport and exercise—but issues associated with over-drinking must also be taken seriously.

Na^+ and K^+ also propagate the electrical signal (or action potential) along a motor neuron and into a muscle, which is an indispensable part of the muscle contraction process.

Briefly, this works as follows.

- When a muscle is resting, the inside of the cell has a slightly negative electrical charge compared with the outside because of the relative concentration of Na^+ and K^+ outside and inside the cell.
- Initial electrical stimulation of a motor neuron makes the nerve cell membrane permeable to Na^+ , meaning that Na^+ will rush into the cell and make the interior of the cell positively charged.
- This response enables the action potential to continue moving along the motor neuron.
- Almost immediately, Na^+ channels close and K^+ channels then open, meaning K^+ quickly leaves the cell and makes the intracellular charge negative again.
- This process only takes a few milliseconds, occurs during every action potential, and occurs all the way along a motor neuron and skeletal muscle membrane.

The important role that Na^+ and K^+ play in the conduction of action potentials means that any alteration to their function may significantly impair the contractile ability of skeletal muscles.

We have already discussed how dilution and/or loss of Na^+ may impair performance and health. There is now good evidence to show that dynamic sport and exercise causes rapid increases in K^+ accumulation outside of the muscle cells, particularly in the muscle interstitial space (the space between the muscle cell membrane and the surrounding connective and other tissues). The increased extracellular concentration of K^+ of course means that the intracellular concentration of K^+ will reduce, which alters the transmembrane concentration gradient of K^+ . The accumulation of extracellular K^+ is greater when muscle contractions are more intense. Once exercise stops, extracellular K^+ concentration will fall rapidly.

Key point

An abnormally low plasma Na^+ concentration is termed hyponatremia. The occurrence of hyponatremia can cause symptoms ranging from muscle weakness and vomiting to brain swelling and death.

Key point

Repeated muscle contractions can lead to a loss of K^+ from the muscle cell. Accumulation of this K^+ outside the cell can make the cell less excitable and therefore reduce whole muscle force production.

Some accumulation of K^+ in the interstitial space around muscle fibres is a good thing, as it is one of the biochemical “signals” that the body uses to regulate blood flow, ventilation and neuromuscular function in line with the demands being placed on the muscles. However, a problem can arise if too much extracellular K^+ accumulates. In this situation, the accumulation can change the balance of the electrical charge across the muscle membrane to a more inhibitory charge and interfere with the movement of Na^+ across the membrane, which together will reduce the excitability of the muscle cell. A consequence of this shift in excitability is that greater neural drive is required to generate an action potential. In extreme cases, the muscle fibres may not be electrically excitable at all, and fewer excitable muscle fibres will equate to a reduced force production capacity of the whole muscle.

Extracellular K^+ accumulation may also contribute to fatigue by stimulating specialized sensory nerves that sit in and around the muscle fibres and respond to changes in concentration of biochemical substances. Stimulation of these nerves can contribute to the sensation of muscle discomfort we feel during sport and exercise (particularly when it is intense and/or prolonged), and may contribute to increases in central fatigue.

Key point

Extracellular K^+ accumulation may also stimulate special sensory nerves that contribute to the sensation of muscle discomfort and to central fatigue.

While the body has some mechanisms it can employ to help reduce extracellular K^+ accumulation and the impact of this accumulation, the available evidence now indicates that during intense and/or prolonged sport and exercise, extracellular K^+ accumulation may be an important contributor to fatigue.

Lack of hydration, hyperthermia and fatigue

As we saw in chapter A.2.1, hydration status influences the body’s ability to perform. In chapter A.1.2 we studied hyperthermia. Both lack of hydration and hyperthermia are linked to fatigue, and they also have an interactive effect.

The “classic” mechanism of dehydration-induced fatigue

The most cited mechanism of dehydration-induced fatigue in sport is as follows (and is summarized in Figure 5).

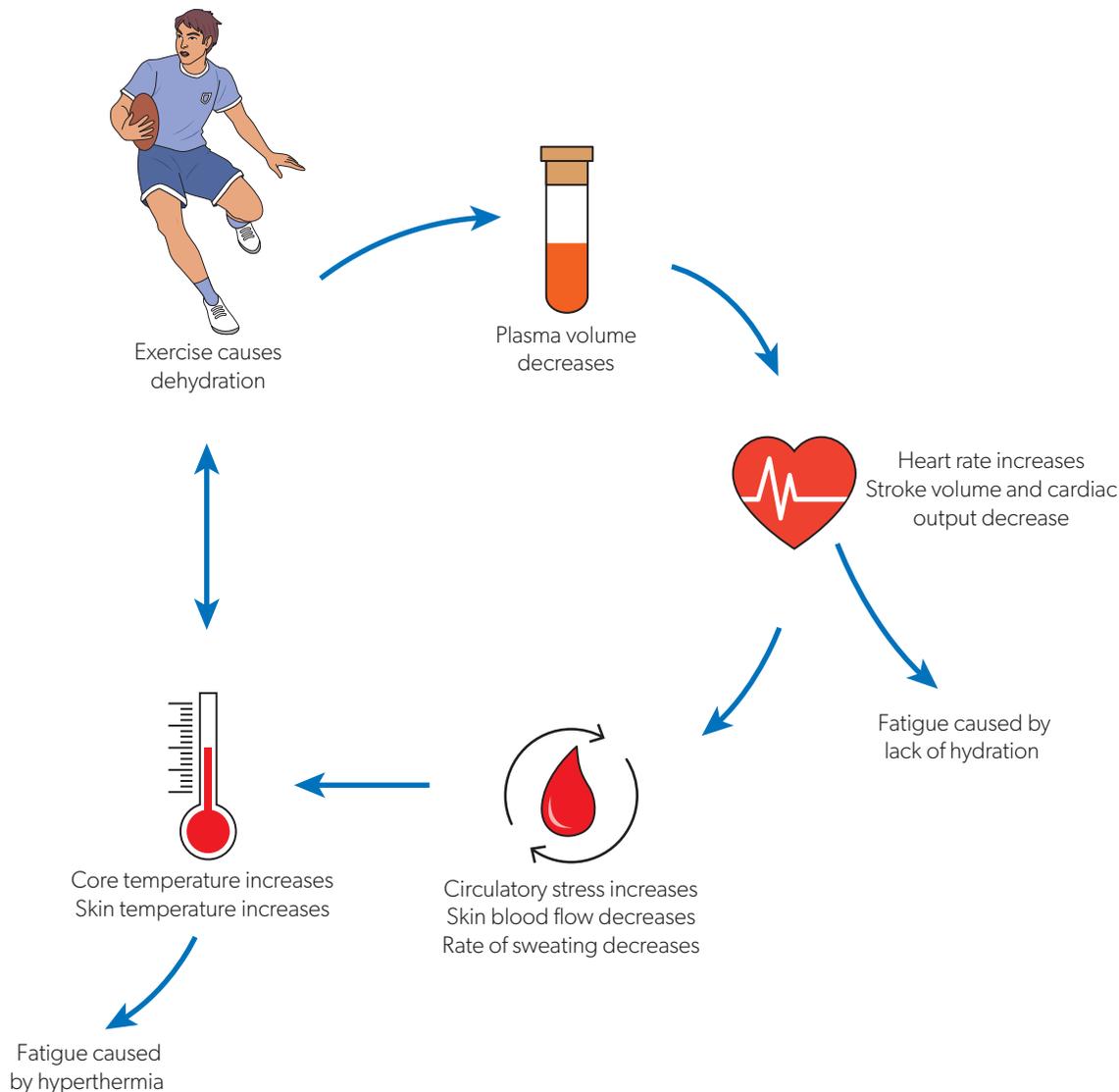
- Increased sweat rate during sport causes a loss of fluid from blood plasma, reducing plasma volume.
- Reduced plasma volume causes less blood to enter the chambers of the heart prior to each heartbeat (termed reduced cardiac filling pressure).
- Reduced cardiac filling pressure contributes to reduced stroke volume (the volume of blood pumped from the heart per beat) and cardiac output (the volume of blood pumped from the heart per minute).
- Heart rate must increase to maintain blood and oxygen delivery to working tissue.

These cardiovascular changes may directly impair performance. However, reduced plasma volume can also lead to competition for blood flow between organs/tissues and the skin (termed circulatory stress). This competition can reduce skin blood flow, impairing evaporative heat loss and leading to an increase in core body temperature (hyperthermia). Therefore, dehydration may impair performance directly through impaired cardiac efficiency, and indirectly by contributing to hyperthermia.

Body water loss during exercise decreases plasma volume, leading to reduced cardiac filling pressure, stroke volume and cardiac output. This impaired cardiac efficiency means that heart rate must increase to maintain appropriate blood and

Key point

Lack of hydration could cause performance impairment by reducing cardiac efficiency, contributing to increased core temperature, increasing the rate of glycogen breakdown or impairing perceptual responses.



▲ **Figure 5** The “classic” mechanism of impaired sport performance with dehydration, including interaction with hyperthermia

oxygen delivery to working tissue. Elevated heart rate could lead to impaired exercise performance. However, if water loss and exercise continue, reduced plasma volume may lead to circulatory stress, which can reduce skin blood flow, impairing evaporative heat loss and increasing core body temperature.

Other mechanisms of dehydration-induced fatigue

Dehydration can increase liver glucose production and muscle glycogen breakdown, possibly due to increased core temperature, which can alter metabolic enzyme activity and mitochondrial function. This link with increased core temperature indicates that dehydration without hyperthermia may not influence exercise metabolism. Greater reliance on carbohydrate oxidation could contribute to fatigue via glycogen depletion.

Perceived exertion may increase, and cognitive function (vision, attention, memory etc.) decrease, during sport when hypohydrated. These changes could contribute to decreased performance by altering factors such as motivation, decision-making and pacing strategies.

Experiments

There are several issues with a lot of hydration research that could have exaggerated the negative effect of dehydration on sport performance. More recent findings indicate that the impact of (non-extreme) dehydration on performance is less than previously thought.

A long-standing principle in sport and exercise science research is that fluid losses $\geq 2\%$ of a person's body mass will impair sport performance, particularly endurance sport performance.

However, there are problems with the hydration research that established the 2% "threshold" for performance decline. These issues are summarized in Table 3. These

problems can significantly affect the research results.

Recent investigations have shown that dehydration does not negatively impact exercise performance lasting from 60 minutes to over 4 hours, regardless of whether the environment is normal or warm, even when participants lose 2%–3% of their body weight. One possible explanation for this discrepancy is that recent research used self-paced, real-world exercise models. These studies were conducted in natural exercise settings or were well-replicated in a laboratory. Self-paced activity allows individuals to regulate their performance, making it more suitable for testing the effects of factors such as dehydration on performance.

▼ **Table 3** Issues with some research into hydration and sport performance, and the impact of these issues on the research findings

The issue	The impact on research findings
Creating a hypohydrated state by placing people in saunas with no fluid intake, using diuretic medications or completing an exercise task in a hot environment prior to the exercise of interest.	Participants would begin exercise in a hypohydrated state, rather than becoming hypohydrated during exercise. Using such strategies may impair exercise performance independent of changes in hydration status.
Research participants are aware that their body fluid balance is being manipulated.	Participants may believe the researchers are expecting a poorer performance when hypohydrated (or a better performance when hydrated), and so, perhaps subconsciously, performance is affected in line with these anticipated beliefs.
Research participants are from different populations than those to which the research findings are applied.	If research is conducted in non-athletes there is no guarantee that the findings will apply to athletes, as athletes differ in many ways (physiologically and psychologically) from one another, and from non-athletes.
Use of fixed-intensity and/or exercise to exhaustion protocols.	Not representative of most real-world sport and exercise scenarios, which are usually self-paced with a goal of completing a set distance in the fastest time or managing physiological/psychological resources dynamically to achieve optimal performance over the event duration.
Use of body mass changes as a measure of changes in hydration status.	Changes in body mass pre- to post-exercise do not accurately reflect body water loss.

Body mass loss can occur during sport without the onset of hypohydration. This suggests that it may not be necessary to consume fluid to prevent body mass loss, or even limit it to 2% of body mass. Body mass loss without hypohydration could even be beneficial for performance as the athlete would have to transport less mass and expend less effort and energy.

However, we should not recommend that all athletes aim to lose body mass during sport—the potential benefit of body mass loss may only apply to certain people. As with almost all physiological processes, there are inter-individual responses that must be considered. Perhaps this is why allowing an athlete to drink to their own perceived needs (termed a "drink to thirst" strategy) is gaining popularity.

Hyperthermia and fatigue

As covered in chapter A.1.2, hyperthermia is an abnormally high core body temperature. There are different severities of hyperthermia, depending on the core temperature reached.

Hyperthermia can occur when the body generates more heat than it can dissipate, primarily through sweating. This happens when muscle activity, radiation and convection (if the air temperature is higher than the skin temperature) contribute to increased heat production, surpassing the body's ability to cool down.

A classic cause of hyperthermia during sport is shown in Figure 5. Briefly:

- Exercise can reduce plasma volume, leading to increased cardiac and circulatory stress via competition for blood flow between core organs and tissues, and the skin.
- This competition can reduce skin blood flow, impairing the ability to lose heat via evaporation and leading to increased core temperature.

Hyperthermia is most common in situations where dissipation of body heat is impaired, such as exercise in the heat and/or humidity, with:

- insufficient air flow
- excessive clothing
- insufficient shade
- a combination of these factors.

Exercise in the heat leads to warmer skin temperatures. This is actually beneficial for facilitating evaporative heat loss and can help convective heat loss by widening the temperature difference between the skin and the ambient air (although this will depend on the temperature of the ambient air). However, warmer skin temperature reduces the temperature difference between the body core and skin, making it more difficult to transfer heat from the core to the skin via conduction and convection. If the ambient air is also humid, evaporative heat loss is greatly impaired because sweat cannot easily vaporize into the air due to the high ambient moisture levels. Therefore, exercise in hot and humid conditions significantly impairs all body heat loss avenues, increasing the likelihood of body heat gain.

How else might hyperthermia contribute to fatigue?

During intense sport in the heat, high blood demand by the working muscle and skin means that the heart may not be able to maintain the required cardiac output. This would particularly be the case if the athlete was hypohydrated, as in this situation cardiac output may already be reduced. So, impaired cardiovascular function is a possible cause of fatigue during sport in the heat.

During prolonged sport in the heat, blood flow to the working muscle is reduced (again, this is exacerbated if the athlete is also hypohydrated). To counteract reduced blood flow, the muscle will extract more oxygen from the blood to retain appropriate oxygen uptake. Reduced muscle blood flow is accompanied by increased muscle glycogen use, and this has been implicated as a possible cause of impaired performance in the heat. However, in most cases of voluntary exercise termination in the heat muscle glycogen stores are adequate,

Key point

Hyperthermia can develop whenever body heat production exceeds body heat loss and is most common in situations where dissipation of body heat is impaired.

suggesting that glycogen depletion is not a common cause of fatigue during sport in the heat.

It is important to note that becoming hyperthermic during sport does not appear to impair the ability of muscles to produce force. However, it is common to see reduced force production/reductions in exercise intensity when hyperthermic. Why is this?

If the ability of the muscles themselves to produce force is not impaired by hyperthermia, then central factors may play a role. When we take part in endurance sport with an elevated core temperature, the metabolic rate of the brain increases but overall brain blood flow and the electrical activity of the brain decrease. These changes have been linked to increases in perceived exertion and reduced power output/speed. Essentially, the athlete finds it harder to maintain intensity and begins to slow down.

During sport in the heat the temperature of blood in the jugular vein (which moves blood from the head to the heart) drops slightly, which implies that the brain is storing heat. Brain temperature is a potentially crucial factor in hyperthermia-related fatigue, as research in animals shows that increasing brain temperature without increasing core temperature impairs the ability and willingness to continue exercising. However, it is difficult to confirm that increased brain temperature has the same effect in humans because we are not able to effectively cool or warm a human brain without also altering core temperature.

Key point

Hyperthermia can impair cardiovascular function, increase muscle glycogen use and increase brain temperature.

Theories

High core temperature or high skin temperature?

Several previous research studies of different people undertaking different forms of exercise in the heat reported that people voluntarily stopped exercise at a very similar core temperature of approximately 40°C.

Attainment of this core temperature was linked to reduced motor drive from the CNS. Taken together, it was suggested that reaching a “critical” core temperature of about 40°C acts as a “safety brake” to prevent the development of health-damaging hyperthermia, or perhaps is the threshold for progressive reductions in performance.

As a result of this research, attainment of a “critical core temperature” has become the most common explanation for impaired sport performance in the heat. However, a core temperature of 40°C is not high enough to cause cellular damage. Also, our CNS can tolerate temperatures of more than 41°C for several hours without damage.

So, why would the body deem 40°C to be a “critical” core temperature?

Furthermore, there is research evidence that endurance sport performance can be maintained with core temperatures higher than 40°C (although this is certainly not the case for everyone).

An important issue with much of the research supporting the critical core temperature hypothesis is that, when researchers raise core temperature during exercise, they also raise skin temperature. Elevated skin temperature can negatively affect sport performance, even if core temperature remains unchanged. This could be due to increased skin blood flow and added strain on the cardiovascular system, as well as a reduced temperature difference between the core and skin, making it harder to release heat to the environment.

If high skin temperature can aggravate cardiovascular strain, it suggests that high skin temperature could exacerbate the negative consequences of hypohydration on sport performance. Overall, athletes performing in the heat, where both hyperthermia and hypohydration are possible, could be susceptible to fatigue associated with high skin temperature.

You should now understand that the causes of fatigue in the heat go far beyond elevated core temperature. In fact, it may have a lot less to do with core temperature than previously thought. We need to consider core temperature, skin temperature, brain blood flow and electrical activity, and brain temperature, as well as the interaction of all these factors. The difficulty in measuring some of these factors in humans, particularly those related to the brain, means that the specific causes of fatigue in the heat are unknown and may remain so for some time.

Key point

The specific causes of fatigue in the heat are still being understood.

Case study

A case of fatigue

On 18 September 2016 Jonathan Brownlee, multiple World triathlon champion and Olympic medallist, was leading the final race of the World Triathlon Series in Cozumel, Mexico. The event—a 1,500 m swim, 40 km road cycle and 10 km road run—was something he had done many times before. However, a few metres from the finish line, Jonathan became extremely disoriented and unsteady on his legs. He stopped running and began staggering to the point that he had to be prevented from collapsing by a race marshal. The only way he was able to cross the finish line was by his fellow competitor and brother, Alistair, essentially carrying him. Jonathan was taken to hospital with symptoms of heat exhaustion. Happily, he made a full recovery. The weather in Cozumel on the day of the race was approximately 30°C with relative humidity of approximately 76%.

1. What do you think may have been the cause(s) of Jonathan's fatigue during the race?
2. What could Jonathan have done differently before and during the race to avoid such excessive fatigue and, ultimately, exhaustion?



▲ **Figure 6** Jonathan Brownlee suffers from fatigue during the World Triathlon Series in Cozumel, Mexico

Insufficient fuel availability and fatigue

Adenosine triphosphate (ATP) is the most important source of chemical energy in the body. ATP has three components: adenine, ribose and three phosphates. High-energy bonds attach the three phosphate molecules to each other. The energy in these bonds is released when ATP is broken down in a hydrolysis reaction, and this energy is used by the cell for various functions such as muscle contraction:



▲ **Figure 7** ATP is broken down in a hydrolysis reaction to release energy. H₂O is water, ADP is adenosine diphosphate, Pi is inorganic phosphate, H⁺ is hydrogen, and ATPase is the name for a class of enzymes that catalyse ATP hydrolysis.

The body only stores sufficient ATP to fuel approximately 2 seconds of maximal-intensity muscle contraction, so mechanisms of ATP replenishment are critical to maintenance of our energy supply. As we studied in chapter A.2.3, three primary metabolic pathways/systems exist:

- the phosphagen (PCr) system
- the glycolytic system
- the oxidative system.

Key point

ATP is the most important source of energy in the body. It is stored in very small amounts, so we need extremely efficient metabolic pathways to replenish ATP continuously.

In glycolysis, glucose (from the blood or from glycogen stored in muscle) is metabolized to resynthesize ATP in a series of chemical reactions that do not utilize oxygen. In the oxidative pathway, glucose and fatty acids are metabolized to replenish ATP in two enzymatic systems called the Krebs cycle and the electron transport chain. The PCr pathway does not use stored glucose or fat; instead, it metabolizes phosphocreatine, a compound present in skeletal muscle. Logic dictates that the availability of food energy is critical to ensuring a sufficient supply of ATP for continued sport performance.

Is ATP depletion a cause of fatigue in sport?

If ATP stores became depleted during sport skeletal muscles would enter a state of rigor, a permanently contracted state. The good news is that sport-induced muscle rigor has never been documented. Repeated short, all-out sprints can be achieved without substantial ATP depletion, despite the rate of ATP breakdown being greatest during this type of activity. Significant ATP depletion is not observed at the point of fatigue during progressive exercise to exhaustion, high-intensity short-duration exercise, or prolonged moderate-intensity exercise. Intramuscular ATP concentrations do not appear to fall below about 60% of resting levels even during intense exercise.

Despite the absence of significant ATP depletion at the whole-muscle level, ATP levels in individual muscle fibres can fall to as low as 20% of resting values following maximal exercise, particularly in type II muscle fibres. Localized ATP depletion may also occur at crucial stages of the excitation-contraction coupling process (the process that enables muscle fibres to contract). Localized depletion could prevent some muscle fibres within a whole muscle from contributing to muscle contraction and, thereby, result in fatigue of the whole muscle. Overall, an important message is that ATP depletion is far from an accepted cause of fatigue in sport.

Key point

ATP depletion, at least at the whole-muscle level, is not a primary cause of fatigue in sport.

Phosphocreatine depletion

Phosphocreatine is a creatine molecule with a phosphate group attached that is particularly important in resynthesizing ATP during explosive, high-intensity sport. Resynthesis of ATP from PCr is driven by the reaction between PCr and ADP, catalysed by the enzyme creatine kinase:



▲ **Figure 8** Resynthesis of ATP from PCr driven by the reaction between PCr and ADP. Cr is free creatine.

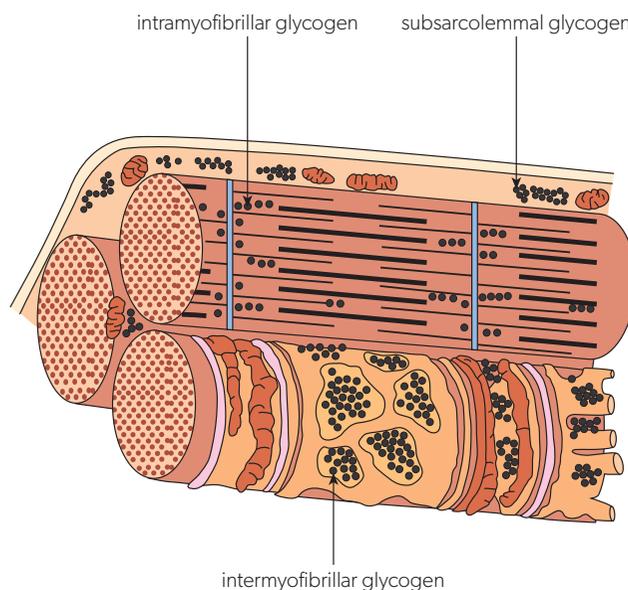
There is sufficient intramuscular PCr to fuel approximately 10 seconds of maximal work. However, our energy systems work synergistically, so PCr stores will not fully deplete during a single maximal effort. PCr content drops to about 35%–55% of resting levels during a 6-second sprint, about 27% of resting levels during a 20-second sprint, and about 20% of resting levels at the end of a 30-second sprint. These significant reductions, along with evidence of a positive relationship between recovery of muscle PCr and muscle power output, suggest that PCr depletion and an associated reduction in the rate of ATP resynthesis are at least partly responsible for the reduced power/speed seen during sprint activities. There are also significant correlations between PCr availability and repeated sprint performance, suggesting that fatigue during repeated sprints typical of team sports like football is also partly dependent on PCr.

Glycogen depletion

Carbohydrate, in the form of muscle and liver glycogen and blood glucose, is the primary fuel during sport, and its contribution becomes greater with increasing exercise intensity. Carbohydrate is the only fuel that can be metabolized aerobically and anaerobically, making it a fuel that generates ATP across a wide range of exercise demands.

Fatigue during prolonged sport often coincides with low muscle glycogen content. There is little evidence to support the idea that low muscle glycogen concentration leads to reduced ATP resynthesis, so what could establish a cause-and-effect relationship between muscle glycogen depletion and fatigue?

Muscle glycogen is localized in three clusters: subsarcolemmal glycogen (located just under the sarcolemma, or muscle fibre membrane), intermyofibrillar glycogen (located between myofibrils) and intramyofibrillar glycogen (located within myofibrils; Figure 9). Depletion of specific glycogen clusters may negatively influence ATP concentrations in a way that would not be detected by measuring “whole muscle” ATP concentration. There is not currently much data on the effect of regional muscle glycogen depletion on ATP resynthesis. However, it is feasible that localized muscle glycogen depletion could impact ATP availability at specific sites of excitation-contraction coupling, impairing contractile function.



▲ **Figure 9** The storage sites of glycogen inside muscle cells

Key point

Phosphocreatine depletion is partly responsible for the fatigue seen during single and repeated sprints. However, it is not the sole reason for fatigue during these activities.

Key point

Carbohydrate is the only fuel that can be metabolized aerobically and anaerobically, making it a crucial fuel source for a broad range of sports.

Key point

Depletion of muscle glycogen in specific locations may negatively impact ATP resynthesis in these locations, and thereby impair specific steps in the excitation-contraction coupling process.

During prolonged sport, intramuscular fuel sources (glycogen and fatty acids) are predominant for approximately the first 90 minutes. If sport continues for longer, blood-borne fuels (glucose and free fatty acids) become more important, largely due to muscle glycogen depletion. Blood glucose levels are maintained predominantly by the breakdown of liver glycogen. An increased use of blood glucose as a metabolic fuel will tax the limited liver glycogen stores, potentially leading to a situation where the liver can no longer maintain blood glucose levels within their optimum range, and hypoglycaemia can develop.

During prolonged sport, blood glucose is an important fuel for working muscles and the CNS. Brain glucose stores are limited; therefore, the uptake of blood glucose is crucial for the brain. Once blood glucose concentration drops below a critical level, brain glucose uptake begins to decline. Therefore, hypoglycaemia may contribute to fatigue in prolonged sport by limiting fuel supply to the brain.

Muscle force production is also greater after prolonged sport when blood glucose levels are maintained, with this greater force production related to better neuromuscular drive. Recent research indicates that depletion of muscle glycogen and hypoglycaemia contribute to fatigue, but that this fatigue is likely to be “central” rather than “peripheral”. However, hypoglycaemia may also contribute to fatigue by impairing fuel availability to the working muscles.

It does appear that there is an individual response to hypoglycaemia, with some people displaying symptoms such as nausea, confusion and dizziness, but others showing no outward signs. This makes a consensus on the influence of hypoglycaemia on fatigue difficult. Currently it appears that hypoglycaemia is not a consistent cause of fatigue during sport but may still be a potential cause in specific situations.

Key point

Hypoglycaemia may impair prolonged exercise performance, likely via central mechanisms. However, there is an inter-individual response to hypoglycaemia that influences its impact on performance.

The rate of glycolysis

Enzymes function optimally at the normal pH of the tissue in which they are located. Intramuscular acidosis may negatively affect the function of key enzymes involved in glycolysis, which would slow the rate of glycolysis, impairing the ability to replenish ATP via carbohydrate metabolism. This impairment would require the athlete to work at a lower intensity to match ATP demand with supply. During maximal intermittent exercise, the contribution of glycolysis to energy requirement progressively declines, and this has been attributed to the inhibition of glycolysis.

However, some research has found no influence of acidosis on muscle glycolytic rate and has suggested that muscle pH reductions typically found during sport have no effect on glycolysis. Methodological differences (such as in the mode, duration and intensity of exercise, and the intracellular environment created within muscle tissue) will contribute to this confusion. Also, we are becoming much more aware of the extent of the interactive effects of different “fatigue agents”, and how the effects of changes in the rate of production of one agent may be exacerbated or attenuated by changes in the rate of production of another. This interactivity may mean that the impact of any single potential fatigue agent, such as acidosis, may be less than previously thought.

Central nervous system drive

High-intensity sport can cause large amounts of H^+ to move from the muscle into the blood. At sufficiently high rates, this can cause extracellular (blood) acidosis. Extracellular acidosis can impair the ability of haemoglobin to hold oxygen,

which in turn can impair oxygen delivery to the brain. If brain oxygen delivery is impaired, central fatigue can develop. Central fatigue can manifest as increased perception of effort and reduced exercise tolerance.

Accumulation of H^+ outside of the muscles can also stimulate specialized sensory neurons that project back to the CNS, relaying information about the metabolic status of the body. The brain would interpret this feedback as the body being in a metabolically challenged situation and would respond by reducing central neural drive to the muscles, which would reduce muscle force production in an attempt to reduce metabolic demand. Of course, this will also impair sport performance.

Explaining the potential influence of metabolic acidosis on sport fatigue is challenging. Current evidence indicates that metabolic acidosis does play a role in fatigue during sport, but this role may be smaller than previously thought.

Key point

Acidosis may contribute to fatigue by slowing the rate of glycolysis and causing central fatigue.



Observations

In endurance events, it is common to see a significant increase in exercise intensity near the end of a race, almost regardless of how hard the athletes were pushing throughout the event. For example, in 2005 the legendary Ethiopian distance runner Kenenisa Bekele set a new world record for the 10 km of 26 min 17 s (this has subsequently been beaten). During the race, Bekele ran the first 9 km at an average pace of 2 min 38 s km^{-1} . However, he ran the final kilometre in 2 min 32 s, 6 seconds faster than his average speed for the first 90% of a world-record setting race. However, an athlete can only make up so much time by increasing intensity in the final stage of a race, so how do we know this approach of putting on an “end-spurt” is an optimal strategy?

Investigate and answer the following research question.

Are there different pacing strategies used in 10 km races where a pacemaker is used compared with racing in the Olympic 10 km final with no pacemaker?

Inorganic phosphate accumulation

When energy demand for muscle contraction is high, phosphate (Pi) can accumulate within the muscle due to ATP and PCr breakdown (Figures 7 and 8). Inorganic phosphate plays very important roles in many biochemical and biological processes, including energy metabolism. However, accumulation of Pi outside of normal physiological concentrations can be a problem.

Elevated Pi concentration can directly impair muscle force by interfering with the ability of the contractile proteins actin and myosin to enter a high force state, which in turn will reduce the force-generating capacity of muscle fibres. This interference occurs early in the fatigue process.

The influence of Pi on the contractile proteins means that the force produced for a given Ca^{2+} concentration is reduced (reduced Ca^{2+} sensitivity). This impaired Ca^{2+} sensitivity may be of particular importance in the later stages of fatigue, when intracellular Ca^{2+} concentration decreases.

Reduced Ca^{2+} concentration in the later stages of fatigue is caused by reduced release of Ca^{2+} from its storage site, the SR.

Key point

Recent research suggests that inorganic Pi accumulation in muscle cells should be considered the primary cause of peripheral fatigue in sport.

Inorganic Pi accumulation can reduce SR Ca^{2+} release in two ways.

- Pi accumulation can impair the function of the SR release channels that allow Ca^{2+} to move from the SR into the muscle cell.
- Some Pi may enter the SR and combine with free Ca^{2+} to form a Ca^{2+} -Pi solid (termed a precipitate). This has the effect of reducing the concentration of free Ca^{2+} in the SR, and therefore the amount of Ca^{2+} that can be released into the muscle cell.

A lot of research is still ongoing investigating the role of Pi in fatigue. However, recent findings have prompted some fatigue researchers to state that Pi should be considered the primary cause of peripheral fatigue in sport.



Linking question

What is the impact of fatigue on muscular contraction? (B.1.3)

Performance in sport is ultimately governed by the ability of the skeletal muscles to contract and generate force in the most effective way for the particular sport, whether that be extremely high levels of force for short periods, less force for prolonged periods, or a combination of the two. However, the ability/inability of the muscles to do this is governed by a multitude of physiological processes. It is important to be aware of how fatigue can impact muscle contraction ability to understand fatigue better and also to potentially reduce the negative impact of fatigue.

Consider:

- how fatigue is thought to influence muscle contraction
- the specific processes involved
- the specific factors that we should consider when trying to identify how muscle contraction is influenced by fatigue
- the factors related to the specific sport, environmental factors, and factors related to the individual athlete.



Linking question

What is the relationship between motivation and fatigue? (C.3)

It is undeniable that an athlete's psychology plays a crucial role in their performance. This psychological aspect has many names ("will", "drive", "motivation", "commitment", "guts", etc.), but can make the difference between success and failure, particularly at the highest level of sport where athletes are often very similar in terms of their physical ability. We are also becoming more aware of the associations between physiological fatigue processes and psychological aspects such as motivation, perception of task difficulty, and the desire to slow down or stop.

Consider:

- whether some athletes are predisposed to experiencing fatigue to a greater or lesser extent than others (due to differences in psychological outlook, personality traits or even previous life experiences)
- whether "brain training" or other psychological interventions have become a more common part of athlete training programmes (to help an athlete become more "resilient" to the psychological impact of fatigue)
- if we are able to measure complex things like motivation, mental toughness and even fatigue severity accurately enough to make robust statements about the links between these things—or if that is currently beyond our ability.



Measurement

Research investigating the effect of fuel availability on fatigue requires careful measurement of the energy status of the body. There are many confounding factors that can influence our energy status, and therefore impair the validity of measurements of energy status. If you were

conducting a piece of research investigating the effect of glycogen availability on fatigue in endurance sport, what things would you need to control for to ensure that you could accurately measure the cause-and-effect relationship between glycogen availability and fatigue?



Global impact of science

Technological developments allow us to study human physiology in ever more complex and detailed ways. As a result, we are gaining more and more understanding of how organ systems, metabolic pathways, hormones, compounds, molecules and elements interact in complex ways to influence sports performance. Of course, this is fantastic for the development of scientific knowledge.

However, it can also expose new opportunities for the unfair/unethical exploitation of this greater understanding to gain a competitive advantage in sport. What are your thoughts on this? Do the benefits of greater knowledge and its potential applications outweigh the risk of misuse of this knowledge? Should the potential negative impacts of research findings be documented and evaluated? If so, who should do this?



Thinking skills

The drive to achieve success in sport means that sport and exercise science is an integral part of gaining a competitive edge. Despite stronger links between research and practitioners, there are many examples across a range of sports of athletes, coaches and teams at the highest level failing to apply the latest findings to their practice. They often use strategies that are either outdated or incorrect.

Why do you think that even in elite sport there is a “disconnect” between what sport and exercise science research tells athletes/coaches/teams they should be doing, and what they are actually doing? How can this disconnect be “fixed”?



Linking question

Can mental toughness “override” fatigue? And would this be a good thing? (C.1.2)

Successful athletes are not only physically gifted, but often also have psychological characteristics that drive their success. One of these characteristics is mental toughness—an ability to cope with the demands of a sports performer.

Consider:

- whether a mentally tough athlete is able to tolerate higher training loads than a less mentally tough athlete
- if mentally tough athletes are less influenced by fatigue, perhaps by being able to block out or dampen the urge to slow down
- if mentally tough athletes are more willing to tolerate the negative sensations associated with a highly fatiguing sporting situation
- if there are any issues with athletes tolerating higher levels of fatigue—for example, it may be beneficial in the occasional training session or competition, but what if this tolerance of high fatigue levels continued for a longer period of time?



▲ **Figure 10** Successful sportspeople have psychological characteristics that drive their success

Recovery for athletes

Most individual and team elite athletes have demanding training sessions and competition schedules. Additionally, elite athletes are exposed to other pressures such as personal relationships, international travel, social media, sponsor needs and demands, and media interest. Strategies for **recovery** include sleep, nutrition, active recovery, stretching and spending time in nature. Many athletes (individual and team sports) have rated sleep and fluid replacement as important contributors to recovery. This is perhaps not surprising because many athletes have normal sleep-wake cycles disrupted as they are often required to wake up early for early morning training sessions.

Overreaching, overtraining and overtraining syndrome

As you saw in chapter A.3.1, training, including overreaching, is an overload process that can result in acute fatigue, and with appropriate recovery (including reduced training intensity, frequency and/or duration) this can lead to adaptation and performance improvement. When training overload continues (days/weeks) but there is an imbalance between training and recovery, overtraining can occur. Symptoms of overtraining include performance decrements, decreased vigour, increased fatigue, and hormonal disturbances. When athletes experience overtraining it can take weeks to fully recover. When this combines with inadequate nutrition (not enough energy intake), illness or sleep disorders, this can lead to overtraining syndrome (OTS), which can take months to recover from. Think of OTS as an imbalance in the training to recovery ratio. That is, too much training or competitions and too little recovery. If this happens, adjust the training load (intensity and/or volume and/or frequency) and/or allow a day of complete rest when performance declines or the athlete communicates they have excessive/abnormal fatigue, or mental and emotional concerns.

During a bout of training homeostasis is disturbed. Heart rate normally takes only a few minutes to return to resting level; oxygen consumption can take hours and muscle soreness can take days. Muscle function and neuromuscular coordination may take weeks to fully recover.

Training-induced adaptations enable the athlete to cope better with the next bout of training. When there is an imbalanced relationship between training and recovery, symptoms of fatigue develop. These symptoms are often followed by decreased performance. Insufficient recovery prevents an athlete from achieving the required frequency, intensity or duration of training. This is why it is important to think ahead and plan recovery strategies to shift the training-recovery balance towards the processes of recovery. In other words, recovery is key for a successful training programme.

Therefore, an increase in training (intensity, volume or both), combined with not enough recovery time, can lead to overtraining. Overtraining can result in decreased performance. This highlights the importance of planning sufficient rest and recovery methods to achieve optimal performance. This is why successful athletes and coaches plan short- and long-term training. They include varied training loads, adequate rest and recovery, and divide training periods into macro-, meso- and microcycles (a periodized training approach) as studied in chapter A.3.1.

Key point

Athletes train and recover to enhance physiological capacity, refine motor patterns, reduce injury/illness risk and improve performance. To train effectively and achieve optimal performance, monitoring and quantifying the training load of an athlete should be a priority. Recovery can suffer from both adverse external conditions (such as a noisy environment when trying to rest) and adverse internal conditions (such as worrying about being dropped from the team).

ATL Thinking skills

Some researchers have suggested excessive strain in athletes is not caused by high training and/or competition demands. Rather, it is caused by a lack of recovery that leads to a state of “under-recovery”.

Detachment from sport is a recovery experience defined as refraining from sport-related activities.

- Physical detachment involves getting a break from the physical exertion of training or competition.
- Cognitive detachment means putting all thoughts about one’s sport aside.
- Emotional detachment is distancing oneself from negative emotions experienced during the day.

Therefore, detachment enables athletes to restore depleted physical and mental resources by allowing a physical, cognitive and/or emotional break from sport-related demands—and helps prevent under-recovery.

Activity 3

Using the information in Table 4, identify whether each of the following is the consequence of under-recovery, overtraining or burnout.

1. Tiredness and performance decrements
2. Exhaustion and performance collapse
3. Illnesses, infections and withdrawal from sports participation.

▼ Table 4

Concept	Symptom	
	Physiological or psychological?	Example
under-recovery	physiological	muscle soreness
	psychological	sleep disturbance
overtraining	physiological	elevated resting HR
	psychological	lack of enthusiasm for training
burnout	physiological	immunodeficiency
	psychological	sport devaluation

Key points

If an athlete is:

- underperforming
- complaining of persistent fatigue
- showing an increased sense of effort in training, or
- saying they are not getting enough sleep

then their trainer should:

- reduce daily training intensity or volume (or allow a day of rest)
- avoid training that lacks variety
- plan training to meet the individual needs of the athlete (for example, an athlete returning from injury compared with a player training between matches at a soccer World Cup tournament)
- encourage and regularly reinforce optimal nutrition, hydration and sleep time
- be aware that other stressors such as sleep disturbance may add to the stress of physical training.

Activity 4

Explain why recovery and stress management need to consider **all** the factors that influence performance. For example:

- training factors (such as frequency, intensity)
- lifestyle factors (such as sleep, nutrition)
- health factors (such as common cold, post-COVID-19 infection)
- social/environment factors (such as family, school).

Assessing recovery

Recovery can mean different things to different individuals, such as “to relax” or “to switch off” or “to restore”. Examples of different time perspectives of recovery include rest, recreation, leisure and vacation. There are also individual preferences and interpretations of recovery activities, for example: sleep, watching a movie at the cinema, participating in a less-intensive activity.

Recovery may refer to short-, mid- or long-term periods, but it is not possible to set a specific time frame for each because there is high intra- and inter-individual variability in the recovery process. Recovery activities should be periodized and continually modified according to the individual needs of the athlete. For example, after a mentally fatiguing training session, if there is a need to reduce pain from muscle damage or if the athlete shows signs of increased physical fatigue. Due to inter- and intra-individual responses to fitness and fatigue, the direct monitoring of fitness and fatigue responses has become common for elite, high-performing and professional athletes to ensure an adequate training load-recovery stress balance. The challenge of individualizing recovery in the context of factors such as the type of sport and training, the training phase of the year and the level of participation is complex.

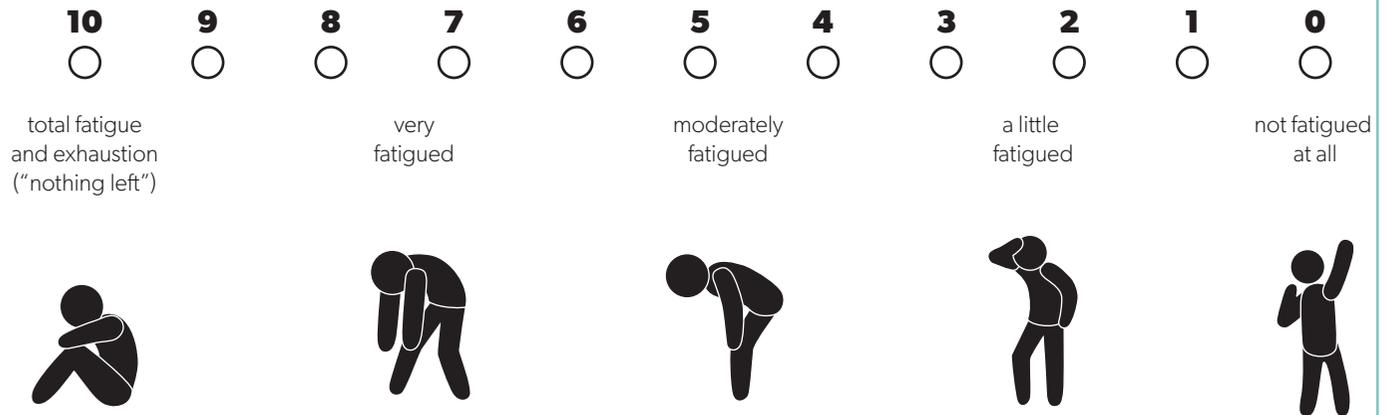
Instruments to monitor the recovery-stress state in athletes include:

- profile of mood states (POMS)—for detecting mood disturbances during or resulting from intensified training
- recovery-stress questionnaire for athletes (RESTQ-Sport)—for describing the recovery-stress balance over a specific time frame (often weekly or monthly)
- short recovery and stress scale (SRSS)—a short version (daily or twice a day) of the acute recovery and stress scale (ARSS), suitable for multiple measurements within short intervals for a detailed picture of the individual recovery-stress status of athletes.

A common method of assessing recovery involves measures of heart rate (or heart rate variability) at rest or after exercise/training. Blood lactate is also used to monitor recovery. There are other methods, such as the amount of creatine kinase in your blood (a marker of muscle damage) and the level of cortisol in your saliva (associated with not enough physical/mental recovery). But these measures are prone to large inter- and intra-individual variability in both baseline values and the post-exercise/training response. Commonly applied psychological measures of the subjective responses of an athlete to single-bout and long-term training loads include the rating of perceived exertion, the profile of mood states and recovery-stress questionnaires for athletes.

Activity 5

Following a bout of exercise, a training session or a competition, rate how fatigued you feel using the *Rating-of-Fatigue Scale* in Figure 11. A response of “0” means you do not feel at all fatigued. A response of “10” means you feel totally fatigued and exhausted.



▲ **Figure 11** Rating-of-Fatigue Scale (Micklewright et al., 2017)

Nutrition and recovery

Post-exercise nutritional recovery is a cornerstone of athlete success, and should be a key planning consideration for training and competition. It is essential for optimal performance that athletes maintain a balance between their nutrition needs and diet, both quantitatively (in terms of calories) and qualitatively (in terms of macro- and micronutrients).

Glycogen

During exercise, glycogen utilization increases with exercise intensity and ambient heat. Therefore, it is important to replace muscle and liver glycogen after exercise. The minimum amount of carbohydrate to consume after exercise is $0.7 \text{ g kg}^{-1} \text{ hour}^{-1}$, but carbohydrate intakes of $8\text{--}12 \text{ g kg}^{-1} \text{ day}^{-1}$ may be required to replace muscle glycogen after prolonged, intense exercise. It usually takes around 24 hours to restore muscle glycogen completely after intense exercise. The first 2 hours after exercise is a critical period for replacing muscle glycogen. Consuming carbohydrate immediately after exercise results in faster muscle glycogen resynthesis compared with ingesting carbohydrate more than 2 hours post-exercise. Muscle glycogen resynthesis is faster when consuming high glycaemic index foods compared with low glycaemic index foods (chapter A.2.2). Carbohydrate drinks have the additional benefit of providing rehydration. In summary, for quicker recovery between training sessions or competitive events, consume high glycaemic index food or drink as soon as is practical after exercise.

Protein

The net balance of muscle protein depends on the balance between muscle protein synthesis and muscle protein breakdown. Consuming around 20 g protein after exercise maximizes muscle protein synthesis, and animal-based protein sources stimulate higher rates of muscle protein synthesis compared with plant-based protein sources.

Creatine monohydrate

Creatine monohydrate (commonly referred to as creatine) is an amino acid found in relatively high concentrations in skeletal muscle. It is one of the most popular nutritional ergogenic aids for athletes.

Research shows creatine supplementation can:

- increase intramuscular creatine concentrations
- improve exercise performance
- improve training adaptations, and may enhance post-exercise recovery.

Creatine is endogenously formed from reactions involving the amino acids in the kidneys and liver. In other words, the body can produce creatine on its own. However, supplementing with creatine is popular among athletes. It is taken exogenously (from external sources) primarily from consuming meat or dietary supplements.

Creatine supplementation is relatively well tolerated in athletes, especially at recommended dosages (3–5 g day⁻¹ or 0.1 g kg⁻¹ of body mass per day).

Adverse events: it is important to consider risks as well as benefits

There is some evidence to suggest that creatine supplementation increases water retention in the short term (several days). However, over longer periods of time (weeks) creatine supplementation does not appear to lead to water retention. Creatine is not an anabolic steroid, and when creatine supplementation is ingested at recommended dosages, it does not result in kidney damage and/or renal dysfunction in healthy individuals. Further, evidence-based research shows that creatine supplementation at recommended dosages does not cause dehydration and muscle cramping.

Is creatine only useful for resistance/power type activities?

Creatine supplementation has been theorized to primarily benefit athletes involved in high-intensity intermittent resistance/power type activities. However, there is a growing body of evidence that athletes from different sports who use creatine supplementation may:

- be able to maintain optimal glycogen levels (it helps athletes who deplete large amounts of glycogen during training and/or performance)
- reduce muscle damage and/or enhance recovery from intense exercise
- experience fewer musculoskeletal injuries, as well as accelerated recovery time from injury
- reduce the risk of heat related-illness when they train and/or compete in hot and humid environments (it has been found to help athletes hyperhydrate and enhance tolerance to exercise in the heat).

Creatine supplementation:

- provides an ergogenic effect for bouts of peak or maximal force production
- results in improvements in strength and fat-free mass
- provides benefits during single and repeated sprints
- appears to provide ergogenic benefits to aerobic endurance bouts
- may enhance recovery from intense exercise (in an acute sense, such as during bouts of high-intensity intermittent exercise).

ATL Thinking skills

For further reading on this topic, look up the following paper.

Fernández-Landa, J., Santibañez-Gutierrez, A., Todorovic, N. et al. Effects of Creatine Monohydrate on Endurance Performance in a Trained Population: A Systematic Review and Meta-analysis. *Sports Medicine* **53**, 1017–1027 (2023). <https://doi.org/10.1007/s40279-023-01823-2>

Polyphenol-rich foods

Polyphenols are a family of chemical compounds that are thought to act as antioxidants that can counteract the harmful effects of free radicals, support the oxidation-reduction (redox) balance and mitigate inflammation. They play a role in maintaining cellular health and can help prevent oxidative stress.

Exercise of high intensity and/or duration, especially with an eccentric component, can induce exercise-induced muscle damage (EIMD). Symptoms of EIMD that can impair performance include:

- impaired force production
- increased muscle soreness
- reduced range of motion.

Humans produce free radicals as part of normal metabolic processes. Free radicals are unstable molecules that can damage cells. Free radicals derived from oxygen are called reactive oxygen species (ROS). Various physiological stimuli (such as alcohol use, smoking and exercise) disturb the redox balance and induce oxidative stress. For example, exercise can increase oxygen consumption up to 20 times (or more) above resting values. In the mitochondria of muscle cells, this translates to 200-fold greater oxygen utilization and the subsequent production of a large amount of ROS.

Inflammation and disruption of redox balance are associated with the body's response to EIMD. Inflammation is the body's natural response to injury. It is marked by increased blood flow, swelling and the release of chemical messengers called cytokines.

Disruption of the redox balance occurs when the production of ROS outstrips the body's antioxidant capacity. This can lead to oxidative stress, an imbalance between free radical production and the body's antioxidant defence system, which can further damage the muscle tissue and delay the healing process.

Polyphenols occur naturally in, for example, fruits, vegetables, cereals and beverages. They are plant-based compounds with antioxidant and anti-inflammatory properties. Plant-derived polyphenol supplements are frequently used by athletes to reduce the negative effects of exercise-induced oxidative stress, accelerate the recovery of muscular function and enhance performance.

Polyphenol-rich foods help recovery of muscle function and reduce muscle soreness after EIMD. This could benefit athletes when there is limited time between competitive events. A study investigated polyphenol supplementation in team sports characterized by intermittent bouts of high-intensity exercise, where performance depends on both aerobic and anaerobic capacity. The

Key point

Creatine supplementation can quickly increase intramuscular creatine stores, improve muscle performance and aid recovery.

Key term

Polyphenols A family of naturally occurring chemical compounds associated with health benefits.

Key point

Recovery is a multilevel process (it is psychological, physiological and social). Recovery includes a broad range of physiological processes, such as sleep, motivated behaviour (such as eating and drinking) and goal-oriented components (such as relaxation or meeting friends). Recovery activities can be passive or active. In many instances, recovery is achieved indirectly by activities, which stimulate recovery processes (such as being active in other sports).

high-intensity eccentric muscle actions (such as jumping or changing direction) result in EIMD, potentially decreasing physical performance. The study found that polyphenol supplementation improved muscle function and reduced muscle soreness in team sport athletes after EIMD—a positive effect, especially when rapid recovery is required. However, the use of polyphenols in the diet is debatable, with many unanswered questions about the use of polyphenol-rich foods and exercise performance and recovery.

Recovery techniques

Athletes use many physical and physiological recovery techniques, including:

- cryotherapy
- ice packs and ice bags
- cryo cuffs
- cooling jackets
- cold water or ice immersion
- cold whirlpools
- cryo-chambers
- thermotherapy (warm water immersion and whirlpools, saunas)
- contrast water therapy (massage, foam rolling, compression therapies, neuromuscular electrical stimulation)
- whole-body vibration
- hyperbaric oxygen therapy.



▲ **Figure 12** Ice immersion for recovery

Psychological strategies are used by many athletes to improve recovery. The strategies help to cope with stress, decrease anxiety, increase motivation, promote a sense of well-being and enhance mental health. Such strategies include:

- progressive muscle relaxation
- imagery
- autogenic training
- personal preference music

- breathing exercises
- prayer.

Additionally, communicating with coaches and socializing with family and/or friends also appear to contribute to effective recovery.

Active recovery

Active recovery, which generally precedes other recovery methods, consists of submaximal activity after fatiguing exercise, training or competition, with the aim of preserving performance level by enhancing recovery between exercise bouts, training sessions or competitive events. This can be within the same day for competitors in sports such as judo, swimming, athletics and rugby 7s, or between days for sports like Grand Slam tennis competitions across a 2-week period, or in-between matches (two per week) for around 1 month for events such as the soccer World Cup.



▲ Figure 13 Active recovery

Active and passive recovery are used during exercise and training sessions, when periods of high-intensity effort are alternated with periods of low-intensity effort. This is to ensure that athletes can reproduce optimal performance, for example, when post-effort PCr is resynthesized and restored after passive recovery between short, maximal sprint repetitions in basketball (short-burst efforts <6 seconds), or active recovery between longer sprints to develop glycolytic capacity for ATP resynthesis and improved capacity for longer-sprint repetitions. Note that deterioration in performance during high-intensity work can indicate incomplete recovery between efforts, which means that the ratio between the durations of high- and low-intensity efforts needs to be carefully considered and monitored.

Active compared with passive recovery results in:

- a faster return to resting lactate levels, by way of lactate oxidation mainly in the active muscle fibres, allowing an earlier return to resting pH
- an accelerated metabolite removal and a return to homeostasis in the muscles and blood.

From a practical application perspective, when performances must be repeated in less than 30 minutes, active recovery accelerates the return to homeostasis and this will have a positive effect on maintaining performance. When maximal effort is followed by longer recovery periods (hours, days or weeks) before another

Key points

- Passive recovery ranges from the application of massage to inactive rest.
- Active recovery involves low-intensity and/or moderate physical activity such as jogging to eliminate the results of fatigue (for example, an NBA player immediately after a match, or the following morning after a half-marathon race).
- Proactive recovery involves a self-determined choice of recovery method based on individual need and preference.

maximal effort is required, other strategies should be used for promoting recovery, including rest. It is also important to consider the influence of the recovery method (active or passive) on muscle-glycogen resynthesis.

ATL Thinking skills

Is active recovery really active recovery or is it continued training?

ATL Thinking skills

Recovery is a physiological **and** psychological process relative to time. Following physical fatigue from training/competition, strategies such as cold water immersion are used to facilitate physiological aspects of recovery. In contrast, when an athlete experiences mental fatigue, a psychological recovery approach will be beneficial.

Recovery and fatigue are on a continuum. They are affected by both physiological and psychological factors. Over time, too much fatigue and insufficient recovery will likely result in poor performance.

Stretching

Stretching is a common practice among sportspeople before and/or after exercise, training or competition. Passive stretching of a muscle-tendon system, without voluntary muscle contraction to induce its lengthening, is frequently used in exercise and sport practice. Passive stretching can be subdivided into:

- static stretching—moving the muscle-tendon close to maximal lengthening, and then holding this position
- cyclic stretching—repeatedly stretching the muscle-tendon and immediately returning to the starting position between stretches.

With cyclic stretching, it is important to start slowly, to avoid stretching muscles too quickly during the initial repetitions. Stretching is believed to be beneficial when combined with other recovery methods.



▲ Figure 14 Stretching

ATL Research skills

What is the difference between a dynamic and a ballistic stretch?

ATL Thinking skills

Some researchers support passive stretching after exercise, training or competition because it appears to:

- increase flexibility
- aid relaxation
- reduce injury risk.

However, other researchers do not support the use of stretching as part of recovery.

What do you think, and why?

ATL Research skills

How long should a static stretch last for each muscle group?

How many repetitions of cyclic stretching would you recommend for each muscle group?

Hydration and recovery

It is well recognized that performance will suffer if dehydration is allowed to develop, and providing adequate rehydration (pre-, during and post-effort) for athletes is key for effective recovery. Depending on your age, sex and body shape, water represents between 40% and 70% of body mass, and accounts for 65%–75% of muscle mass, and approximately 50% of fat mass.

Activity 6

Per cent dehydration from an exercise/training bout or competitive event can be calculated as follows:

$$\text{per cent dehydration} = \frac{\text{mass of water lost (cm}^3\text{)}}{\text{weight before (wB)}} \times 100$$

where,

$$\text{mass of water lost} = \text{weight before (wB)} - \text{weight after (wA)}$$

Calculate your per cent dehydration immediately after a training bout or competition.

Measurement

Why is it important to ensure the athlete is naked, dry and has an empty bladder for weigh-ins pre- and post-exercise/training?

ATL Research skills

What is hypovolemia?

Dehydration and physical performance

As discussed earlier in this chapter, fluid loss due to sweat evaporation can negatively affect performance. Typical fluid needs for athletes are much higher during training and competition. For example, track and field athletes might need to increase daily fluid needs (above daily fluid needs) up to around 6 l day^{-1} and American football players up to 15 l day^{-1} due to training/competition sweat losses. This would be dependent on various factors such as training/competition intensity and duration, air temperature and humidity, acclimatization status, body size and individual sweat rate, event and clothing/uniform worn.

The following are key considerations for rehydrating after exercise.

- Athletes can assess their rehydration requirements after exercise by measuring nude body mass before and after exercise, and calculating the difference (each kg of body mass loss \cong 1 l of fluid). Athletes may continue to lose fluid, from sweating, for a period post-exercise. Therefore it is recommended that they consume 150% of fluid lost during exercise.
- Ingesting only water after exercise will reduce blood osmotic concentration, increasing water in urine, which is excreted, potentially leading to a negative fluid balance. Instead, it is recommended to consume fluids containing $20\text{--}50\text{ mmol l}^{-1}$ sodium post-exercise to achieve euhydration. Additionally, fluid retention is greater after ingesting fluids with 3%–12% glucose compared with water alone.
- Regularly replacing lost fluids in moderate volumes over a longer period (4–5 hours) results in better fluid balance compared with replacing lost fluids in large volumes over ≤ 3 hours.
- Drinks containing caffeine and alcohol may cause greater urine output compared with water, electrolyte and electrolyte-carbohydrate drinks.
- A combination of water and food achieves greater fluid balance compared with ingesting only electrolyte drinks, while combining electrolyte drinks and food is more effective than only water and food.

The 2023 IOC consensus statement on hydration for athletes highlighted:

Dehydration impairs performance in most events, and athletes should be well hydrated before exercise. Sufficient fluid should be consumed during exercise to limit dehydration to less than about 2% of body mass. . . Sodium should be included when sweat losses are high, especially if exercise lasts more than about 2 h. Athletes should not drink so much that they gain weight during exercise. During recovery from exercise, rehydration should include replacement of both water and salts lost in sweat.

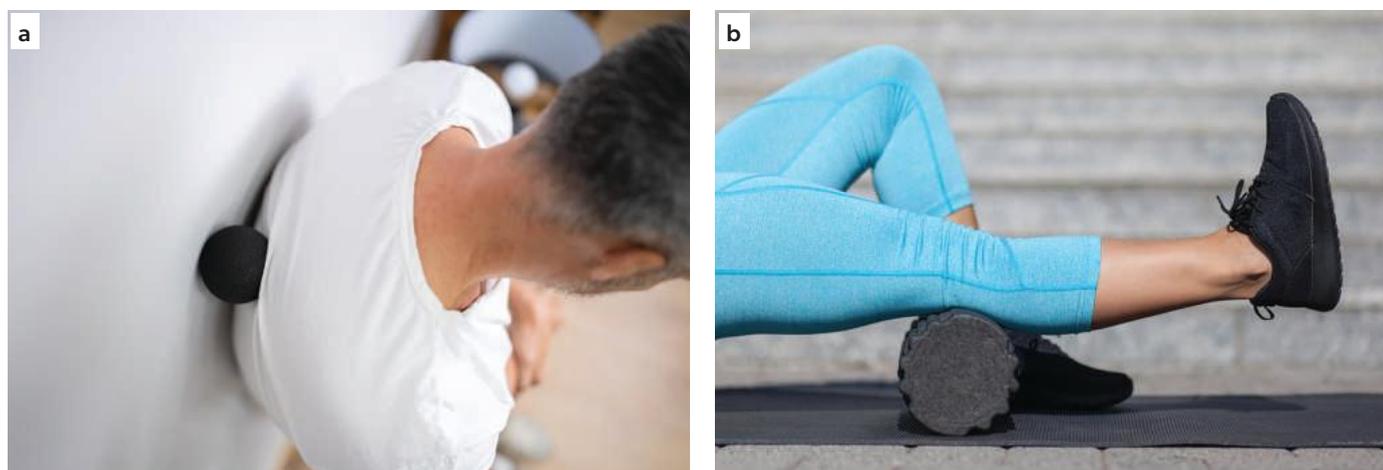
Self-myofascial release

More recently self-massage has gained popularity among elite (and recreational) athletes to enhance performance and recovery. Common tools used include the foam roll and roller massager. These instruments for self-massage are affordable, time-efficient, simple to use and easy to access.

Key point

While the sensation of thirst is useful in dictating the need for fluid intake during daily life, thirst is relatively insensitive in acutely tracking hydration status during exercise. Personalized hydration strategies play a key role in optimizing the performance and safety of athletes during sporting activities, especially in hot environments.

When exercising in cold environments, or at high altitudes, athletes must be vigilant and mindful of their fluid needs. Exercise in the cold can still produce large amounts of sweating, especially when heavy clothing is worn, while also diminishing thirst sensitivity, and potentially lead to insufficient fluid replacement. Therefore, it is important athletes know their individual fluid replacement needs during exercise in hot and cold environments to ensure they can develop a plan for competing while optimally hydrated.



▲ **Figure 15** Examples of SMR tools: **a** foam ball and **b** foam roller

Self-myofascial release (SMR) is achieved either by using body weight to apply pressure to the soft tissues, or by applying pressure in target muscles using upper-body strength. SMR can enhance short-term flexibility recovery, increasing joint range of movement. Beyond pain during SMR, there are no major adverse effects and SMR is thought to be a safe intervention for use in sports to enhance performance and recovery from exercise.

Key term

Self-myofascial release (SMR)

Self-massage techniques, such as the use of foam balls and rollers, which may assist recovery.

ATL Thinking skills

What recovery strategies are most valued and commonly used by parasport populations, and why?

ATL Thinking skills

With post-exercise massages, neither blood flow nor range of motion appear to be affected. There is only a slight increase in muscle temperature, and removal of metabolites is not sped up. However, there is some evidence to suggest that post-exercise massages improve perceived recovery (a feeling of well-being) for the next training session or competition. Additionally, post-exercise massages appear to promote reduction in muscle cramps and stiffness, helping the athlete become more comfortable with, and have a higher tolerance for, subsequent exercise and/or training bouts.

Compression garments

Compression garments are broadly defined as apparel that apply mechanical pressure to body tissues. They include knee-high and above-knee socks, calf sleeves, shorts, waist-to-ankle tights, arm sleeves, short and long-sleeve shirts, and full-body suits.

Compression garments are used by athletes across the competitive spectrum, from recreational to elite, during exercise and recovery from exercise.

Compression garments worn during recovery appear to have a positive benefit on subsequent bouts of endurance and resistance exercise. For example, compression garments are associated with reductions in lactate dehydrogenase during recovery and are consistently associated with decreases in perceived muscle soreness when worn following fatiguing exercise.



Experiments

Some studies have investigated the recovery of sprinting, jumping and team-sport-specific capabilities, with compression garments worn during recovery. However, they used a placebo recovery intervention (such as non-compressive placebo tights) rather than a control group.

The lack of a control group (no recovery intervention) in these studies means it is difficult to rule out the possibility of a placebo effect. In other words, if the non-compressive tights “work”, then the “true” effect of the compression garments is not known.



Linking question

Do placebos positively affect recovery? (Inquiry 1)

Consider:

- whether anecdotal accounts are a substitute for valid and reliable scientific data
- if placebo effects improve recovery simply because the athlete expects an improvement
- if a placebo will improve recovery if an athlete has a strong belief that it will be beneficial
- if a placebo will improve recovery if an athlete is told it will improve performance
- the reasons for using double-blind experimental design to find out if placebos affect recovery
- why studies investigating “do placebos affect recovery” include: an intervention group, a placebo group and a control group
- whether or not enhanced exercise recovery via psychophysiological mechanisms (placebo effect) has been researched enough.

Cold and heat local thermal applications

Cold and heat local thermal applications are generally used for the treatment of soft-tissue injury after exercise or sport. With cooling (e.g. an ice pack), metabolic activity decreases, capillaries constrict, there is an anti-inflammatory effect, a drop in nerve conduction (i.e. reduced pain sensation), and increased muscle stiffness. With heat application, there is an increase in metabolic activity, vasodilation (increasing the supply of oxygen, nutrients, and antibodies), a drop in neuromuscular spindle activity, and reduced muscle stiffness, resulting in an increased range of motion.

Cold water immersion and air cryotherapy

Water immersion submerges all or part of the body in cold water, warm water, or a combination of cold and warm temperatures (contrast water therapy). It usually lasts for 5–30 min. Air cryotherapy exposes all or part of the body to cold air temperatures ranging from -85°C to -195°C for 1–3 min.

Cold water immersion (CWI) is more effective in reducing muscle soreness (including reducing DOMS) and improving muscular power than active recovery, contrast water therapy and warm water immersion.

Air cryotherapy is more effective than CWI for immediately recovering muscular power (1 hour post-exercise) and for recovering muscular strength.

Post-exercise CWI is an effective intervention to enhance the recovery (1 hour post-exercise) of endurance performance, particularly following exercise in warm-to-hot environmental conditions.

Muscle power is impaired in the short term (1–6 hours) following CWI. Therefore, practitioners must ensure athletes have an appropriate warm-up if using CWI between closely scheduled performances.



Experiments

The quality of experimental evidence depends on careful control of variables.

Why do studies investigating the effects of CWI need to ensure blinding of participants?

Consider:

- the placebo effect
- different body parts that have the CWI
- different CWI temperatures
- how participants might limit the applicability of findings.

Sleep for recovery

Sleep is a desired state of unconsciousness. Humans spend about one-third of their lives asleep. Sleep deprivation (abnormally long periods of wakefulness) appears to cause an impairment in endurance capacity, such as slower running when effort is voluntary and self-paced. Interestingly, strength and anaerobic exercise do not seem to be influenced by up to 24 hours of sleep deprivation. However, sleep is critical for recovery from training or hard exercise. Lack of sleep is associated with feelings of tiredness and muscle soreness, and decreased motivation to train at the next training session.

Sleep allows rest following a period of wakefulness. To be described as “adequate sleep” there needs to be enough sleep duration combined with high sleep efficiency (the ratio of sleep duration to time spent in bed). The disruption of sleep-waking cycles can have consequences for both behaviour and exercise performance. For the athletic population, adequate sleep quality and quantity are fundamental for effective recovery from training and competition to achieve optimal performance.

Activity 7

Search online for the Pittsburgh Sleep Quality Index (PSQI) instrument questionnaire to determine your sleep quality.

There are two distinct sleep states.

- Rapid eye movement sleep (REM)
- Non-rapid eye movement sleep (NREM)

REM sleep comprises about 20% of sleep in adults each night, spread over several periods. NREM sleep is subdivided into three stages related to the depth of sleep (1 = light sleep and 3 = deep sleep). Deep sleep is characterized by slow-frequency brain waves, slow heart and respiratory rates, and lower blood flow in the brain. Human adults enter sleep via NREM sleep. The cycle between NREM and REM sleep is repeated, usually three to four times per night.

Electronic device use and sleep

Studies have shown electronic device use in bed prior to sleep, particularly smartphones, is widespread in children, adolescents and adults. This is associated with disturbed sleep and poorer sleep quality.

Three mechanisms have been put forward to explain how media use might affect sleep quality.

- Exposure to bright light, such as that emitted by a mobile phone screen, suppresses the secretion of melatonin (a sleep-promoting hormone), delaying sleep onset and disrupting our sleep.
- Media use tends to have no predefined beginning or end points, and this can disrupt sleep.
- Media content (such as violent content) can effect sleep or induce arousal, fright and stress reactions, and this has been associated with difficulties falling asleep and/or poor sleep quality.

What is a good night's sleep?

The USA-based National Sleep Foundation's consensus statement agreed that a good night's sleep consisted of:

- sleep latency (time to transition from wake to sleep) ≤ 15 min
- one or fewer awakenings per night
- wake after sleep ≤ 20 min (reduced time spent awake between sleep onset and wake after sleep onset)
- sleep efficiency (ratio of time spent sleeping to total time in bed) $\geq 85\%$.

Additionally, a poor night's sleep is indicated by:

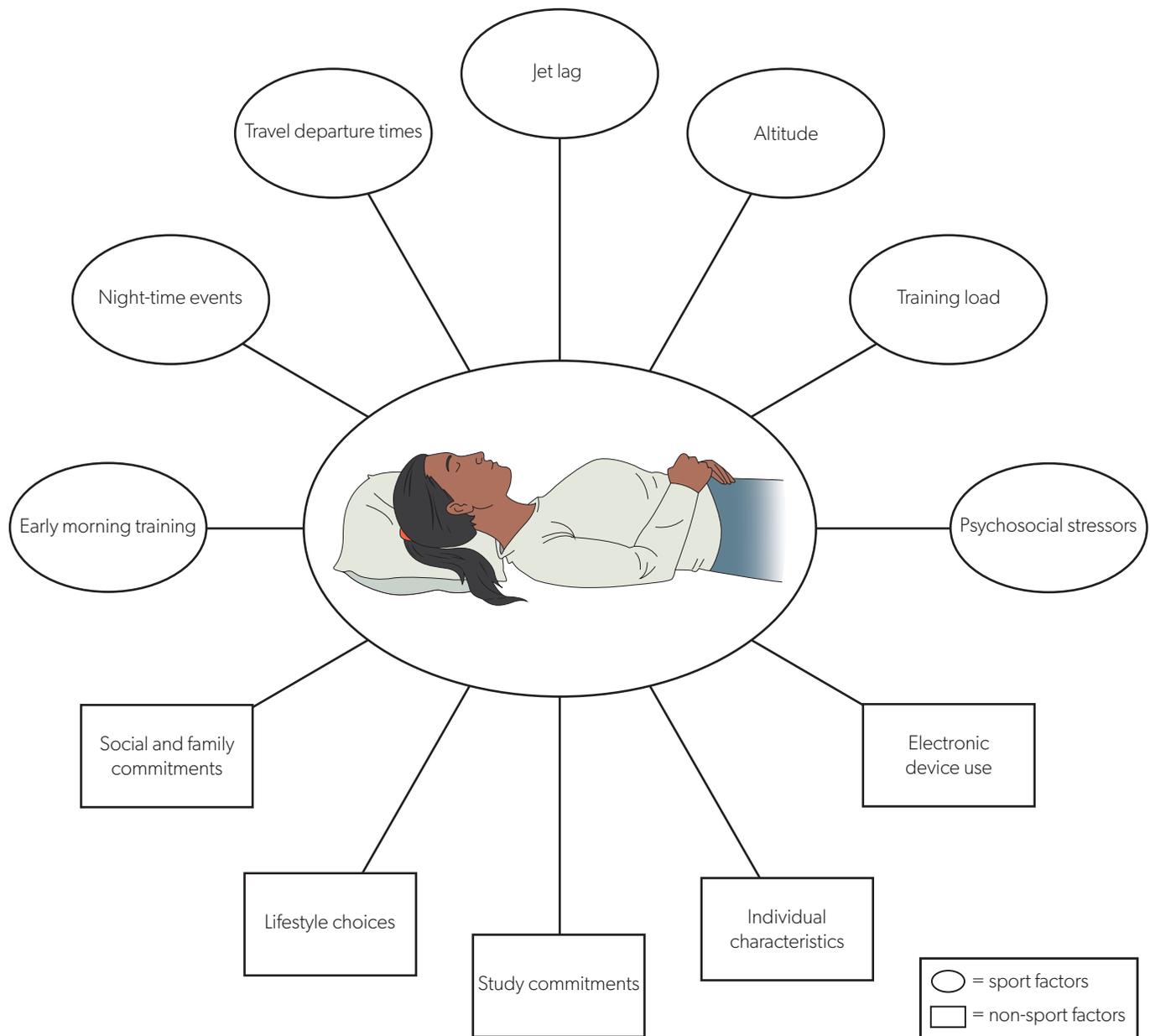
- sleep latency > 60 min
- four or more awakenings per night
- wake after sleep ≥ 51 min
- sleep efficiency $\leq 64\%$.

Sleep disturbance in athletes

Recent studies have shown that athletes perceive sleep as an important recovery mode. However, a recent review of sleep studies in elite athletes (Roberts, Teo, 2019) concluded:

Athletes were often unable to achieve sleep recommendations during training or competition periods. Sleep was impaired the night of competition compared with previous nights. Early morning training, increases in training load, travel departure times, jet lag and altitude can impair athletes' sleep.

Both sport and non-sport factors have the potential to disturb sleep in athletes, as shown in Figure 16.



▲ **Figure 16** Factors affecting sleep disturbance in athletes

Night-time scheduling of elite sport events has become commonplace. This can delay the time when athletes can go to bed for sleep because of, for example, post-event media commitments, recovery routines and time for injury treatment (if required). Additionally, elevated arousal following the event has

been associated with increased sleep latency (the time taken to transition from wakefulness to sleep). All of this can lead to reduced total sleep time (almost 40% reduction for some athletes), negatively impacting recovery, and limit preparation for the next training session or an upcoming competition.

Some sports, such as swimming, traditionally have early morning training sessions. There is evidence that this contributes to reduced sleep in the athletes. Further, psychosocial stressors (such as a recent poor performance) can cause stress and anxiety in athletes. This can disturb their sleep, and may result in poorer competition performance.

Key point

Some sleep loss the night before training or competition does not appear to be an issue for subsequent aerobic performance, but there may be an increased perception of effort during the training or competition.

Effects of sleep loss on sporting performance

There is a negative impact of reduced sleep on decision-making and executive function. A study reviewed the effects of sleep loss (≤ 6 hours of sleep in any 24-hour period) on exercise performance (anaerobic power, speed/power endurance, high-intensity interval exercise, strength, endurance, strength-endurance and skill). The “skill” category for inclusion was a task that required a high cognitive component for execution (such as tennis serving and basketball free-throw shooting). They concluded that acute sleep loss may have a negative impact on next-day exercise performance of around a 0.4% decline in performance for every hour spent awake following sleep loss.



Experiments

Why is randomization important for study designs investigating the interaction between sleep loss and physical performance in athletic populations?

ATL Thinking skills

Dual-career athletes, who combine sporting endeavours with academic studies, are now commonplace in high-performance sport. The balance of this can be complex for those who are attempting to perform simultaneously at the highest level both academically and athletically. What might be the effect of academic and sporting stressors on sleep quality in dual-career athletes?

Key point

Sleep loss can impair cognitive function, such as decreased alertness, slowed response and reaction times, and decreased attentional capacity.



Linking question

Do the amount and quality of sleep obtained by an athlete influence their predisposition to injury? (B.3.1)

Consider:

- the relationship between chronic suboptimal sleep patterns and the risk of musculoskeletal pain and sports injury
- that the amount of sleep that has been consistently found to be associated with increased risk of injury is ≤ 7 h of sleep on a chronic basis, which increases injury risk by 1.7 times
- a single night of suboptimal sleep does not appear to be associated with increased injury risk.

Do naps improve sleep in athletes to aid recovery?

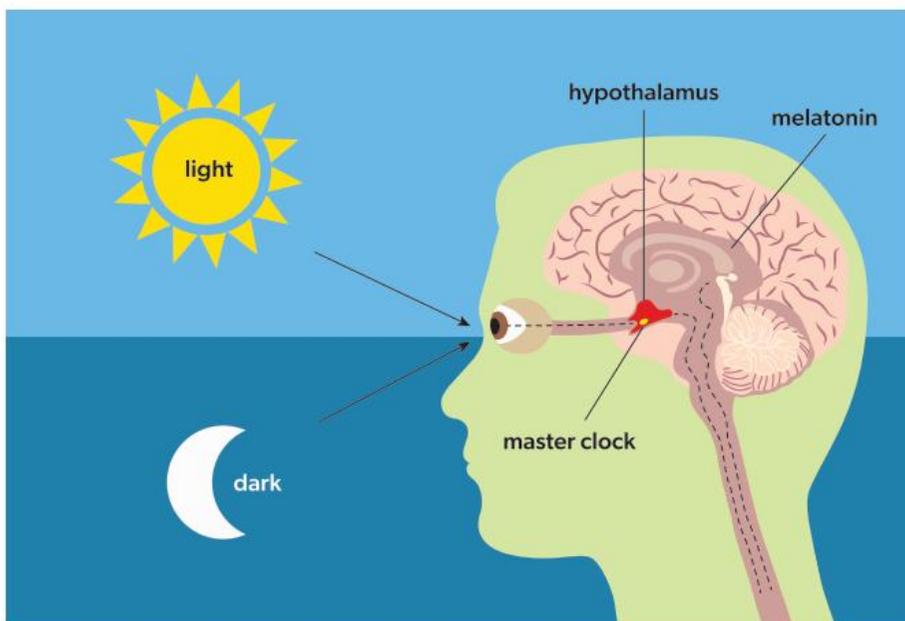
Naps (20–30 minutes) may help physical and cognitive performance, particularly if taken during the mid-afternoon hours. However, naps in the late afternoon/early evening can disrupt night-time sleep duration, sleep efficiency and sleep onset latency. Note that performance following a nap may be impaired.

The circadian system

The word “circadian” is related to the Latin phrase “circa diem” meaning “approximately a day”.

A central “circadian”, located in the hypothalamus, regulates the **circadian system**. Additionally, there are peripheral clocks located in almost every cell of the body. The master and peripheral clocks are synchronized by time-givers (zeitgebers). Examples of time-givers are light, sleep–wake transition, physical activity, social cues and meals. Light is the most important time-giver of the circadian system.

Around 2 hours before habitual bedtime, with the onset of dim light progressing to darkness, melatonin (a hormone produced by the pineal gland) is secreted. Melatonin aids sleep. Additionally, the circadian rhythm of core body temperature oscillates $\sim 0.8\text{--}1.0^\circ\text{C}$ between a night-time minimum (lowest level of alertness) and a daytime maximum every 24 hours. When core body temperature is lower, it is easier to initiate sleep than when core body temperature is higher.



▲ Figure 17 Endogenous (internal) circadian rhythm

Melatonin and circadian rhythms

The sleep-wakefulness cycle of the circadian rhythm is linked with responses of the pineal gland to cues (daylight/darkness) from the environment. The pineal gland secretes melatonin at dusk (when it starts to grow dark), and melatonin secretion is inhibited on exposure to (morning) light. Melatonin secretion leads to the onset of sleep, accompanied by an increase in peripheral vasodilation (and increased heat loss) in humans. Body core temperature is linked to this initiation of sleep, falling by approximately 0.3°C in the first few hours after the onset of sleep.

Chronotype

Re-entrainment (realignment of the endogenous circadian system with the timing of the external environment) following a time-zone change depends on an individual’s **chronotype**.

Key points

- External stimuli are called zeitgebers (time givers); they include sunlight, food, noise and social interaction.
- Zeitgebers help to (re)set the biological clock to a 24-hour day each day.

ATL Thinking skills

Does melatonin:

- increase or decrease alertness?
- prevent or induce drowsiness?

Key point

There is a direct interaction between melatonin and body temperature: ingesting melatonin decreases body temperature by $0.1^\circ\text{C}\text{--}0.3^\circ\text{C}$ when resting.

Key term

Chronotype Describes an individual's predisposition towards morning or evening alertness.

ATL Research skills

How do our circadian rhythms and chronotype change with age?

ATL Research skills

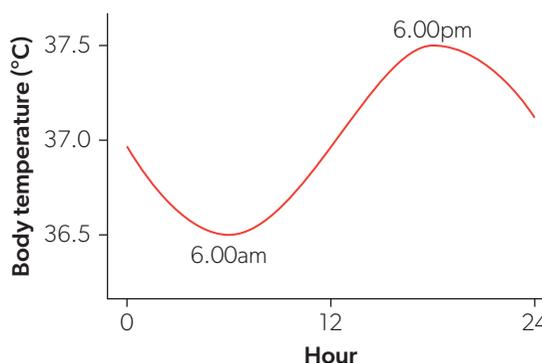
Core body temperature displays a circadian rhythm, with body temperature increasing during the daytime and decreasing during the night time. Additionally, resting core body temperature (typically measured in the early morning when waking up before any activity) is typically 0.3°C – 0.7°C higher during the luteal phase of the menstrual cycle compared with the follicular phase.

How might both these factors impact an athlete when preparing for a competition in a hot environment?

Chronotype is the tendency for someone to be a morning-type, an intermediate-type or an evening-type person with a preference to sleep at a specific time as determined by genetics, environmental and age-related factors. Individual differences in daily rhythms allow for a classification of individuals according to their chronotype. Morning-type individuals (M-types) show early bed and wake-up times, with peak arousal early in the day, whereas evening types (E-types) have later preferred bed and wake-up times, feeling at their best towards the end of the day. Neither/intermediate types (N-types), who constitute around 60% of adult populations, show less extreme patterns. Interestingly, some studies have shown that the further away a population is from the equator the higher the number of E-types, and significant shifts towards E-types are also observed in populations living in the city, possibly linked to higher artificial light exposure.

Influence of circadian rhythms on sports performance

There are regular fluctuations in core temperature that occur throughout the day of around $\pm 1^{\circ}\text{C}$, giving a normal resting range of 36.5°C – 37.5°C . A 2021 study reviewed the influence of circadian rhythms on sports performance. The researchers reported that daily body temperature reaches its peak in the late afternoon, showing its minimum value during the night, between 4.00 am and 5.00 am.



▲ **Figure 18** Changes in body temperature across a 24-hour period

This study found:

- Time of the day has a greater influence on sporting performance than the day of the week on which the physical activity is practised.
- Optimal time of the day for any physical exercise is between 4.30 pm and 6.30 pm.
- Evening-chronotype athletes are the most affected by practising sport outside of their optimal training time.
- Morning-chronotype athletes show enhanced performance in the early evenings, whereas for the evening-chronotype athletes it will be later.
- In strength training, the time of the day did not seem to be related with the improvements in performance.
- Best results for aerobic activities are obtained in the afternoon.
- It is important to take into account the chronotype of the athletes to know what is the best time of the day to carry out training sessions.
- The motivational factor of competitions can influence sports performance, regardless of the time of day at which the competition is held.

Travel fatigue and jet lag

Travel is an additional stress for many professional athletes, whether it is short, frequent journeys, or long-haul flights that cross time zones. Travel may be needed to get to and from competitions, or for training purposes (such as warm-weather or altitude training).

There are consequences of travel on performance (such as decreased concentration and alertness) and recovery (including recovery from the journey). These consequences should be considered to ensure optimal post-travel performance.

Recovery is the return to baseline levels of performance (including physiological and psychological functioning) after training and competition. When athletes have to travel before and after competition, the optimal recovery process slows down. Time lost to travel can impede recovery processes, such as disrupted routines/training schedules and/or inhibited injury treatment. This can affect athlete preparation for the next competition, especially if it involves long-haul flights, which cause travel fatigue and/or jet lag. Both can result in adverse effects on physical and cognitive performance, as well as increased illness and injury risk.

Travel fatigue

Travel fatigue is tiredness or exhaustion associated with a long journey either:

- north → south/south → north
- west → east/east → west.

It is usually less severe than jet lag, and can be either acute or cumulative (due to repetitive travel). Travel fatigue can have multiple causes including:

- prolonged exposure to mild hypoxia (if flying)
- cramped/confined/uncomfortable sitting conditions
- restricted movement/muscle inactivity
- noise (for example, from engines or other passengers)
- disruption of eating and sleeping patterns
- stress of checking in, baggage claim, security and customs clearance, etc.
- dehydration caused by exposure to dry cabin air on a flight
- the mental monotony/boredom of a long journey.

Symptoms may include general fatigue, confusion, irritability and headaches. Usually, a good-quality night's sleep will resolve travel fatigue symptoms.

While travel distance or duration seems to be the key factor in the magnitude of travel fatigue experienced, there are strategies that help prepare for training/competition. For example:

- minimize the time between your last "proper" sleep at the place of departure and first "proper" sleep at the destination
- plan a high training load and intensity before travel to allow for expected relative rest associated with travel

Key points

- Jet lag symptoms are experienced when three or more time zones are crossed in succession.
- The severity of jet lag increases with the number of time zones crossed.
- Flights to the east are associated with more jet lag than flights travelling westward.
- Jet lag can induce feelings of disorientation, fatigue, irritability, lightheadedness, impatience, lack of energy, and problems with appetite and bowel movements.
- Jet lag requires several days to dissipate; sleep difficulties do not disappear after a good night's sleep (as they do with travel fatigue).
- The number of days it takes to recover from jet lag equates to about two-thirds of the number of time zones crossed.
- Effects of jet lag lessen as the body clock adjusts to its new time zone.
- Jet lag (and travel fatigue) associated with prolonged travel across multiple time zones has many challenges for athletes, ranging from simple discomfort, to reduced exercise capacity and recovery, to a suppressed immune system and elevated risk of infection.

- during the journey follow a hydration plan involving regular intake of water
- post-travel, sleep in a cool, dark and quiet environment, and do not allow screen time to interfere with napping or sleeping
- train at low to moderate intensity on arrival.

Jet lag

Many elite and professional athletes have to travel long distances via airlines to compete (and train). The airline environment has limited movement and cabin air that has a reduced oxygen partial pressure and lower humidity. This is because many commercial flights occur at altitudes around 11,000 m—and humans cannot tolerate this—so cabin pressures are typically those found at around 2,500 m (and $\downarrow O_2 =$ hypoxia). So, drier air at lower oxygen pressures may increase insensible water loss and the evaporation of water from the athlete's skin surface during the flight.

Jet lag occurs when three or more time zones are crossed during a flight. It is important to note that travel fatigue and jet lag may co-occur when travelling east or west. Jet lag is a loss of synchrony between the internal circadian rhythms and the new destination time (circadian rhythms initially retain their habitual rhythms of the place of departure). Symptoms include:

- poor sleep
- daytime fatigue
- gastrointestinal disturbances.

Recovery from jet lag requires external factors in the new environment/destination, particularly the light-dark cycle across 24 hours, to act as zeitgebers (time-givers) and promote resynchronization of the human body clock to align with the new time zone.

The human body clock needs to either advance (east travel) or delay (west travel) depending on the athlete's travel direction. Symptoms are worse the greater the number of time zones crossed, and the experience of jet lag is influenced by the direction of travel.

For longer flights eastwards, jet lag tends to be more severe and longer lasting than travel fatigue. Resynchronization takes approximately 1 and 0.5 days respectively per east and west time-zone crossed, suggesting it is easier to adapt to westward travel (possibly because eastbound flights "shorten the day" whereas westbound flights "lengthen the day"—and it is easier to stay up late than to go to bed early). Studies have shown that eastward travel takes a greater toll on the performance of athletes than westward travel. However, high inter-individual variation exists for jet lag symptoms and their severity.

Based on the available research evidence, from both non-athletic and athletic populations, Table 5 suggests some ways to help manage travel fatigue and jet lag in athletes.

Recovering from mental fatigue

Mental fatigue (MF) has been described as a psychobiological state caused by prolonged periods of demanding cognitive activity that negatively affects physical and cognitive performance.

Research has shown that MF may:

- negatively influence health and well-being
- impair sport performance (for example, a decline in technical skills and decision-making)
- increase stress/anxiety
- decrease the ability to concentrate/focus
- decrease motivation to train and/or compete.

The mechanisms behind MF are poorly understood, but there is some evidence suggesting the negative impact is primarily mediated by greater perceived exertion in mentally fatigued athletes (Kellmann, Beckmann, 2022). MF can occur acutely (for example, on competition day) or from repetitive bouts of training and/or competition on a single day (for example, during round robin matches in rugby 7s), or over days (for example, heptathlon and decathlon track and field events spread over 2 days) or weeks (for example, Argentina, the soccer World Cup winners in 2022, played seven games in 29 days).

Educating athletes and coaches about recovery and mental recovery in sports is an important first step in recovering from MF. Developing self-regulation via self-monitoring of MF (with a diary or questionnaire) can help raise an athlete's understanding and awareness. Athletes and coaches will likely need help with selecting and implementing a mental recovery strategy. Current findings support psychologically oriented strategies to recover from MF, including breathing techniques, mental imagery, power naps and mental detachment. A recent study highlighted the importance of detachment from sport for athletes' adequate physical and mental recovery. Detachment involves getting a break from sport-related demands.

It is recommended that athletes physically and mentally detach from sport demand during the recovery phase.

- Physical detachment means taking a break from the physical exertion (for example, stopping sport-related activity for a few days).
- Mental detachment means putting thoughts about sport aside (for example, with a conscious distraction from the demands of training and competition, such as listening to music).

Other strategies that have the potential to aid recovery from MF include:

- some nutritional supplements (such as caffeine)
- spending time in natural environments (such as green spaces, seaside, mountains)
- rest days where the time is spent outside the athlete's sporting context (such as watching a movie).

The intention here is to "switch off" after performing. Remember that recovery is a highly individualized process—so choose mental recovery strategies which are suitable for your individual needs to ensure you get a break from:

- always thinking about your sport
- any kind of effortful thinking
- feeling life is controlled by sport
- the monotony of the daily training routine.

▼ **Table 5** How to manage travel fatigue and jet lag in athletes

pre-travel	educate athletes about travel fatigue and jet lag; plan for a morning flight after a good night's sleep
during travel	wear comfortable, loose-fitting clothing; drink water, avoid drinks with diuretic effects
post-travel	sleep in a cool (18–20°C), quiet environment; schedule a 20- to 40-minute daytime nap

Key points

- Prolonged mental exertion negatively influences attention, action monitoring and cognitive control, which can result in a lack of concentration and alertness.
- The main consequences of mental fatigue are a decline in endurance-based activities (earlier exhaustion, lower self-selected power output, increased completion time of a task) and in tasks involving a high degree of sport-technical skill and sport-decision-making.
- Mental recovery comprises the return to baseline levels of mental abilities (concentration) and the restoration of mental energy to regain performance levels.
- Athletes are often taught by coaches how to "switch on" to perform, but not how to "switch off" after performing to achieve desired resting experiences and mentally recover. There is a life outside of sport!



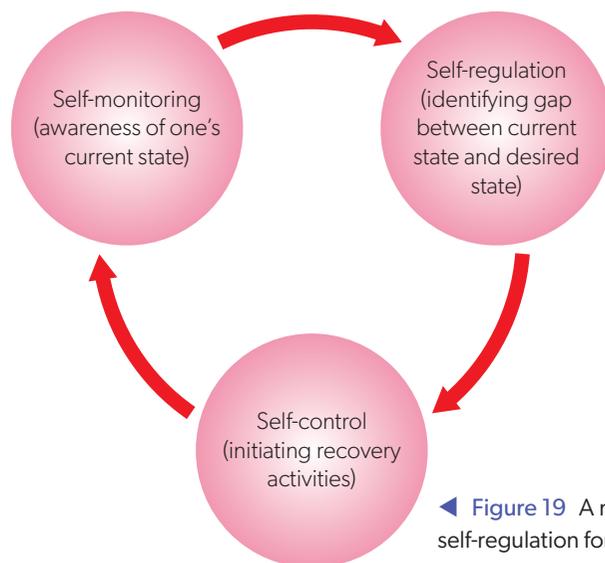
Linking question

Are self-regulation skills important for post-performance recovery? (C.3.2)

Consider:

- self-regulation skills play an important role before and during performance
- recovery self-regulation is identifying one's current state, one's desired future state and undertaking actions to minimize the discrepancy between both states during the recovery phase (such as between training sessions or competitions)
- self-monitoring is a key self-regulatory skill for successfully regulating post-performance states
- there is an important role for the regulation of cognition and emotion as complete recovery is only accomplished when both physical and mental resources are replenished
- self-control is required to initiate appropriate, and sometimes effortful, recovery activities when athletes are tired, stressed or in a negative mood.

Figure 19 shows the cyclic nature of this self-regulation recovery process.



◀ **Figure 19** A model of self-regulation for recovery



▲ **Figure 20** A basketball player

For example, imagine a basketball player who has just underperformed, but who has to play a match 2 days later (Figure 20). The time between games will allow them to recover physically. However, will they be able to regulate the negative thoughts and emotions related to their previous performance? Can they initiate the appropriate behaviours (actions) to recover for the next game?

Practice question

Evaluate nutritional strategies involving creatine monohydrate and polyphenol rich foods for recovery post training. (6 marks)

Summary

- Fatigue is a complex, multifaceted phenomenon that can manifest in different ways and be influenced by a host of environmental, activity and athlete-specific factors.
- Causes of fatigue can present anywhere in the chain of events that leads to voluntary muscle contraction.
- PCr depletion can contribute to fatigue during high-intensity, short-duration activities.
- Depletion of muscle glycogen can lead to fatigue by impacting specific activities/sites of excitation-contraction coupling.
- Liver glycogen depletion could impair the ability to regulate blood glucose concentration, leading to hypoglycaemia. In turn, hypoglycaemia may impair muscle glucose uptake, but also CNS metabolism.
- Acidosis caused by increased H^+ production can interfere with how Ca^{2+} performs its roles in muscle contraction, thereby reducing muscle force production.
- Glycolysis may also be impaired with acidosis, which would reduce the rate at which ATP can be replenished and again reduce muscle force production.
- Hydrogen production can also cause blood acidosis, which may impair oxygen delivery to the brain and stimulate sensory nerves that contribute to an increased perception of effort during sport.
- Inorganic phosphate accumulation is becoming known as one of the, if not the most, important causes of peripheral fatigue in sport as it can negatively impact multiple important steps in the muscle contraction process.
- Dehydration and hyperthermia can independently impair performance and combined may have an even larger negative performance impact.
- Dehydration can be tolerated to a larger extent than previously thought by people performing real-world sport without performance decrement.
- Skin temperature may be more important than core temperature (within reasonable limits) as a driver of fatigue.
- To gain a greater understanding of potential fatigue mechanisms in a sporting situation, the environment in which the sport takes place, the physiological and psychological demands of the sport itself, and information about the individual athlete should all be used to form hypotheses about the likely fatigue processes at play. One size does not fit all!
- Athletes have demanding training sessions and competition schedules. It is important to plan for rest and recovery to achieve optimal performance.
- When there is an imbalanced relationship between training and recovery, symptoms of fatigue develop, often followed by decreased performance.
- During recovery from exercise, training or competition, rehydration should include replacement of both water and salts lost in sweat.
- There are various strategies athletes can use to aid recovery, such as cold water immersion.
- Sleep quality and quantity are fundamental for effective recovery from training and competition to achieve optimal performance.
- It is important to plan to manage travel fatigue and jet lag in athletes.
- It is important to educate athletes and sports coaches about recovery from mental fatigue.

Check your understanding

After reading this chapter, you should be able to:

- outline the primary “types” of fatigue
- discuss the latest views on how fatigue may be conceptualized, and how these views could improve our understanding of fatigue
- outline some of the primary potential causes of fatigue in sport
- appreciate the complexity and interactive nature of fatigue
- understand the need to plan for recovery from exercise, training and competition
- distinguish between short-, mid- and long-term recovery
- describe ways of measuring and monitoring recovery
- distinguish between active and passive recovery
- explain why hydration is important for recovery
- outline nutrition to enhance recovery, including creatine and polyphenols
- discuss some other modes of recovery (massage, compression garments, thermal applications, cryotherapy)
- explain why sleep is important for recovery
- distinguish between travel fatigue and jet lag
- outline how to recover from mental fatigue.

Self-study questions

1. Write a paragraph outlining why the study of fatigue is complex and subject to debate and indecision.
2. Briefly describe and distinguish between the three main ways in which fatigue has been conceptualized.
3. A field hockey player is playing their fourth match in 6 days in a tournament. The match started at 6.00pm and is against a superior team. It is a windy, humid evening.
 - a. Which of the potential fatigue mechanisms mentioned in this chapter may apply to this athlete? Explain your answers.
 - b. What other factors, outside of the match itself, may influence how the player experiences fatigue during the match?
4. Distinguish between PCr depletion and glycogen depletion.
5. Outline how heat may contribute to fatigue.
6. Explain why lactic acid is not directly related to fatigue during prolonged endurance exercise.
7. Define recovery.
8. Distinguish between endogenous and exogenous creatine sources.
9. Outline what physical, cognitive and emotional detachment are for an athlete trying to recover from intense training bouts.
10. Explain what “jet lag” is.
11. Discuss how to manage travel fatigue and jet lag in athletes.
12. Distinguish between passive and active modes of recovery from exercise.
13. Outline three general recommendations to maintain and enhance recovery in sports.
14. Explain why recovery monitoring should be individualized.

Data-based question 1

Performance in many sports requires athletes to complete short bouts of maximal-intensity work interspersed with short recovery periods. As a result, there is a lot of research investigating performance determinants of repeated sprint training.

A study investigated the effects of recovery duration on the ability to complete a repeated sprint running test (6 × 40 m sprinting). On three separate occasions, a group of junior national-level football players (mean age 16 years) performed the repeated sprint running test, with each sprint separated by either 15, 20 or 25 seconds of passive recovery.

Table 6 shows best 40-metre sprint time and the overall time to complete all six sprints for each recovery. Data are mean (\pm SD).

▼ Table 6

	15 s rest	20 s rest	25 s rest
Best sprint time (s)	7.36 (0.10)	7.35 (0.16)	7.33 (0.13)
Total time (s)	46.12 (0.85)	45.41 (0.94)	44.82 (0.90)

(Adapted from Padulo et al., 2015)

- List:
 - the recovery durations in order of best sprint performance, from best to worst (1 mark)
 - the recovery durations in order of total time, from best to worst. (1 mark)
- Distinguish between the 15 s and 20 s groups, and the 20 s and 25 s groups. (2 marks)
- Discuss the relevance of these results to competitive soccer. (4 marks)

Data-based question 2

A study investigated the sleep practices of elite (national-level; $n = 115$) and sub-elite (regional-level; $n = 223$) athletes (age range 23–25 years) from a variety of sports.

The Pittsburgh Sleep Quality Index (PSQI) was used as a self-report measure of sleep quality. The athlete responses to some of the items on the PSQI are shown in Table 7.

▼ Table 7 Athlete responses to the PSQI

	Athlete level	Athlete responses to the PSQI (percentage)			
		Not during the last month	Less than once per week	Once or twice per week	Three or more times per week
Cannot get to sleep within 30 min of going to bed	elite	34	21	23	30
	sub-elite	45	25	37	21
Wake up during the night	elite	26	21	23	30
	sub-elite	17	25	37	21
Have to get up to use the bathroom	elite	33	21	25	21
	sub-elite	28	34	20	18
Problems staying awake during the day	elite	57	25	11	6
	sub-elite	56	30	12	2

- Identify which group had the lowest percentage who *wake up during the night* less than once per week. (1 mark)
- Calculate the difference between sub-elite athletes who *cannot get to sleep within 30 min of going to bed* less than once per week and once or twice per week. (1 mark)
- Compare and contrast the groups for *problems staying awake during the day*. (3 marks)



B.1

Generating movement in the body

How are the structure and function of the musculoskeletal system related to movement of the human body?

The positions and movements of the body can be described relative to planes and axes of rotation. Connective tissue binds together, supports and strengthens body tissues, such as skeletal muscles, and joints of the skeletal system hold bones together in ways that allow for movement and flexibility. Muscle tissue produces body movements and stabilizes body positions. In producing movement, bones act as levers, and joints function as the fulcrum of these levers. This topic has many implications for sport performance and sports equipment design.

B.1.1

Anatomical position, planes and movement

Syllabus understandings

B.1.1.1 The human skeleton is divided into an axial component and an appendicular component. These have different primary functions.

B.1.1.2 Movements occur in one or more planes, and rotations occur along one or more axes.

B.1.1.3 Anthropometry, the measurement of body segments and proportions of the human body, has applications in many areas of sport and health science.

AHL

Introduction

The human body is made up of bones, joints and muscles that allow it to perform a wide range of movements. To understand how bones, joints and muscles are involved in sporting actions such as running, jumping up to spike a volleyball, kicking a football or throwing a javelin, it is important to know about the position and movements of body parts, and to understand how they work together.

Anatomical terminology

The body is made up of structures such as bones, muscles and organs. It is often divided into segments, for example, the trunk, thigh and upper arm. The positions or locations of these structures are often described in relation to the positions of other body parts. In anatomy, numerous terms are used for this purpose. Sometimes, these terms are included in the names of muscles or other structures in the body, and this can give you a hint about their location. The terms that are commonly used appear in the key terms box.



▲ Figure 1 Understanding the position and movement of body parts is crucial for analysing sporting actions

Key terms

Inferior Below or further away from the head.

Superior Above or nearer to the head.

Proximal Nearer to where a limb attaches to the body.

Distal Further away from where a limb attaches to the body.

Posterior Behind or nearer to the back.

Anterior In front of or nearer to the front.

Internal Located inside or further away from the surface.

External Located on or near the surface.

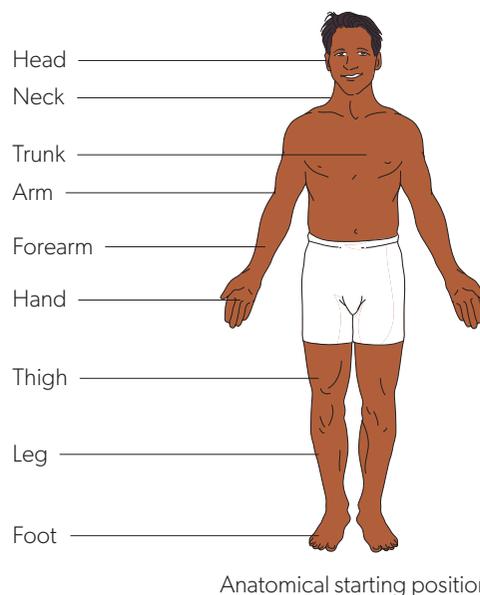
Lateral Further away from the midline of the body.

Medial Closer to the midline of the body.

Intermediate Between two structures, one of which is medial and one of which is lateral.

The position of each of these structures can be affected by posture or how an individual stands.

Reference positions allow you to clarify exactly what starting posture an individual is in (refer to Figure 2). Reference positions are also useful when describing and demonstrating joint movements. An example of a reference position is the anatomical body position, where the individual stands upright, facing straight ahead with the feet parallel and close together, and the palms facing forward.



▲ Figure 2 Anatomical body position

Skeletal system

The skeletal system is made up of the bones, cartilage, ligaments and joints of the body. It accounts for approximately 20% of body weight. The skeleton roughly determines the shape and size of the body (although this is also affected by nutrition, physical activity and posture). There are 206 bones in the skeleton and it is divided into two parts (refer to Figure 3).

- The **axial component** contains 80 bones and includes the skull, ribs, sternum and vertebral column.
- The **appendicular component** has 126 bones and includes the pectoral (shoulder) girdle, the pelvic (hip) girdle and the bones of the upper and lower extremities (the arms and legs).

The pectoral and pelvic girdles attach the upper and lower extremities to the axial skeleton. The scapula and clavicle make up the pectoral girdle and the bones of the upper extremity include the humerus, ulna, radius, carpal bones, metacarpals and phalanges. The bones of the lower extremity include the femur, tibia, fibula, tarsal bones, metatarsals and phalanges.

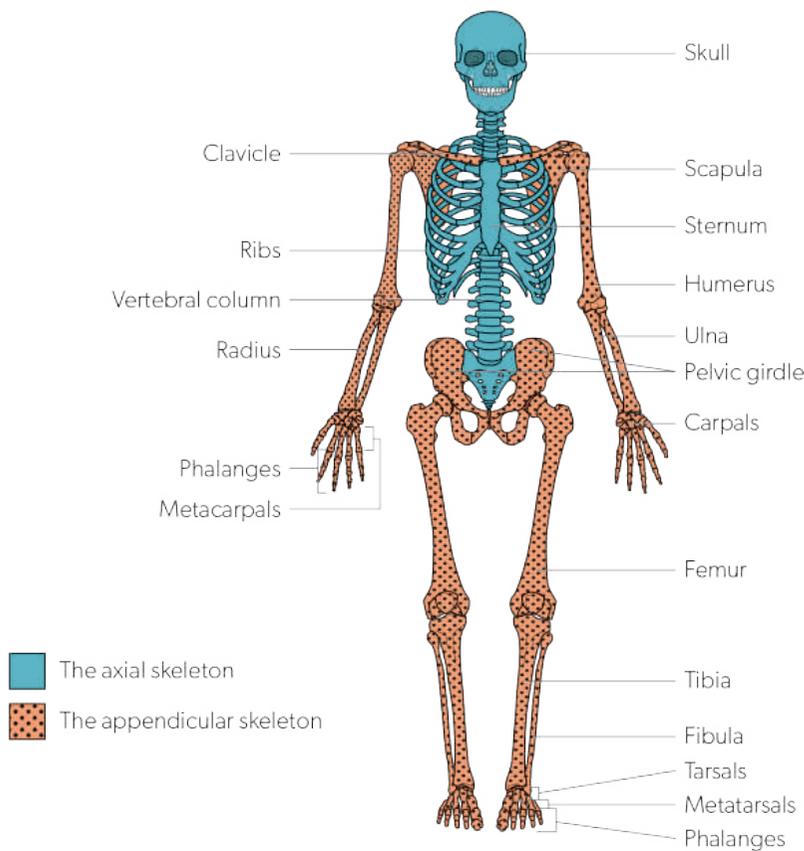
Activity 1

Use the terms in the key terms box to describe the positions of different parts of the body. The body parts can be muscles, organs, limbs or any other structure you know the location of. For example, the lungs are internal to (inside) the ribcage.

Activity 2

Stand in a relaxed position. Now stand in the anatomical body position.

Can you think of any body parts that change location relative to each other when you stand in these two different positions?



◀ **Figure 3** Bones of the axial and appendicular skeleton

The skeleton has several functions (refer to Table 1).

▼ **Table 1** Functions of the skeleton

Function	Description
protect vital organs	<ul style="list-style-type: none"> the ribcage surrounds the heart and lungs the skull encloses the brain the vertebrae surround the spinal cord
support and maintain posture	<ul style="list-style-type: none"> the skeleton provides a framework for the body each part bears the weight of all structures of the body above it the vertebral bones get bigger as you move down the body as they have to bear more weight the bones of the lower extremities are larger than those in the upper extremities as humans walk on their feet rather than their hands
provide attachment points for muscles	<ul style="list-style-type: none"> muscles run from one bone to another, and they are connected to the bones via tendons bones are not completely smooth but have roughened areas or prominent landmarks where the tendons of muscles usually attach when muscles and tendons contract, they pull on the bones causing movement at the joints
store and release minerals, such as calcium and phosphorus	<ul style="list-style-type: none"> these minerals are important for muscle contraction and nerve activity minerals are released into the blood to maintain mineral homeostasis and be distributed to other parts of the body
haemopoiesis	<ul style="list-style-type: none"> haemopoiesis is the production of red blood cells, white blood cells and platelets in bone marrow bone marrow is typically located in flat bones such as the ribs and sternum or in the ends of long bones such as the femur and humerus
store energy	<ul style="list-style-type: none"> lipids are stored in yellow bone marrow, which is located inside long bones lipids provide important chemical energy reserves

Axial component of the skeleton

The bones of the axial skeleton (skull, sternum, ribs and vertebral column) enclose important structures in the body and, therefore, their main function is to provide protection.

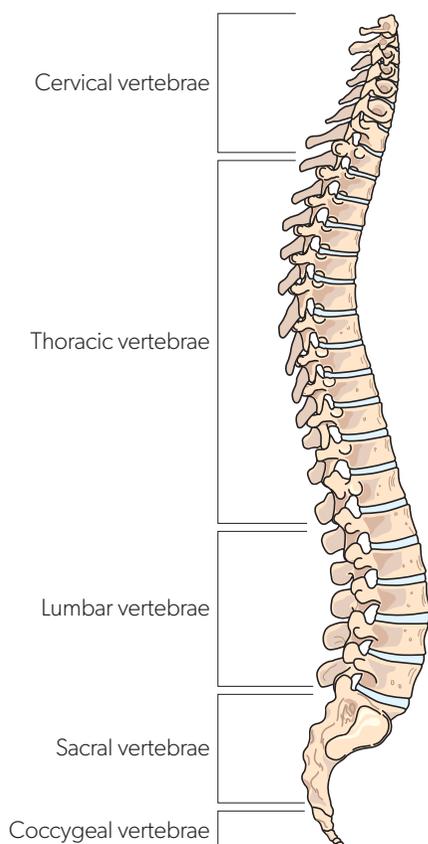
Skull

The skull sits on top of the vertebral column and is divided into the cranium and the face. As well as protecting the brain, the bones of the skull also protect the eyes and ears and contain the teeth.

Vertebral column

There are 33 vertebrae in the body, all stacked on top of each other to form the vertebral column. This column is very strong, but it is also flexible as it bends anteriorly (forwards), posteriorly (backwards), laterally (to the side) and rotates.

The vertebrae are divided into sections (Figure 4). Together they make up about 40% of the total height of the body.



▲ **Figure 4** Lateral view of the vertebral column

ATL Research skills

Correct posture is seen as a key element in maximizing performance and the correct growth of humans. Research the use of yoga or pilates as a means for correct postural development.

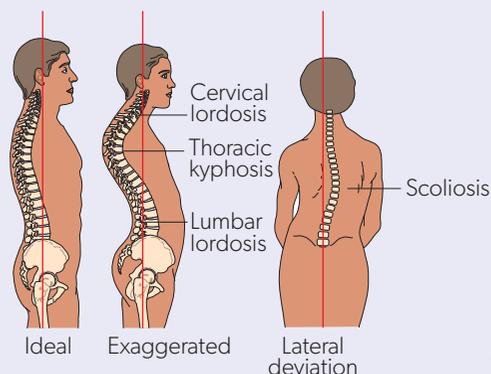
ATL Thinking skills

Problems with spinal curves

An exaggerated lumbar curve or large arch in the lower back is called lumbar lordosis. This is often associated with obesity, poor posture, and tightness and/or weakness in the hip, back and abdominal muscles.

An exaggerated thoracic curve or having excessively hunched shoulders is called kyphosis. This is associated with poor posture, and tightness and/or weakness in the chest, neck and upper back muscles.

An excessive lateral curvature in the spine is called scoliosis. This may resemble an “S” or a “C” shape when looking at the spine from behind. If this is due to poor posture, muscle tightness and/or muscle weakness, it can be fixed. However, if it is congenital (present since birth) and due to a structural deformity such as a hemivertebra (half vertebra), surgery may be required.



◀ **Figure 5** Ideal posture, lordosis, kyphosis and scoliosis

Sternum and ribs

The sternum is a flat bone that starts at the bottom of the throat and runs about halfway down the chest in the centre. The ribs are curved bones that articulate with the sternum at the front and the thoracic vertebrae at the back. There are 12 pairs of ribs in total. Together, the sternum, ribs and thoracic vertebrae form the thoracic cage. The intercostal muscles, which are essential for breathing, are located in between the ribs, which is why any damage to the ribs also affects breathing.

Appendicular component of the skeleton

The appendicular skeleton is mostly involved in movement.

Upper body

In the upper body, the pectoral (shoulder) girdles are formed by the clavicles and scapulae. The clavicles articulate with the sternum anteriorly and this is the only bony connection between the pectoral girdle and the axial skeleton.

The humerus is the bone in the upper arm and is a typical long bone, enlarged at the upper and lower ends. The upper end articulates with the lateral part of the scapula to form the shoulder joint, while the lower end articulates with the proximal ulna to form the elbow joint. The ulna is one of two long bones in the lower arm, the other being the radius. Together these bones form the radioulnar joint, where the bones rotate around each other.

At the wrist, the radius and ulna articulate with the carpal bones. Each finger has three phalanges, while the thumb has only two. These bones form the individual joints within the fingers, which allow very fine, specific movements.

ATL Thinking skills

Biological sex differences and the skeleton

The bones of the skeleton of the biologically male sex are usually larger and heavier than the bones of the skeleton of the biologically female sex. As the muscles are usually bigger, they exert more of a pull on the bones, so the prominent ridges and bumps, which provide points for muscle attachment, are usually larger in the biologically male sex.

However, the main difference is that the pelvis is wider and shallower for the biologically female sex. Why do you think this is?

Lower body

The structure of the upper and lower extremities is very similar. The pelvis is made up of three bones fused together—the ilium, ischium and pubis. It articulates with the sacrum and therefore provides the link between the lower extremities (the legs) and the axial skeleton.

There is one long bone in the upper leg called the femur, which is enlarged at both the proximal and distal ends. The femur is the longest and heaviest bone in the body. The tibia is the prominent bone found anteriorly in the lower leg—this is often called the shin bone. The fibula is another long bone, which runs parallel and lateral to the tibia.

The patella (or kneecap) is a small triangular bone located at the front of the knee joint. The patella increases the leverage of the tendon of the quadriceps femoris muscle, maintains the position of the tendon when the knee is bent (flexed) and protects the knee joint.

At the ankle joint, the tibia and fibula articulate with the talus, which is one of the tarsal bones. However, the most prominent tarsal bone is the calcaneus, which forms the heel bone. The distal row of tarsals articulates with the metatarsals, which, in turn, articulate with the phalanges. Again, each toe has three phalanges except the big toe which has only two.

ATL Research skills

The diaphragm and the internal and external intercostal muscles are involved in breathing.

Carry out research to answer these questions.

1. Explain what happens to the thoracic cavity during breathing.
2. Identify which muscles are used in:
 - a. inspiration
 - b. expiration
 - c. forced expiration.

Key term

To articulate To form a joint.

Key point

The axial skeleton's main function is to provide protection for important structures in the body, while the appendicular skeleton is mainly involved in movement.

Joint and movement type

The musculoskeletal system is the arrangement of bones, joints and muscles that permits movement of the human body in sports and exercise. The body segments are articulated by the **synovial joints** at which two or more bones meet. Usually, movement consists of **rotation** of one segment relative to another at the joint. This rotation is caused by forces originating from the muscles, other parts of the body, or external actors (such as gravity, sporting implements or other people). Understanding the movements possible at the joints and how the muscles control these movements is crucial for us to be able to analyse human activity in sport and exercise.

When segments of the human body move, it is useful to describe the movements precisely and concisely. Therefore, there is a system of naming the movements of the body's segments that is used in sport, exercise and health. Knowledge of these terms will greatly assist description and analysis of motion, as well as promote greater understanding between sports scientists, physical educators, coaches and sports medicine practitioners.

Activity 3

In which plane does each of the following movements take place?

1. Backwards somersault
2. Cartwheel
3. Squat exercise
4. Lateral leg raise

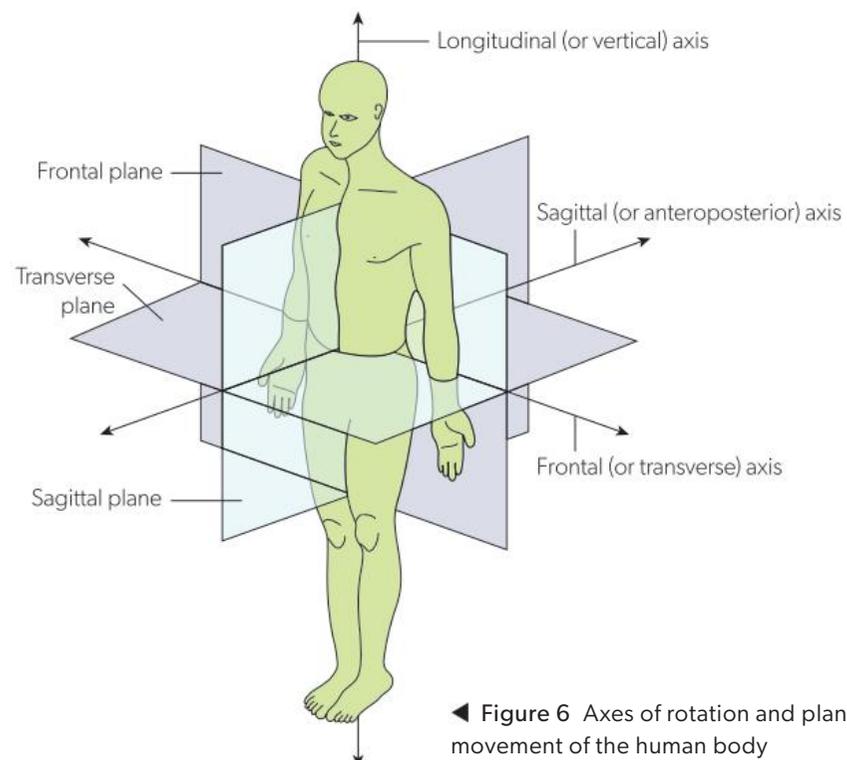
Axes of rotation and planes of movement of the human body

There are several planes and axes that provide a reference for describing the motion at the joints as well as movement of the whole body. These axes and planes use the same anatomical terminology introduced earlier in the chapter.

There are three fundamental axes of rotation:

- the sagittal axis (going from front to back)
- the frontal axis (going from left to right)
- the longitudinal axis (going from top to bottom).

For the whole body, these axes pass through the centre of gravity as shown in Figure 6.



◀ **Figure 6** Axes of rotation and planes of movement of the human body

For individual joints these axes pass through the joint centre. Of course, at some joints (particularly triaxial joints—refer to chapter B.1.2) the axis of rotation may be at some oblique angle and not about one of the reference axes, depending on the position of the static bone and the motion of the moving bone at the joint. Also, at individual joints, practitioners may refer to the “longitudinal axis”, meaning the axis from the proximal end to the distal end of the moving bone at the joint.

Movement of the body’s segments at the joints can be considered to be in three planes. Of course, it is possible to move in a combination of two or more of these planes. When applied to the whole body, these planes go through the centre of gravity (Figure 6) and are:

- the frontal plane (cuts the body front from back)
- the sagittal or median plane (cuts the body left from right)
- the transverse plane (cuts the body top from bottom).

These planes can also refer to movements at individual joints.

Movements at the joints

The movements of the body segments at the joints are given particular names. Now the reference axes of rotation and planes have been defined, these movements can be described (Table 3). The movements are usually assumed to start with the segments of the body in the anatomical starting position, with the individual standing upright, facing straight ahead with the feet parallel and close together and the palms facing forward.

▼ Table 3 The fundamental movements that apply to all joints

Motion in the sagittal plane	
flexion	closing of the joint angle around the frontal axis at the joint
extension	opening of the joint angle around the frontal axis at the joint
Motion in the frontal plane	
abduction	opening of the joint angle around the sagittal axis at the joint
adduction	closing of the joint angle around the sagittal axis at the joint
Motion in the transverse plane	
medial (inward) rotation	the anterior surface of the moving bone moves towards the medial (inside) aspect of the body
lateral (outward) rotation	the anterior surface of the moving bone moves towards the lateral (outside) aspect of the body

These are the main fundamental movements that apply to all joints, as long as the structure permits movements around the appropriate axes. For example, the elbow joint flexes when it bends and extends when it straightens, but the structure of the joint does not permit abduction, adduction, or medial or lateral rotation. Conversely, the shoulder joint flexes when the arm is raised and extends when it is lowered (these two movements are the opposite to what might be expected), abducts when the arm is raised from the side and adducts when it is lowered again. The humerus (upper arm) can also undergo rotation around the frontal axis at the shoulder joint, demonstrated by the fact that when the elbow is kept fully extended, the hand can still go from facing anteriorly to posteriorly (medial rotation) and back again (lateral rotation).



Activity 4

Complete Table 2 by identifying the plane of movement and the axis of rotation for the following trampoline skills.

▼ Table 2

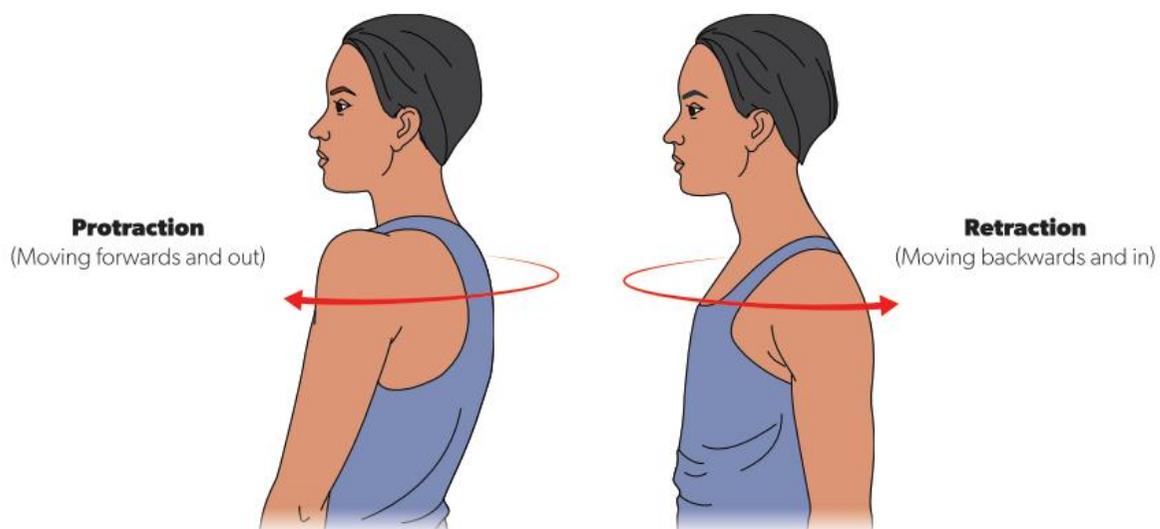
Trampoline skill	Plane of movement	Axis of rotation
Pike jump		
Seat drop		
Tuck jump		
Front somersault		
Half-twist		

When the word hyper (Greek for “beyond” or “more than”) is added to any of these terms, this usually indicates that the action is beyond 180° or back past the starting position. It is also sometimes defined as movement of a body segment into the space posterior to the body when it is in the anatomical position. For example, hyperextension of the shoulder is when the arm extends in the sagittal plane and then continues past the anatomical position behind the body.

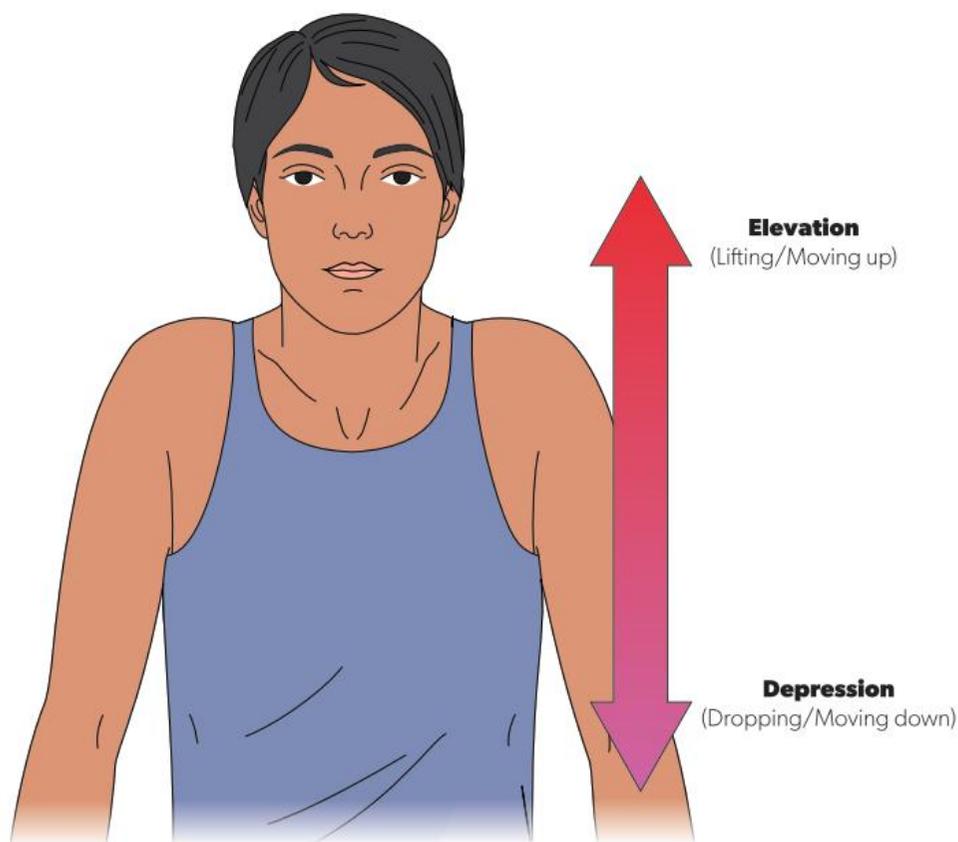
There are also some commonly used terms that apply to particular joints as listed in Table 4.

▼ Table 4 Movements that apply to particular joints

Movement	Description	
elevation	lifting or moving upwards	<ul style="list-style-type: none"> shrugging the shoulders at the acromioclavicular joint to elevate the scapula
depression	dropping or moving downwards	<ul style="list-style-type: none"> returning shrugged shoulders to the anatomical position to depress the scapula
protraction	anterior movement of a body part in the transverse plane	<ul style="list-style-type: none"> shoulder blades are forward and outward (“rounded” shoulders)
retraction	a movement of a protracted part of the body back to the anatomical position	<ul style="list-style-type: none"> shoulder blades are backward and inwards on your back
horizontal extension	opening of the joint angle around the transverse plane when the body segment has already been flexed to 90°	<ul style="list-style-type: none"> if the arm is flexed (raised in the sagittal plane) to 90° and then brought towards the midline of the body horizontal, this is horizontal adduction (horizontal flexion)
horizontal flexion	closing of the joint angle around the transverse plane when the body segment has already been flexed to 90°	<ul style="list-style-type: none"> if the arm is moved horizontally away from the midline when already flexed to 90°, this is horizontal abduction (horizontal extension)
dorsiflexion	flexion of the ankle joint	<ul style="list-style-type: none"> moving the foot up and down in the sagittal plane
plantarflexion	extension of the ankle joint	
eversion	medial rotation of the ankle joint	<ul style="list-style-type: none"> “rolling” the foot at the ankle from the anatomical position, if the foot is moved so that the sole faces inwards, this is inversion if the foot is moved so the sole faces outwards, this is eversion
inversion	lateral rotation of the ankle joint	
pronation	medial rotation of the radioulnar joint (not the wrist joint)	<ul style="list-style-type: none"> forearm (and the hand) rotation, even when the elbow is flexed if the elbow is flexed to 90° from the anatomical position, pronation would take the hand from “palm upwards” to “palm downwards”, and vice versa for supination
supination	lateral rotation of the radioulnar joint (not the wrist joint)	
opposition	movement of the thumb across the palm to touch fingertips on the same hand	<ul style="list-style-type: none"> distinctive digital movement that gives humans and other primates the ability to grasp and manipulate objects very precisely
reposition	returning the thumb to its anatomical position next to the index finger	



▲ Figure 7 Protraction and retraction



▲ Figure 8 Elevation and depression

Combinations of fundamental movements

There are several movements that are actually combinations of the fundamental movements listed above, but which are given a single name for ease of understanding.

Circumduction

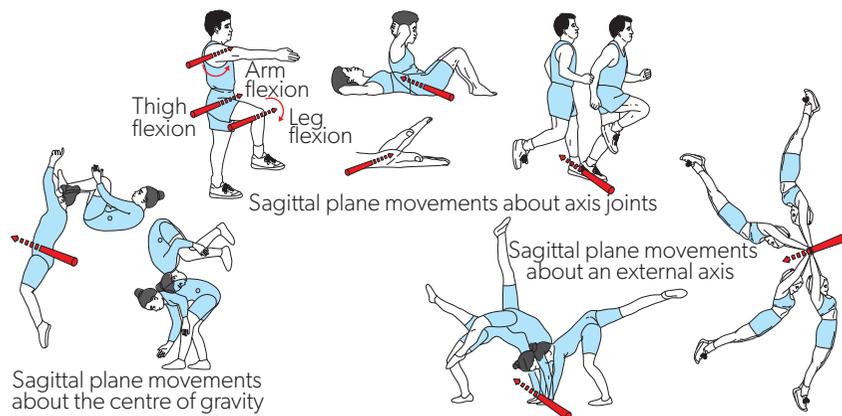
This is the “circling” of a body segment at a joint, for example, moving the arm in a circle around the shoulder, such as in cricket bowling. This particular

movement is actually a combination of hyperextension, abduction, extension and adduction. Circumduction may include other movements in the circling action depending on the direction, axes of rotation and the particular joint. Circumduction commonly occurs at the shoulder, hip, wrist, ankle and thumb, meaning it requires at least a biaxial joint—refer to chapter B.1.2.

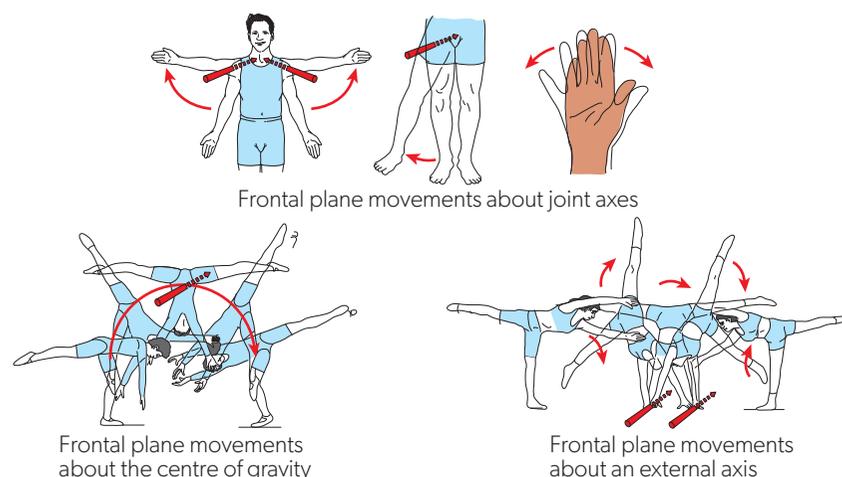
Pronation and supination of the foot

These movements are often used by sports medicine practitioners to describe motion of the foot at the ankle joint (combined with the other joints in the foot) during walking or running. Pronation combines dorsiflexion, eversion and abduction of the ankle and foot, and often occurs just after landing in walking or running as the body’s weight is absorbed. Supination is plantarflexion, inversion and adduction and often occurs during push-off in walking and running as the ankle is used to propel the person forward and upward. Not all individuals demonstrate pronation on landing, however; it depends on their body structure and their movement technique.

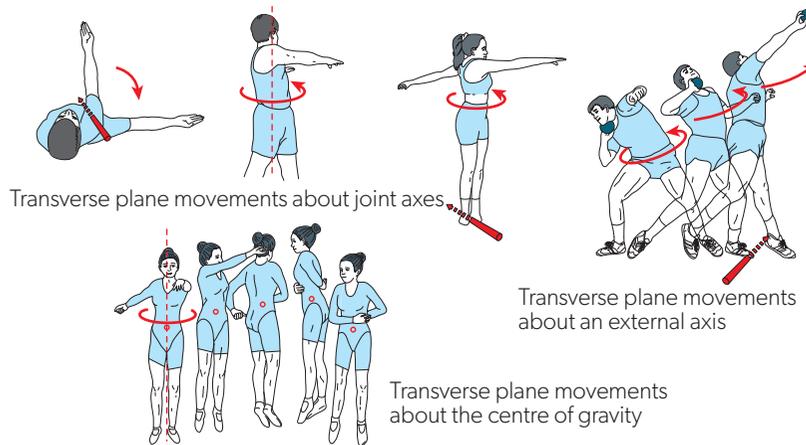
Examples of some movements are shown in Figures 9–11.



▲ Figure 9 Sagittal plane movements



▲ Figure 10 Frontal plane movements



▲ Figure 11 Transverse plane movements

Range of motion

The range of motion (ROM) at any particular joint depends on four factors:

- the shape of the surfaces of the articulating bones in the joints
- the position and length of the restraining ligaments
- the effects of the muscles and tendons at the joint
- the amount of soft tissue (skin, fat, muscle) at the joint.

A large ROM is usually beneficial for sporting performance as it means forces can be applied over a greater distance. However, excessive ROM is sometimes called hypermobility and can make joints susceptible to dislocation or damage. This can be a problem for performers in those sports and activities that require a large amount of flexibility, such as gymnastics or ballet dancing.



Linking question

Can understanding and applying the correct anatomical terms of movement increase the rate of learning a skill? (C.2.1)

Consider:

- descriptive language and a mental picture of the movement being performed
- whether or not mental imagery can enhance the execution of a skill
- anatomical terms, visualizing a movement and improving the quality of a movement
- effective communication between coaches and athletes
- augmented reality (for example, using a screen, smartphone or tablet to observe computer-generated virtual images), virtual reality (such as a 3D world instead of 2D images) and efficient learning.

Anthropometry and ergonomic design

Anthropometry for the design and sizing of sports and exercise equipment

Anthropometric data measure human body dimensions, proportions and physical characteristics. Databases of anthropometric data are used by equipment manufacturers in the sports and exercise industry in several ways, including:

This work must not be reproduced, stored, transmitted or circulated in any other form.

ATL Thinking skills

What effect might the use of anthropometric databases and ergonomic design have on cognitive load and decision-making during sport?

- designing equipment for the diversity of body sizes and proportions
- ensuring a better fit (for the various body types)
- reducing the risk of injury or discomfort (sizing).

Additionally, analysis of anthropometric databases aids equipment manufacturers in understanding the relationship between body dimensions and sport performance characteristics. This means they can design equipment that enhances performance by optimizing factors such as aerodynamics, balance, leverage and ROM. By incorporating anthropometric databases into their design processes, equipment manufacturers can create products that are better suited to the diverse range of body sizes in the general population, promoting inclusivity, an enhanced user experience and satisfaction with sports and exercise equipment.

ATL Thinking skills**The evolution of sports equipment**

The first international Olympic Games in modern history was held in 1896 in Athens. The American athlete William Hoyt used a wooden pole to win the pole vault competition with a height of 3.30 metres. Since then, more flexible poles made of fibreglass or carbon fibre have been introduced. The current world record exceeds 6 metres, almost double the height of William Hoyt's winning jump.

Explain how the evolution of sports equipment design has led to improvements in power output and energy return during sports performance using:

- tennis rackets
- golf clubs
- bicycle frames
- bicycle helmets
- sprint prostheses.

Ergonomic design

Ergonomic design takes into account the human body's biomechanics (and physiology) to create equipment and environments that minimize discomfort and fatigue. By providing proper support, padding and ergonomic contours, equipment can reduce pressure points, minimize muscle strain and improve overall comfort. This allows athletes and individuals to focus more on their performance and expend less energy on unnecessary discomfort or fatigue.

Ergonomic design promotes correct posture and body alignment, which is crucial for efficient movement and performance. Proper alignment reduces stress on joints, muscles and tendons, enabling smoother and more efficient biomechanics. This reduces the risk of injuries and allows individuals to optimize their movement patterns, leading to improved efficiency and performance.

Ergonomically designed equipment facilitates an optimal ROM, enabling athletes to move freely and efficiently. Restrictive or poorly designed equipment can limit movement, hinder technique and negatively impact performance. Ergonomic considerations ensure that equipment allows for natural joint movements and freedom of motion, enabling athletes to perform their movements with minimal constraints or energy expenditure.

In sports and exercise equipment that involves interfaces or controls, ergonomic design focuses on creating intuitive and user-friendly interfaces.

Testing and feedback sessions allow manufacturers to understand how their equipment affects performance. This iterative approach helps refine designs to meet the needs and preferences of the target users.

Case study**Customized swimming goggles using a 3D facial scan of the swimmer**

Swimming goggles are produced as "one-size-fits-all", which often does not work well. Many swimmers' goggles leak water during swimming; the swimmer may lose some visibility in the water and drag may increase. Leakage occurs because the swimming goggles do not fit the facial structures of the user—they do not provide an effective seal on the face. To create a tighter seal, competitive swimmers often overtighten the fastening strap, causing discomfort on the eyes due to increased pressure. Coleman et al. (2017) developed customized swimming goggles using a 3D facial scan of the swimmer to prevent leakage and, importantly, reduce drag.



▲ Figure 12 For competitive swimmers, custom fit swimming goggles can reduce drag

Case study

Designing equipment for individual performance in Paralympic sit-ski

Sometimes there may be a mismatch between an athlete's body and available equipment, resulting in suboptimal performance conditions. For Paralympic athletes this is a major issue. Nesheim et al. (2022) have suggested a "human-to-product" path for Paralympic cross-country skiing, which was introduced in the Paralympics Winter Games in 1976 in Örnsköldsvik, Sweden. Athletes compete in cross-country skiing

distances ranging from 1 km to 30 km. Special rules for the skiers are that the buttock must be secured onto a seat in the race, and the maximum height between this contact point and the skis is 40 cm. All equipment that increases the athlete's performance except the design and seating position is restricted. Nesheim et al. (2022) investigated how an individual human geometry can be fitted into different positions on a sit-ski (Figure 13).



▲ Figure 13 The three experimental sit-ski positions, from left to right: position 1, 2 and 3

They tested three different sit-ski positions with elite Paralympian sit-ski athletes. Ski poles were adjusted to match the height of the shoulder for each position, on a Paralympic competition track (on snow and including

an uphill section) in Trondheim (Norway). They recorded mean time, and the maximum heart rates during both the uphill and flat sections of the sit-ski course. These are shown in Table 5.

▼ Table 5

	Mean time (min:sec)	Heart rate maximum uphill (bpm)	Heart rate maximum on the flat (bpm)
Position 1	5:57	157 ±1	126 ±4
Position 2	6:00	148 ±5	127 ±1
Position 3	5:52	155 ±2	130 ±3

Some qualitative comments from the athletes were:

- overall, position 1 felt more demanding than positions 2 and 3
- position 3 felt more demanding than position 2 when going uphill
- position 3 was the most comfortable on the flat section.

1. Which position had the fastest mean time?
2. Which position had the highest maximum heart rate for the uphill sections of the course?
3. Which position had the highest maximum heart rate for the flat sections of the course?

This type of study opens up more possibilities in designing sports equipment based on individual human geometry, especially for Paralympic sports equipment.

Linking question

How does the use of anthropometry assist with the design of protective equipment? (B.3.2)

Consider:

- sizes and proportions of protective equipment for comfort
- sizes and proportions of protective equipment to minimize the risk of injury
- ergonomics and the ROM and joint angles of athletes
- identifying areas of the body that are most vulnerable to injuries in specific sports
- sex-specific design
- customization and personalization of protective equipment.

Linking question

Can the ergonomic design of sporting implements aid in skills acquisition? (C.2.1)

Consider:

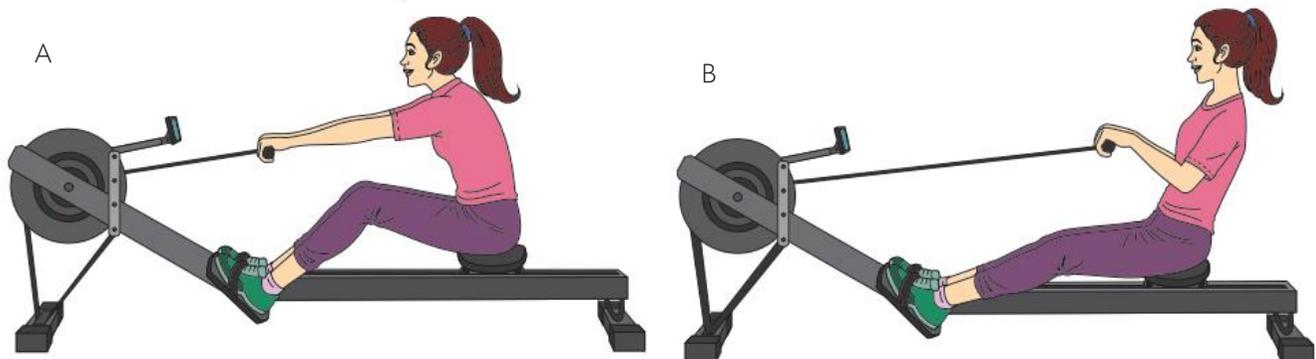
- anatomy of the learner (for example, hand size relative to ball size)
- matching the functional capacities of the performer/scaling
- constraints and skill acquisition
- implicit motor learning
- efficient movement
- control of movements
- reduce fatigue/practise for longer
- reduce risk of injury
- confidence and motivation.



▲ Figure 14 Many sports, including lacrosse, require the use of sporting implements

Practice question

The diagram shows a rower using a rowing machine. Analyse the movement at the knee and hip as the rower moves from position A to position B in the diagram. (6 marks)



▲ Figure 15

Summary

- The axial skeleton includes the skull, sternum, ribs and vertebrae. Its main function is protection.
- The appendicular skeleton includes the pelvic and pectoral girdles and all the bones of the upper and lower extremities. Its main function is movement.
- Specific anatomical terminology is used to describe the relative position of body parts and movements of the body.
- Anthropometric data can help manufacturers develop performance-enhancing sporting equipment.
- Ergonomic design takes into account the human body's biomechanics (and physiology) to create equipment and environments that minimize discomfort and fatigue.

AHL

Check your understanding

After reading this chapter, you should be able to:

- describe the anatomy and function of the axial and appendicular skeleton
- use anatomical terminology to describe relative positions of body parts
- provide some examples of movements in the context of planes and axes
- outline how anthropometry has applications in sports and health science.

AHL

Self-study questions

1. List the **three** fundamental planes and **three** fundamental axes of rotation in the human body.
2. Distinguish between pronation and supination, and inversion and eversion.
3. Outline **three** functions of the skeletal system.
4. Identify the plane of movement and the axis of rotation for the following physical activities:
 - a. sit-up/trunk curl exercise
 - b. a set shot in basketball
 - c. throwing a dart towards the bullseye of a dartboard
 - d. arm recovery during swimming when doing the front crawl.
5. Explain why customized swimming goggles have been developed for elite swimmers.

AHL



Data-based question

Children are often encouraged to participate in sports based on their body shape. For example, many tall young people are encouraged to play basketball. A study compared the body size (height, arm span) for two groups: group 1 were professional basketball players and group 2 were recruits in a national army. Table 6 shows descriptive statistical data (mean \pm SD) for both groups.

▼ Table 6

		Height (cm)		Arm span (cm)	
		mean	SD	mean	SD
Group	<i>n</i>				
Basketball	2,990	195.9	9.1	206.7	10.8
Army	4,082	175.6	6.9	181.4	8.5

1. Identify which group had the lower arm span. (1 mark)
2. Calculate the difference in mean height between the groups. (2 marks)
3. Suggest why the basketball players have a larger standard deviation for both height and arm span. (4 marks)

B.1.2

Structure and function of connective tissues and joints

Syllabus understanding

B.1.2 The structure of connective tissues and joints are related to their function in enabling movement.

Introduction

Connective tissue is one of the most abundant tissue types in the body. Connective tissue has a variety of functions. It binds together, supports and strengthens other body tissues, protects internal organs and permits movement. Other functions are associated with compartmentalizing structures such as skeletal muscles (dividing and separating different groups of muscles), acting as a site of stored energy reserves (fat tissue) and acting as a site of immune responses. Joints are classified structurally (based on their anatomical characteristics) and functionally (based on the type of movement they permit).

This chapter will outline and explain how the structures of connective tissues and joints are related to their function in enabling movement.

Connective tissues

Bones

As we saw in chapter B.1.1 (refer to B.1.1 Figure 3), the bones in the human body vary widely in size and shape. The main factor in determining the size and shape of bones is their location and function. The four main types of bones are long, short, flat and irregular.

- Long bones usually have a long cylindrical shaft and are enlarged at both ends. They can be large or small but the length is always greater than the width. Long bones are the most important bones for movement. They include the femur, metatarsals and clavicle.
- Short bones are small and cube-shaped and they usually articulate with more than one other bone. Short bones include the carpals of the hand and tarsals of the foot.
- Flat bones usually have curved surfaces and vary from being quite thick to very thin. These bones provide protection and the broad surfaces also provide a large area for muscle attachment. Flat bones include the sternum, scapula, ribs and pelvis.
- Irregular bones have specialized shapes and functions and include the vertebrae, sacrum and coccyx.



▲ Figure 1 Connective tissues and joints enable movement

ATL Research skills

Sesamoid bones

Another type of bone found in the body is the sesamoid bone. These are short bones embedded in tendons where large amounts of pressure develop.

- Identify three areas of the body where sesamoid bones are found.
- What is the largest sesamoid bone in the body?
- It is embedded in the tendon of which muscle?
- What is its main function?

Activity 1

Use a skeleton or a picture of a skeleton to help you with these tasks.

- Identify the bones of the axial skeleton and the appendicular skeleton.
- Indicate what type of bone each one is.
- Most bones are not entirely smooth and have rough areas and prominent landmarks where muscles, tendons and ligaments often attach. See if you can feel the prominent bony landmarks on your arms, legs and trunk. Can you identify which bones these are?

Functions of bone and the skeletal system

Bone tissue and the skeletal system perform several basic functions (Table 1).

▼ Table 1 Functions of the bone tissue and skeletal system

Function	Description
support	<ul style="list-style-type: none"> • the skeleton is a structural framework that supports soft tissues and provides attachment points for the tendons (of most skeletal muscles)
protection	<ul style="list-style-type: none"> • the skeleton protects many internal organs from injury (for example, the rib cage protects the heart and lungs)
assistance in movement	<ul style="list-style-type: none"> • skeletal muscles attach to bones, and when muscles contract they pull on bones to produce movement
mineral homeostasis	<ul style="list-style-type: none"> • bone tissue stores several minerals, such as calcium and phosphorus—when required, bone can release minerals into the blood to distribute them to other parts of the body
blood cell production	<ul style="list-style-type: none"> • within certain bones (such as the sternum, vertebrae and femur) a connective tissue called red bone marrow produces red blood cells
triglyceride (fat) storage	<ul style="list-style-type: none"> • triglycerides stored in yellow bone marrow—primarily found in the long bones (such as the tibia and humerus)—are an important energy reserve

Key points

The functions of bone tissue include to:

- support soft tissues and provide attachment for skeletal muscles
- protect internal organs
- assist in movement together with skeletal muscles
- store and release minerals
- contain red bone marrow, which produces blood cells
- contain yellow bone marrow, which stores triglycerides (fats).

ATL Research skills

Range of motion (ROM) varies between different joints and between individuals. Many factors can affect ROM including the shape of bones and flexibility of the ligaments and muscles—these are the same factors that influence joint stability. Explain how other factors such as age, sex, muscle bulk, physical fitness, injury, work and exercise habits also affect ROM.

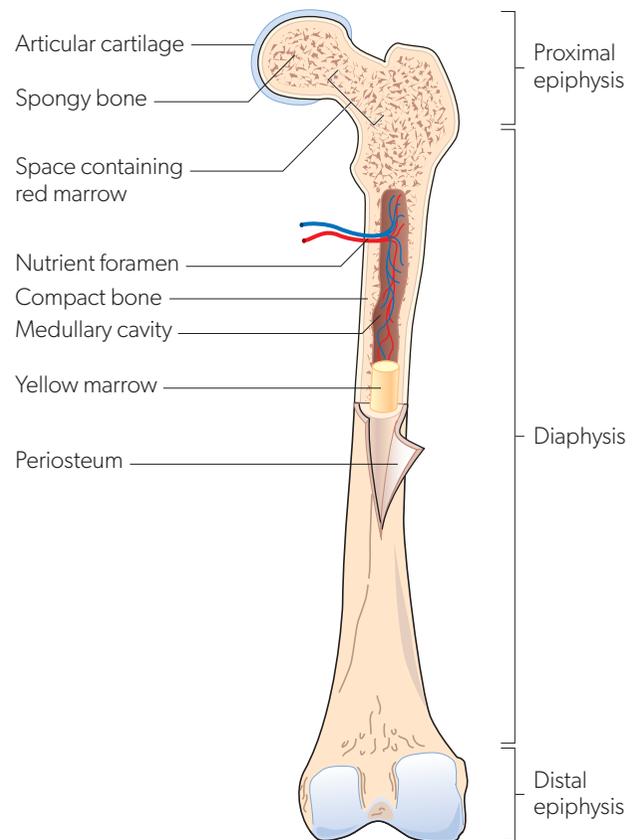
Structure of bone

Bone contains a neatly arranged matrix of protein (collagen) fibres along with water and mineral salts. When the mineral salts accumulate in between and around the collagen fibres, they crystallize and the tissue hardens. However, the collagen fibres also provide high tensile strength, in other words bone resists

being stretched or torn apart. This structure has been likened to reinforced concrete where metal rods run through a block of concrete to reinforce it and give it strength.

The structure of bone can be described by examining a long bone (Figure 2). The shaft or midsection of a long bone is called the diaphysis and is made up of compact bone or hard bone. Compact bone is relatively solid and dense, has few spaces and is also found in the outer layer of most other types of bone. It is important for protection and support and resists the stress of weight placed on long bones. The ends of the bone are called the proximal and distal epiphysis, and these are made of cancellous or spongy bone. Cancellous bone has an irregular latticework structure (like honeycomb) where there are many spaces. Cancellous bone is also found in short, flat and irregular bones. As red bone marrow is stored in cancellous bone, blood cell production occurs here.

A thin layer of articular cartilage covers the ends of the bone where they articulate with other bones to form joints. The main functions of this cartilage are to reduce friction between the bones and absorb shock. The area of bone that is not covered by articular cartilage is covered instead by a thin, shiny white membrane called the periosteum. This forms the outer lining of bone and is important for bone growth, repair, nutrition and attachment of ligaments and tendons. The medullary (marrow) cavity is the space within the diaphysis where yellow bone marrow is stored. There is a small opening in the diaphysis called the nutrient foramen. Blood vessels pass through here, enter the medullary cavity and provide the bone marrow and compact bone with blood and nutrients.



▲ Figure 2 Structure of a long bone (the femur)

Case study

Bone as a dynamic tissue

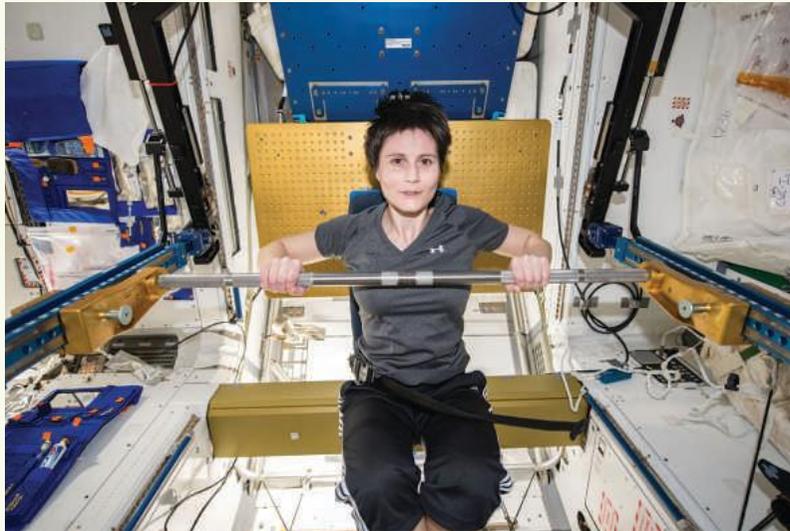
Bone is a dynamic tissue, which means that it is constantly changing in response to activity levels or disuse. Bone cells are continually broken down and removed through a process called resorption and these cells are then replaced with new cells through bone deposition. If the amount of bone that is deposited equals the amount that is resorbed, then bone mass remains constant. An increase in bone mass results in increased strength, whereas decreased bone mass is associated with decreases in strength.

As discussed in chapter A.3.2, weight-bearing physical activity is essential for bone health. Bone can alter its structure and properties if there is a change to the mechanical stress placed on it. The main types of mechanical stress are the skeletal muscles pulling on the bones and the effects of gravity. According to Wolff's law, bone in a healthy person or animal will adapt to the load it is placed under. This means that if a bone is exposed to a greater load, for example through

training, there will be increased mineral salt deposits and greater production of collagen fibres to increase bone strength and the ability to resist this load.

Those who repeatedly apply high stresses to the bones have noticeably higher bone mineral density and stronger bones. In contrast, those who are sick and confined to bed, or those who break a leg and are on crutches, experience restricted weight-bearing activity. This results in too much bone resorption and not enough bone deposition. An active lifestyle therefore supports bone health and reduces the risk of developing osteoporosis.

A special case is that of astronauts who are on space missions. Spaceflight osteopenia can result in losses of up to 1% of bone mass per week as well as decreases in bone strength. Special equipment has been designed to allow astronauts to perform high-intensity workouts while on missions.



▲ Figure 3 Flight engineer and astronaut Samantha Cristoforetti exercises on the specially designed Advanced Resistive Exercise Device (ARED) on the International Space Station

1. What are the bone cells that are involved in resorption and deposition called?
2. What precautions would an astronaut have to take immediately after returning to Earth?
3. Identify a sport that would increase bone density in the lower limbs.
4. Identify a sport that would increase bone density in the upper limbs.
5. Can you think of any sports where bone mass or bone mineral density might be higher in one limb compared with the same limb on the opposite side of the body? Why would this happen?

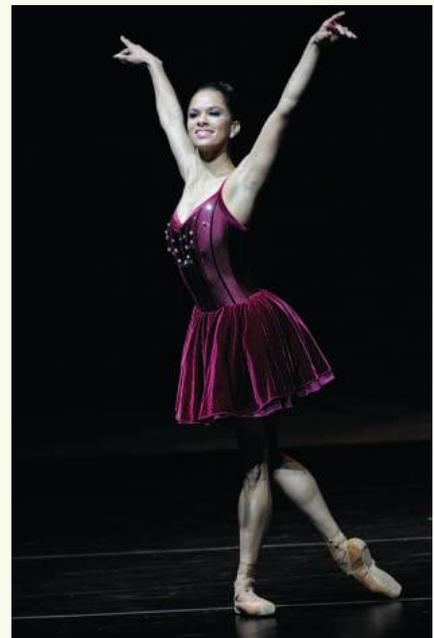
Case study

Bone health and nutrition of ballet dancers

A study (Lambert et al., 2020) reported that professional female ballet dancers exhibit reduced bone mineral density, fat mass, and lean mass compared with the general population. Ballet dancers have, on average, a low bone mineral content (BMC) with elevated fracture risk, low body mass index (BMI) for age and low energy intake. They also have a higher risk of developing relative energy deficiency in sport (RED-S) (chapter A.2.2).

A 2011 study (Burckhardt et al., 2011) aimed at a better understanding of the interactions of these factors in young ballet dancers, especially with regard to nutrition. They found that BMI for age was found to be normal in only 42.5% of the dancers, while 15.7% had a more or less severe degree of thinness. Food intake was below the recommendations for a normally active population in all food groups except animal proteins, where the intake was more than twice the recommended amount. In this population, with low BMI and intense exercise, BMC was low and associated with nutritional factors. They concluded that ballet schools should promote balanced diets and normal weight and should recognize and help dancers avoid eating disorders and delayed puberty caused by extensive dancing and inadequate nutrition. For example, Moore et al. (2023) found that 96% of university female ballet dancers were low in carbohydrate intake, 92% low in protein, 100% low in vitamin D, and 96% low in calcium.

Discuss how to change the mindset of some dancers towards their nutritional needs for bone health.



▲ Figure 4 American ballet dancer Misty Copeland has spoken publicly about delayed onset of puberty and challenges with bone health

Joints

A joint or articulation is where two or more bones come into contact or articulate with each other. The main function of joints is to increase mobility of the body and limbs. Think about how difficult it would be to do a free throw in basketball or to drink from a bottle if you had no elbow joint. The body contains several types of joints, which are classified according to a number of features. The most basic classification relies on the presence or absence of a joint cavity, in other words, if there is a gap between the articulating bones.

Joints are further classified depending on the shape of the articulating bones or the types of tissue that connect the bones together. The shape of the bones and, subsequently, the amount of movement allowed vary between joints; therefore, the structure and function of joints are highly interrelated. Some joints allow little or no movement, others allow movement in one direction only, while others allow a wide range of movements in several directions.

Joint movement and stability

Joint movement is inextricably linked to joint stability. Generally, the more movement a joint has, the less stability it has and the greater the risk of injury. Several factors affect stability around the joints including:

- the shape of the bones and whether they interlock with each other or not
- the area over which the bones are in contact
- the flexibility of the ligaments
- the influence of other soft tissue structures (such as muscles, tendons or joint capsules).

Ligaments

Depending on the joint, there can be numerous ligaments surrounding it. **Ligaments** are strong, flexible tissues that connect bone to bone. They can be in the form of strap-like bands or round cords, and generally pass over joints. This allows them to provide stability and help maintain the normal bony arrangement. Ligaments restrain joint movements once they reach normal limits and resist movements that the joint was not designed for. For example, in the anatomical body position, there are ligaments located on the medial and lateral sides of the elbow joint. Their function is to resist sideways movements of the elbow.

While ligaments are generally very strong, they can be torn if they are suddenly and violently stretched. Also, they are not very elastic and take a long time to return to their original length after they have been stretched. If they are stretched abnormally for prolonged periods, they may be permanently damaged and may never return to their original length. This means that they can no longer provide stability for joints, and there is an increased risk of joint injury.

Cartilage

Cartilage consists of a dense network of collagen (a protein that is the main organic part of connective tissue) fibres and elastic fibres. The strength of cartilage is due to its collagen fibres, and it also has resilience (ability to return to

ATL Research skills

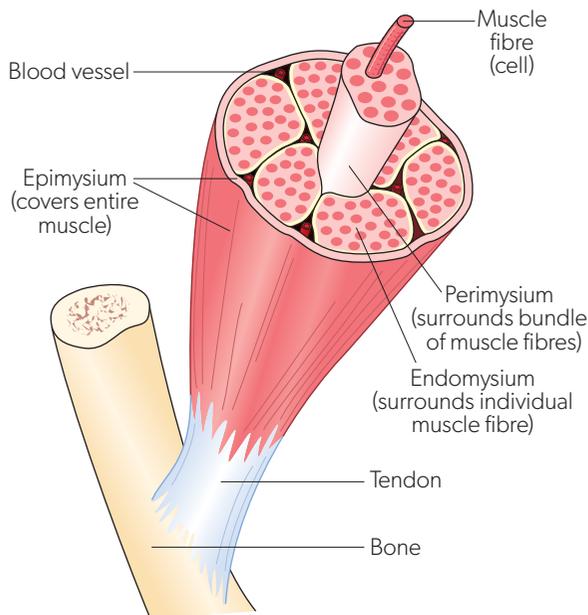
Look up a definition of the term “mentalization” and research whether there is a link between hypermobility and mentalization in dancers.

ATL Thinking skills

A dislocation is when the bones that form a joint come out of their normal alignment. It is often due to forceful movements or impact, and results in damage to the joint capsule and surrounding muscles and ligaments.

Identify a joint that is commonly dislocated.

its original shape). Unlike other connective tissues, cartilage has no blood vessels or nerves, except in the perichondrium (the membrane that covers cartilage). Hyaline cartilage is the most abundant cartilage in the body. It affords flexibility and support and, at joints, reduces friction and absorbs shock. When injured, cartilage repair proceeds slowly, in large part because cartilage lacks its own blood supply.



▲ Figure 5 Bone, tendon, fascia and muscle fibre

Fascia

Fascia is a type of connective tissue that is located in between and surrounding other tissues of the body such as muscles and bones. Fascia is made up of fibrous tissue, adipose (fatty) tissue and fluid. It can be superficial, for example, just under the skin, or deep, for example, when it surrounds the muscles and attaches to bones. In general, skeletal muscles work together in groups to carry out specific actions rather than working independently. They are divided into compartments that contain groups of muscles that have the same function. Each compartment is surrounded by fascia and the same nerve innervates all of the muscles in the compartment.

There are three layers of fascia in each individual skeletal muscle. These are called the epimysium, perimysium and endomysium (Figure 5).

- The epimysium is the outer layer that covers the entire muscle.
- The perimysium surrounds bundles of muscle fibres or fascicles. These fascicles are long, cylindrical and vary in length and width depending on the muscle.
- The endomysium is the layer of fascia that surrounds the individual muscle fibres.

Tendons

When these layers of fascia continue on beyond the muscle fibres, they form **tendons**, which are tough, flexible bands of fibrous connective tissue connecting muscle to bone. Tendons can be in various forms such as a rounded cord or a broad, flat sheet called an aponeurosis. Groups of tendons can also be enclosed in tubes of fibrous connective tissue called tendon sheaths, such as those found in the wrist. These sheaths contain synovial fluid, which helps to reduce friction as the tendons move back and forth across each other. Tendons are very strong and transmit the forces generated by muscles to bone; therefore, they play an important role in muscle contraction and joint movement. The fleshy middle section of the muscle is called the muscle belly, which becomes prominent when the muscle contracts.

Unlike ligaments and tendons, muscles have a good nerve and blood supply. The nerves that bring the impulses from the central nervous system to the muscle are called motor neurons. These neurons release neurotransmitters into the blood that stimulate the muscle to contract and produce force. There is also a rich network of capillaries that provide the muscle with oxygen, nutrients and calcium and remove waste products. This means that muscles are good at repairing damage, for example, if a muscle is pulled or strained.



Linking question

How does training affect the stability and movement of connective tissue? (A.3.1)

Consider:

- role of connective tissue (such as tendons and ligaments) in the body
- training and strength of connective tissue
- strength of connective tissue and injury risk
- stretching/mobility/flexibility exercises, joint mobility/stiffness and efficient movement
- inadequate recovery and overuse injuries
- insufficient recovery and tissue health
- implications of poor technique.

Types of joints

There are three main types of joints: fibrous, cartilaginous and synovial. Fibrous and cartilaginous joints have no joint cavity, whereas synovial joints do.

Fibrous joints have a thin layer of fibrous tissue connecting the edges of the two bones. This is continuous with the periosteum and no movement is allowed at these joints. An example would be between the sutures in the skull.

In **cartilaginous joints**, the bones can be separated by a fibrocartilage disc (such as the intervertebral disc located between adjacent vertebrae), or by a thick layer of hyaline cartilage (such as that connecting the ribs to the sternum). There is limited movement allowed at these joints.

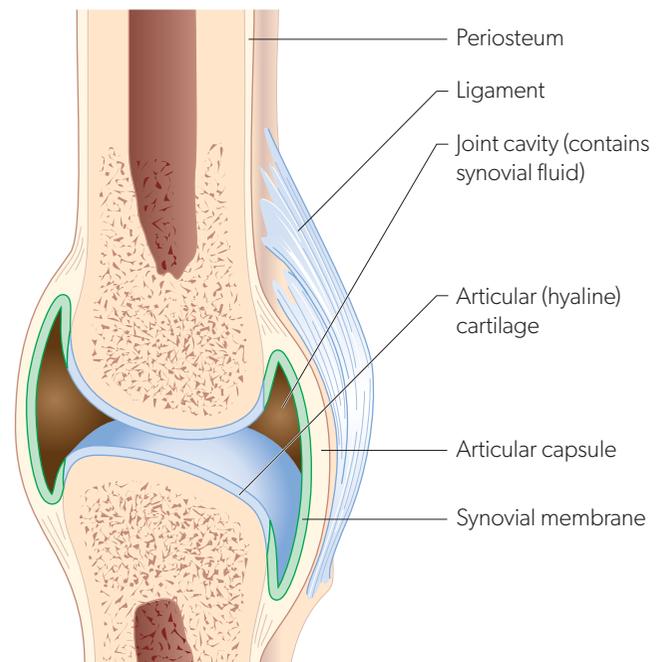
Synovial joints are the most commonly occurring joints in the body and are the most important joints for mobility. They have several distinctive features, as you will notice in Figure 6.

Structure of synovial joints

The space between the bones is called the joint (articular) cavity.

A smooth, white layer of articular cartilage covers the articulating surfaces of the bones. This is usually hyaline cartilage but can occasionally be fibrocartilage. The main functions of cartilage are to reduce friction, absorb shock and protect the bones. It varies in thickness depending on the amount of stress that it is exposed to. Cartilage can wear away from normal wear and tear or overuse (osteoarthritis) and, when it does, the bones grate on each other causing friction and pain during movement.

A sleeve-like structure called an articular capsule surrounds the joint. This capsule is flexible enough to allow joint movements to take place while the tensile strength protects the joint from dislocation. In some joints, the fibres of these capsules are arranged in parallel bundles to form ligaments that provide additional support.



▲ Figure 6 Structure of a synovial joint

ATL Thinking skills

In which joint do you think articular cartilage would be thickest? Why?

The inside of the capsule is lined by a synovial membrane that secretes synovial fluid. This fluid has the consistency and appearance of uncooked egg whites, which makes it quite viscous; however, it does become more fluid with movement. It lubricates the joint cavity, reduces friction and provides nutrients to the cartilage.

Menisci are semilunar discs of fibrocartilage that are found between some articulating bones, for example, between the femur and tibia in the knee joint. The shapes of these bones are not very well matched, but these menisci allow the bones to fit together more tightly. This provides greater cushioning and stability to the joint.

Bursae are small fluid-filled sacs found where two structures rub against each other, for example, between ligament and bone, between tendon and bone, or between skin and bone. As bursae are lined by a synovial membrane, they provide lubrication to the structures and therefore reduce friction. Bursae are found in areas of high stress all over the body.

TOK

There is evidence of the study of anatomy in ancient Egypt as far back as 1600 BCE. Throughout the history of anatomy, there has been controversy over the use of human dissection, with the practice forbidden by many cultures. Historically, sources of cadavers (deceased human bodies) for this purpose have included bodies of executed criminals and illegal thefts from graveyards, as well as people donating their bodies to science.

Recent exhibits of real human bodies, such as Body Worlds, have blurred the lines between science and art, but have also raised ethical concerns around consent.

1. Discuss from an ethical standpoint how we have gained this knowledge and how our access to real human anatomy is being used today.
2. Compare and evaluate the use of cadavers versus online tools as a means of improving knowledge of anatomy.

Types of synovial joint

Most joints in the body are synovial joints and can be classified further depending on how much movement is allowed. The main types of synovial joints are gliding, hinge, pivot, condyloid, saddle, and ball and socket joints.

- Of all the synovial joints, **gliding joints** have the least amount of movement. The surfaces of the bones are flat or slightly curved, and they glide back and forth and from side to side across each other. Gliding joints are found between the tarsal bones and between the carpal bones.
- **Hinge joints** bend (flex) or straighten (extend) in one direction only, for example the elbow joint. Similar movements take place at the knees and in the small joints between the phalanges of the fingers and toes. Usually the surface of one bone is convex and it fits into a reciprocally shaped concave surface.
- In a **pivot joint**, one bone forms a ring in which the other bone rolls or pivots, allowing rotation of the joint, for example, the radius rotates around the ulna at the radioulnar joint.

- **Condylod joints** are formed where an oval or egg-shaped convex surface fits into a reciprocally shaped concave surface. For example, they are found between the radius and carpal bones of the wrist and allow movement in two directions (you can move your wrist both up and down and from side to side).
- In a **saddle joint**, the bones are shaped like a saddle and a rider sitting in the saddle. An example of a saddle joint is found between the metacarpal of the thumb and the carpal bone next to it. These joints can move in two directions (side to side and up and down).
- **Ball and socket joints** can move in all directions and therefore have the greatest amount of movement. They are formed when the sphere-shaped head of one bone fits into a rounded cavity on the other bone, for example the shoulder and hip joints.



▲ Figure 7 Synovial joints include the hip joint (ball and socket), knee joint (hinge) and elbow joint (hinge)

Activity 2

For each of the major joints in the body, identify the type of joint it is and in which directions you can move it.

JOINT	DESCRIPTION	DIAGRAM
Gliding joint For example, between the tarsal bones and between the carpal bones	usually flat or slightly curved bones	
Hinge joint For example, elbow joint	a convex surface fits into a concave surface	
Pivot joint For example, radioulnar joint	rounded surface of one bone rolls around in a ring formed by bone and ligament	
Condylod joint For example, between the radius and carpal bones	oval or egg-shaped convex surface fits into a reciprocally shaped concave surface	
Saddle joint For example, between the carpal bone and metacarpal of the thumb	a saddle-shaped bone fits against another bone shaped like the legs of a rider sitting in the saddle	
Ball and socket joint For example, shoulder joint	sphere-shaped head of one bone fits into a rounded cavity on the other bone	

▲ Figure 8 Types of synovial joint

ATL Thinking skills

Which of the following describes saddle joints?

- Uniaxial (movement around a single axis)
- Biaxial (movement around two axes)
- Triaxial (movement around three axes plus all directions in between)

ATL Thinking skills**Osteoarthritis**

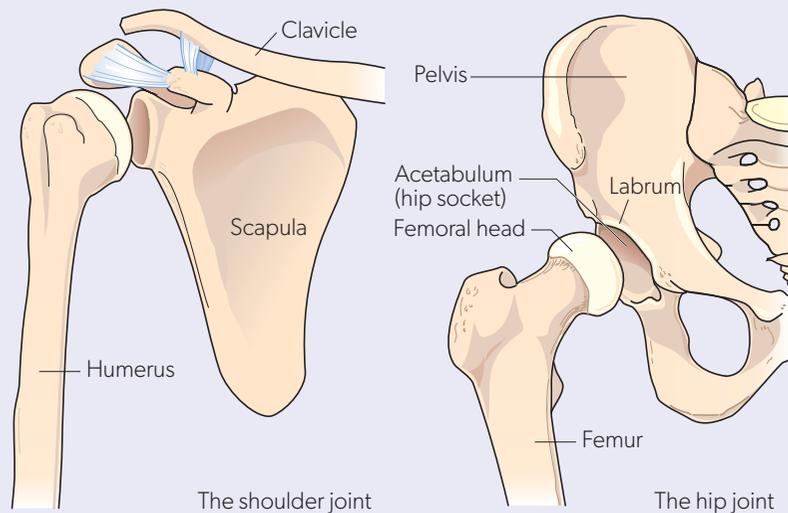
Osteoarthritis is a degenerative condition where the articular cartilage in the joints deteriorates because of overuse or general wear and tear. It occurs most commonly in weight-bearing joints such as the hips and knees. In some cases, new bone tissue develops forming bone spurs, which decrease the size of the joint cavity between the bones. Symptoms of osteoarthritis include stiffness, decreased mobility and grating of the bones against each other, which may cause pain and discomfort. Articular cartilage has no blood supply; therefore, it relies on synovial fluid for nutrients and oxygen and is unable to repair any damage. As it also has no nerve supply, any pain that is felt is due to damage to the surrounding tissues rather than the cartilage itself.

Can you distinguish between osteoarthritis and rheumatoid arthritis?

ATL Research skills**Mobility and stability of the shoulder and hip joints**

Both the hip and shoulder are ball and socket joints. However, their structures are very different, which affects movement and therefore stability. Look at the diagrams of the shoulder and hip joints and think back to the factors that affect joint stability.

- Based on bone structure, which joint do you think is more mobile? Which is more stable? Explain your answers.
- What other factors do you think might influence this?
- How do mobility and stability influence the function of the shoulder and hip joints?
- What effect do these have on injury risk?



▲ Figure 9 Shoulder and hip joints

Practice question

An individual medley race requires a swimmer to swim the four main competitive strokes (butterfly, backstroke, breaststroke, freestyle). Using examples, outline five types of movements of synovial joints during an individual medley race. (5 marks)

Summary

- Joints can be classified as fibrous, cartilaginous and synovial depending on if there is a joint cavity and how much movement is allowed.
- The features of a synovial joint include the joint cavity, joint capsule, synovial membrane, articular cartilage, bursae and menisci.
- Types of synovial joint include gliding, hinge, pivot, condyloid, saddle, and ball and socket joints.

Check your understanding

After reading this chapter, you should be able to:

- outline the structure and functions of connective tissues
- outline the structure and functions of different types of joints and different classes of synovial joints.

Self-study questions

1. Outline the factors that affect the stability of a joint.
2. Describe how fibrous, cartilaginous and synovial joints differ.
3. State what type of joint the elbow is.
4. Outline the function of synovial fluid.
5. Explain the function of bursae.

Data-based question

Dance has been linked to a high number of injuries. Possible risk factors of injuries in dancers are joint hypermobility and fatigue. Hypermobility is a term that describes where a joint is able to move beyond its normal range of movement, and fatigue can contribute to injury vulnerability in dancers. A study explored the frequency and characteristics of injuries in 73 ballet dancers (age range 10–18 years).

Table 2 shows a comparison of variables according to injury status (higher scores = more).

▼ Table 2

	Group 1: without injuries (n = 28)	Group 2: with injuries (n = 45)
Years of dance practice	8.0	8.0
Hours of dance training per week	14.5	15.0
Mean joint hypermobility	3.0	5.0
Perceived fatigue during training	5.0	6.0
Fear of injury	4.0	3.0

Source: adapted from Dondin and Baeza-Velasco (2023).

1. In terms of joint hypermobility, state who had more injuries: the dancers with less joint hypermobility or the dancers with more joint mobility? (1 mark)
2. Identify which group perceived less fatigue during their dance training. (1 mark)
3. Suggest **two** reasons for the difference in fear of injury scores. (2 marks)

B.1.3

Muscular function

Syllabus understandings

B.1.3.1 The body uses different types of muscular contractions to create movement and stability. Each type of contraction has a different function.

B.1.3.2 The sliding filament theory describes the interaction between myofilaments and the molecules responsible for sarcomere or muscle contraction.

AHL

Introduction

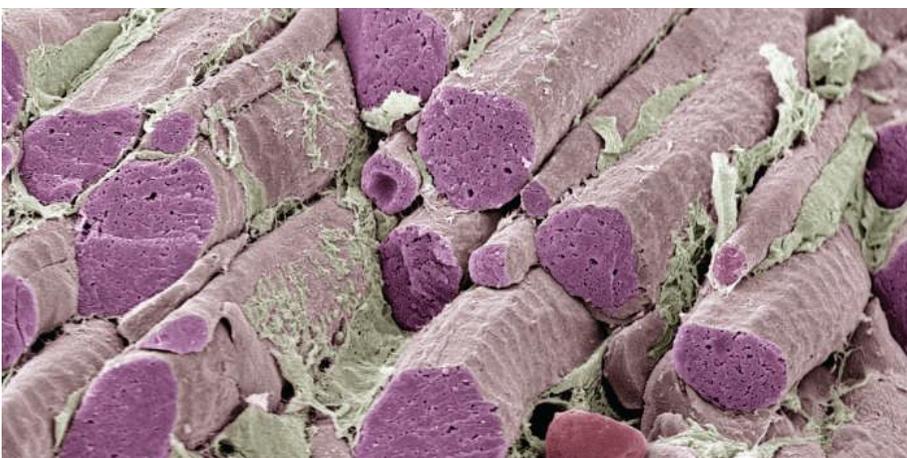
There are more than 600 muscles in the human body. They vary in size, shape and structure. Together, they make up about 40%–50% of the body's weight.

There are three types of muscle, each with different functions.

- **Skeletal muscle** is under voluntary control and has a striated appearance, which means that it has alternating dark and light bands that are visible if you examine it under a microscope. Skeletal muscle has tendons that attach mostly to bone, therefore the main function of this type of muscle is to move the skeleton.
- **Cardiac (or heart) muscle** is also striated but it is under involuntary control; therefore, it contracts without you having to think about it consciously.
- **Smooth muscle** lines the walls of blood vessels and hollow organs such as the stomach and intestines. It is also involuntary, but it does not have a striated appearance like skeletal and cardiac muscle.

Muscle has four main functions.

- Movement occurs through the interaction of bones, skeletal muscles and joints. When skeletal muscles contract, they exert forces on tendons, which then pull on the bones causing joint movement.



▲ Figure 1 Skeletal muscle viewed under a scanning electron microscope (SEM)

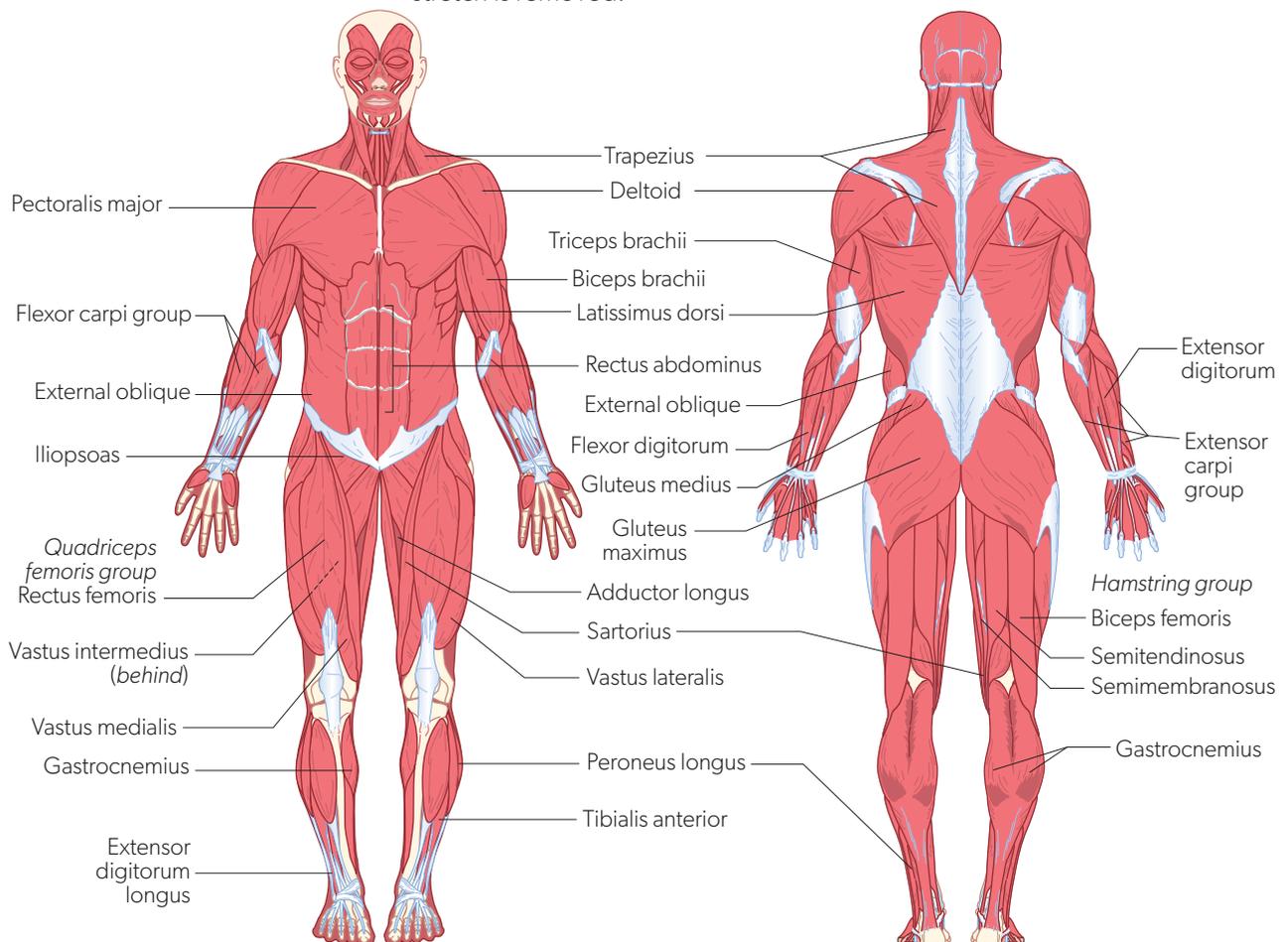
- Muscles also move substances within the body. For example, smooth muscles help move food through the gastrointestinal tract, cardiac muscle pumps blood to all the tissues in the body, and skeletal muscle helps return venous blood to the heart.
- When postural muscles contract, they help to stabilize and maintain body positions. For example, the posterior neck muscles contract to keep the head in an upright position, otherwise it would fall forwards. Therefore, muscles can be active even if there seems to be no movement at the joint.
- When muscles contract either voluntarily or involuntarily (as with shivering), they can generate up to 85% of body heat.

In this chapter, the main focus is on the larger skeletal muscles that are important for movement of the joints.

Properties of muscle tissue

The properties of muscle include contractility, extensibility and elasticity.

- **Contractility** is the ability of muscle to contract and generate force when it is stimulated by a nerve. Muscle tissue is the only tissue in the body that has this property. Muscles are usually arranged in pairs so that when one muscle is contracted or shortened, the opposing muscle is stretched.
- **Extensibility** is the ability of muscle to be stretched beyond its normal resting length.
- **Elasticity** is the muscle's ability to return to its original resting length after the stretch is removed.



▲ Figure 2 The muscular system

This work must not be reproduced, stored, transmitted or circulated in any other form.

To illustrate this, think about what happens when you lift a glass to drink some water. First, a nerve sends a signal to the muscle on the front of the arm (biceps brachii) telling it to contract. The muscle shortens using the property of contractility. As the elbow bends, the muscle on the back of the arm (triceps brachii) is stretched and lengthens, thus demonstrating the property of extensibility. When the arm is lowered again, the triceps goes back to its original length because of elasticity.

An average muscle fibre can shorten to about 50% of its original resting length and stretch to about 150% of the original resting length.

Neuromuscular function

As discussed in chapter A.1.1, the nervous system is made up of millions of nerve fibres, all carrying minute electrical signals. The central nervous system (CNS) consists of the brain and spinal cord and is where most sensing and control take place. The peripheral nervous system is the arrangement of nerves extending from the spinal column to the limbs and other parts of the body.

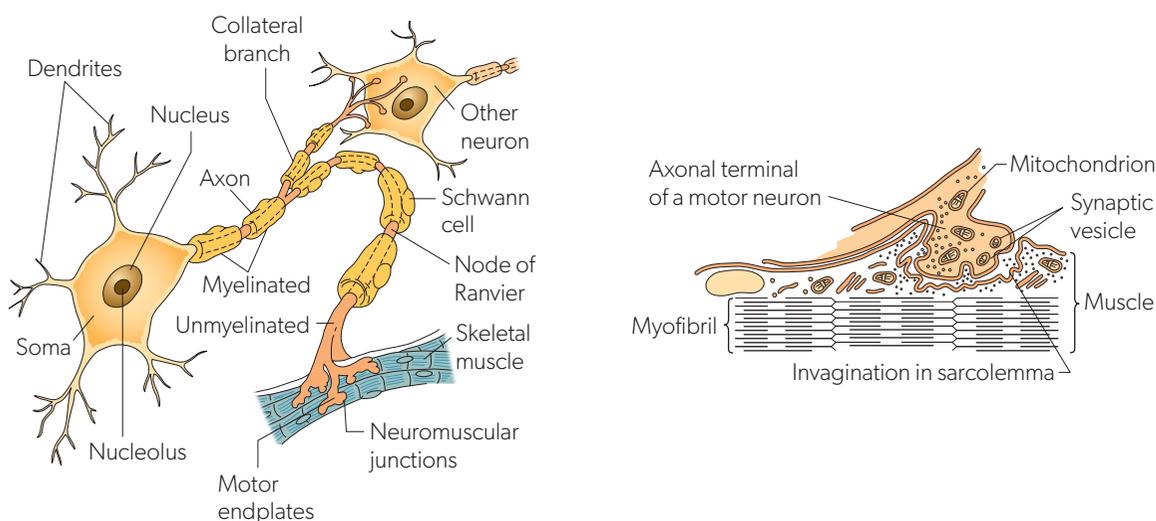
Motor neurons are those nerves that carry information from the CNS to the muscles and that signal muscles to contract or relax. There are about 200,000 motor neurons in the human body, and they are often called the efferent system.

Nerve cells from the brain send electrical impulses to the muscles to enable coordinated muscle contractions.

Molecules such as adenosine triphosphate (ATP) and phosphocreatine (PCr) provide the energy necessary to fuel muscular contraction. ATP is the main energy “currency” in living cells. ATP is used to transfer the chemical energy needed for metabolic reactions. Structurally, ATP consists of three phosphate groups attached to an adenosine unit. Refer to chapter A.2.3 for more on how the body produces energy using ATP.

Structure of neurons

The neuron consists of various components that have different functions in the transmission of nerve signals. The structure of a motor neuron is shown in Figure 3.



▲ Figure 3 Structure of a motor neuron

The soma, or cell body, is contained within the spinal cord or in clusters just outside it called ganglia. Dendrites link the neuron to other neurons and allow information to flow between different nerves. The axon is the main component of nerve signal transmission. It is similar to an electrical wire and has a cover made of myelin, a protein that makes sure the electrical signal is insulated from surrounding tissues. The myelin covering has gaps in it called nodes of Ranvier, which aid transmission of the information.

At the end of the neuron where it meets the muscle cell, the axon is unmyelinated. The neuron joins the muscle fibre at the neuromuscular junction or motor endplate, and there is actually a gap between the neuron and muscle fibre called the synapse, across which transmission of the electrical nerve signal stimulates the muscle.

Motor units

Muscle is organized into motor units. A **motor unit** is a single motor neuron and the muscle fibres that it innervates. The number of muscle fibres per motor neuron may be as high as 2,000 (for example, in the gluteus maximus on the back of the hip) or as small as 10 (for example, in the eye). A large number of muscle fibres per motor neuron allows a single motor neuron to cause the muscle to generate large forces; a small number of muscle fibres per motor neuron gives small forces but great precision. The number of muscle fibres stimulated by one motor neuron is called the innervation ratio.

When the motor unit is innervated by the motor neuron all of its muscle fibres contract at once. This is called the **all-or-none principle**—all of the muscle fibres attached to one motor neuron are either relaxed or contracted.

Types of motor unit

There are three types of motor unit, which vary in type of muscle fibre, as well as size.

- **Type I motor units** consist of mainly type I (slow-twitch) muscle fibres and have fairly slow nerve transmission speeds and small muscle forces. However, they can maintain contractions for a long time, as they are fatigue resistant.
- **Type IIa motor units** consist mainly of type IIa (fast-twitch) muscle fibres, have fast neural transmission times and stronger contraction forces, and are also resistant to fatigue.
- **Type IIx motor units** also consist mainly of type IIa (fast-twitch) muscle fibres. They generate the fastest contraction times and largest forces, but these fatigue at a high rate and so cannot maintain contractions for a long period of time.

Type I motor units would therefore be useful for events requiring small forces over a long time period such as walking or jogging. Type IIa motor units would be more appropriate for activities that require larger forces but still occur over a long time, such as swimming and cycling. Type IIx motor units produce very large forces very quickly so would be critical in sprinting, jumping, throwing and weightlifting.

ATL Research skills

Carry out research to find out whether type I motor units have a larger or a smaller neuron diameter than type II motor units.

Motor units, muscle fibre type and exercise

Not all muscle fibres are alike. On average, most muscles are composed of roughly 50% type I fibres, 25% type IIa muscle fibres and 25% type IIx muscle fibres. However, the exact percentage of each of these fibre types varies greatly in various muscles and among individuals.

In general, type I muscle fibres have a high level of aerobic endurance, and they are very efficient at producing ATP from (the oxidation of) carbohydrate and fat. ATP is needed to provide the energy for muscle fibre contraction (and relaxation).

Slow-twitch and fast-twitch muscle fibre types are occasionally referred to by the alternative terms fatigue-resistant (FR) and fast-fatigue (FF) fibre types, respectively, due to their properties.

Have you ever seen an apple turn brown when it is left out for a while? That is an example of oxidation. The oxygen in the air reacts with certain compounds in the apple, causing it to change colour. In simple terms, oxidation is a process where certain things combine or react with oxygen.

As long as oxidation occurs, type I muscle fibres will continue producing ATP. In contrast, type II muscle fibres have relatively poor aerobic endurance when compared with type I muscle fibres. They are better at performing anaerobically (without oxygen). In the absence of adequate oxygen, ATP is formed through anaerobic energy pathways. Type IIa motor units generate more force than type I motor units, but they fatigue more easily. Type IIa muscle fibres are used during shorter, high-intensity endurance events, such as the 1,500 m run or the 400 m freestyle swim.

Type IIx muscle fibres are predominantly used in highly explosive events such as the 100 m sprint run and the 50 m sprint swim.

ATL Research skills

Skeletal muscle fibre type is classified according to contractile speed as slow twitch (type I) or fast twitch (type II). Fast-twitch fibres can be further differentiated into intermediate (type IIa) and fast-glycolytic fibres (type IIx). With regard to performance level, elite athletes (sprint or endurance) possess a higher predominance of one fibre type (more type II or I fibres, respectively) compared with their sub-elite counterparts. Athletes with a greater proportion of type II fibres are more likely to succeed in sprint events (such as track sprint cycling) and power-type events (such as the “snatch” Olympic lifting), or cyclic movements requiring high frequency (such as 200 m track sprint running). In contrast, athletes with more type I fibres are likely to have greater success in endurance-type events such as marathon running.

Carry out research to answer the following questions.

In well-trained athletes:

- is there similar maximal force capability between different muscle fibre types?
- are there any differences in the number of mitochondria in different muscle fibre types?
- do muscle fibre types differ with respect to myoglobin content?
- do muscle fibre types differ with respect to capillary density?

The principle of orderly recruitment

When a motor unit is activated, all the muscle fibres in the motor unit contract to develop force. Activating more motor units is the way muscles produce more force. Conversely, when little force is needed, only a few motor units are recruited. Both type IIa and type IIx motor units contain more muscle fibres than type I motor units do. When you exercise or play sport, as the intensity of the activity increases, skeletal muscle contraction involves progressive recruitment of type I, followed by type II motor units, with the number of muscle fibres recruited increasing in the following order: type I → type IIa → type IIx.

This is known as the principle of orderly recruitment. This order of recruitment of motor units is directly related to the size of their motor neuron, with smaller motor neurons recruited first.

Hypertrophy, atrophy and motor unit recruitment patterns

Hypertrophy is an increase in the size or mass of an organ or body tissue. Fibre hypertrophy is an increase in the size of existing muscle fibres. So, how does a muscle increase in size? There are two types of muscle hypertrophy: transient and chronic. During and immediately following a single exercise bout, transient (lasts only for a short time) hypertrophy develops, mainly from fluid accumulation in the muscle. The fluid comes from the blood plasma and returns to the blood within a few hours.

Chronic hypertrophy is the increase in muscle size that happens with long-term resistance training. With chronic hypertrophy there are structural changes in the muscle resulting from an increase in the size of existing individual muscle fibres (fibre hypertrophy), or an increase in the number of muscle fibres (fibre hyperplasia), or in both. It is well known that resistance training promotes increased muscle strength and mass, or maximal force production, and that these outcomes are from neural and musculoskeletal adaptations, resulting in increased voluntary activation of muscle (your brain is sending stronger and more powerful signals to your muscles, telling them to work harder). Research (Alix-Gages et al., 2022) has shown that early muscle strength gains from a long-term resistance training programme are due to changes in the pattern by which nerves activate the muscle fibres—neural factors (increased motor unit recruitment and/or rate of motor unit recruitment) contribute the most to strength gains during the first 8–10 weeks of training, with muscle fibre hypertrophy becoming a major contributor after about 10 weeks of training (Kenney et al., 2021).

Atrophy is the loss of size, or mass, of body tissue, such as muscle atrophy with disuse. Research has shown that muscles that are not used for weeks or months start to decrease in size, and there is an association between loss in muscle size and loss in muscle strength (Bickel et al., 2011). Muscles can become inactive through immobilization (for example, a broken leg in a cast) or when people stop training. The muscle atrophy effect seems to be greater in type I muscle fibres. The good news is that muscles do recover when activity and/or training is resumed. However, the recovery period following immobilization is substantially longer than the period of immobilization itself.

ATL Thinking skills

Skeletal muscle hypertrophy is used by athletes of many sports (such as judo) to improve performance. Additionally, greater muscle mass has been associated with better health. Skeletal muscle hypertrophy is accompanied by an increase in mineral, protein or substrate abundance (Sedlmeier et al., 2021). Think of substrate as the “fuel” or the “building blocks” for muscle growth—nutrients, such as protein, are necessary fuel for muscle growth. With resistance training there is also increased connective tissue hypertrophy.

ATL Research skills

What happens to muscle mass and strength during an extended spaceflight where astronauts are in an environment where the gravitational forces are considerably less than those on Earth?

Muscle contraction types

When muscles contract, the ends of the muscles are drawn towards the centre of the body. However, muscles can move the body segments by varying the force of contraction and where the muscle’s line of action is relative to the joint.

Isometric muscle contraction

An isometric contraction is another name for a static (without moving) muscle contraction. Think of an arm wrestling when the contest remains static.

Isotonic concentric muscle contraction

When muscles contract at a speed controlled by the sportsperson it is called isotonic.

When a muscle creates movement by shortening its length, this is called an isotonic concentric muscle contraction.

Isotonic eccentric muscle contraction

Muscles can exert force even while lengthening. An eccentric contraction is any muscle action in which the muscle lengthens. An isotonic eccentric contraction is when the muscle is contracting, but the effect of the muscle force is less than that of the resistance—the ends of the muscles actually get further apart, even though the muscle is still contracting, for example, when doing plyometric exercise, such as two-footed bounding over closely placed hurdles without stopping, or jumping on and off a low box top and immediately jumping again on landing.

Isokinetic motion

Isokinetic motion is when a muscle contracts so that the body segment to which it is attached moves at a constant speed around the joint. This type of movement is very rare in sport and exercise (most movements have an acceleration phase and a deceleration phase), and usually requires complex equipment to ensure the segment rotational speed is constant. This type of motion (regulated by equipment) is useful in rehabilitation when a therapist wants to make sure the speed of a limb is not excessive. However, as in isotonic contractions, just because the body segment moves at a constant rotational speed, it cannot be assumed that the muscle is contracting at a constant speed due to the different angles of pull through the ROM.

The final way for a muscle to affect segment motion is to relax. The muscle contraction force is zero. However, it should be noted that there still may be some resistance to movement (especially if the muscle is being moved beyond its relaxed length) due to the residual extensibility and elasticity of the muscle and tendon.



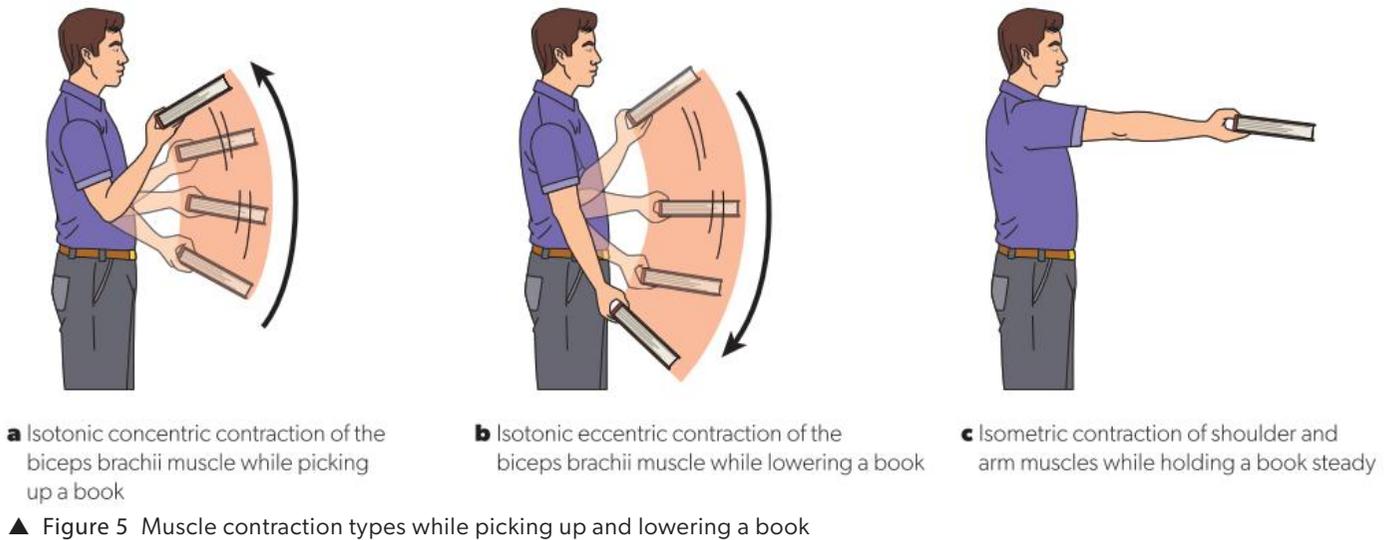
▲ Figure 4 Isotonic eccentric contraction

Key points

Isotonic concentric muscle contraction: the muscle *shortens* as it generates force against a resistance. The force generated by the muscle is greater than the opposing force or resistance, such as a bicep curl.

Isotonic eccentric muscle contraction: the muscle *lengthens* while generating force against a resistance. The force generated by the muscle is less than the opposing force or resistance, such as when you slowly lower the dumbbell in a controlled manner during a bicep curl.

Muscular function

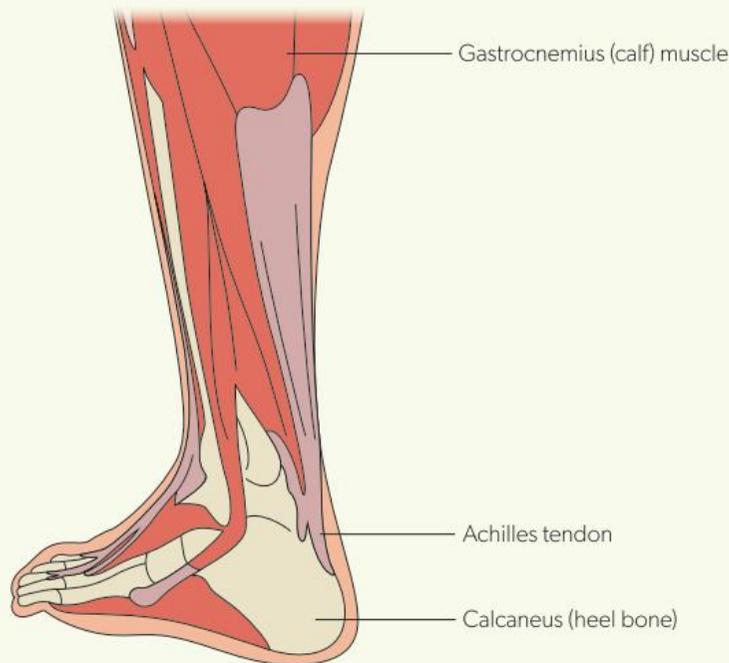


Case study

The Achilles tendon

A tendon is connective tissue that attaches muscle to bone and transmits the force of the (contracting) muscle to bone. Tendons must be strong enough to transmit force to bone and be capable of storing and releasing elastic energy. So, muscles are attached to tendons, which pass over joints and pull to create movement. Tendons vary in length and structure. The Achilles tendon of the gastrocnemius (calf) muscle attaches the muscle to the calcaneus (heel bone), as shown in

Figure 6 below. The Achilles tendon is the thickest, strongest and largest tendon in the human body, but despite its size and strength, it is the most commonly injured tendon in the human body. Achilles tendon tears take a long time to repair, sometimes leaving long-term functional limitations. A number of professional athletes, including the basketball great Shaquille O’Neal, have retired early due to a torn Achilles tendon.



▲ Figure 6 The Achilles tendon connects the gastrocnemius muscle to the calcaneus

ATL Thinking skills

Eccentric contraction and muscle soreness

Muscle soreness may be due to a variety of factors, but one of the most common is the sub-cellular damage (and the associated inflammation) that becomes apparent one or two days after exercise. This is called delayed onset muscle soreness (DOMS), and seems to be related to exercise that has large amounts of eccentric exercise (for example, running downhill, in which the quadriceps muscles contract eccentrically at the knee to control the body weight). The mechanical breaking of the actin–myosin bonds that occurs in eccentric contraction combined with the large muscle forces that can be produced in this type of exercise result in various biochemical and mechanical changes in the muscle.

These then cause inflammation, stiffness and pain that peak 24–48 hours after exercise, although this can last up to 10 days. The muscle damage can be monitored by examining the levels of creatine kinase, an enzyme involved in the breakdown and synthesis of muscle proteins. The most effective method of treating DOMS is light exercise, although some studies have suggested non-steroidal anti-inflammatory drugs (NSAIDs), massage or ice baths *may* help.

Have you ever experienced DOMS after intense exercise? Think about the activity that caused this, what muscles you were using and how you were using them.

Roles of muscle in joint movements

Muscles are used in various ways when joints are moved. These roles depend on the desired movement, the type of muscle used, the position of the muscles relative to the joint and the type of contraction.

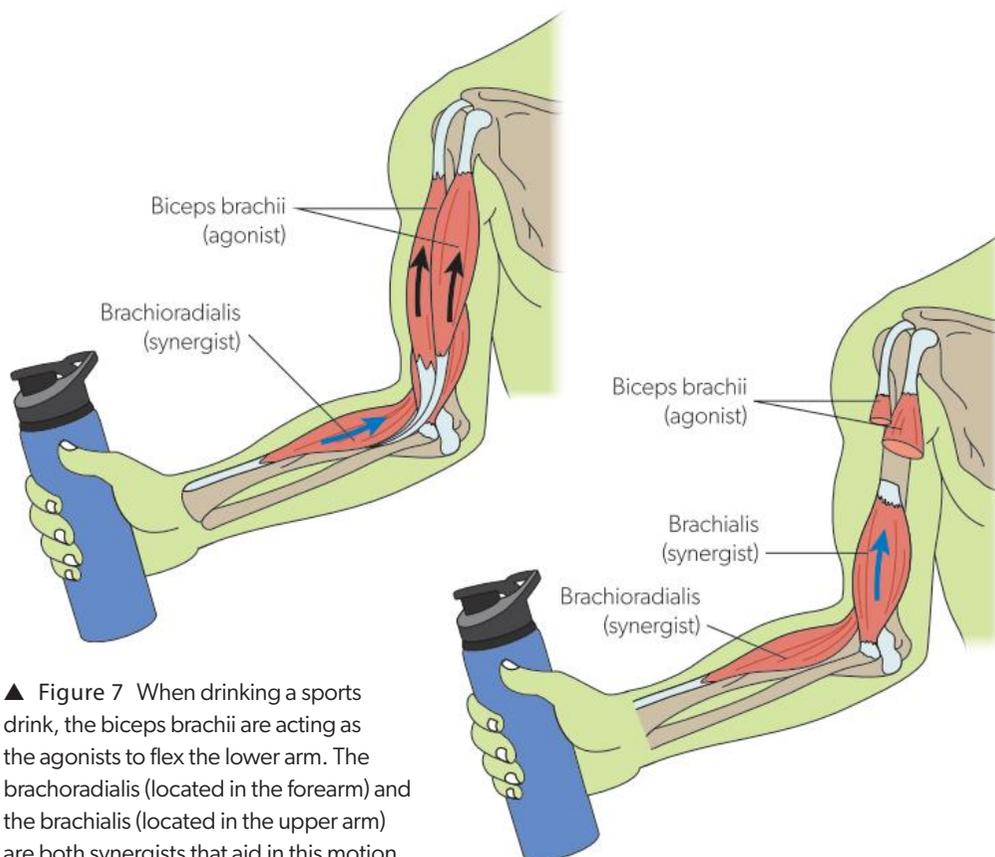
- **Agonist** (mover). In this role, the muscle contracts concentrically to move the bone relative to the joint. The muscle shortens and the muscle torque is greater than any resistance torque. There are different levels of agonist: prime, assistant or emergency. For example, when lifting a weight (elbow flexion) during a bicep curl, the prime mover or agonist would be the biceps brachii (the large muscle on the anterior surface of the upper arm), and the assistant movers would be the brachialis (a smaller muscle on the anterior surface of the elbow) and the brachioradialis (the muscle that runs from above the elbow to the wrist on the anterior surface of the forearm).
- **Antagonist**. If a muscle contracts eccentrically, then it is often acting as an antagonist for the joint action. This means it acts in the opposite direction to its usual concentric function and gets longer even though it is contracting, for example, when lowering the weight during the bicep curl (elbow extension), the biceps brachii and the other two muscles act as antagonists to slow the descent (if the muscles relaxed, the weight would simply fall due to gravity). Note that the triceps brachii (the muscle on the posterior surface of the upper arm) does not contract in this action—this would simply “throw” the weight to the floor as the elbow would be extended actively at speed, rather than under control.
- **Fixator** (stabilizer). When muscles contract, both ends are drawn towards the middle of the muscle. However, if only one end of the muscle is required to move a body segment, then the body segment to which the other end of the muscle is attached (usually the other segment of the joint) must be kept stationary. Therefore, this will require at least one other muscle to contract (usually isometrically) to prevent this segment from moving so that the agonist may move the desired segment. These other muscles are called fixators or stabilizers and are very important. This is one of the main ideas behind the principle of core stability—the muscles of the core must be strong so they can hold the trunk of the body steady while the agonists or antagonists move the limbs.

- **Synergist** (neutralizer). Most muscles have more than one action at a joint. For example, when the biceps brachii contracts, it not only flexes the elbow joint but also supinates the radioulnar joint. Therefore, if these extra actions are not required, other muscles must be used to prevent them. These muscles are named synergists or neutralizers and contract (usually isometrically) to prevent unwanted actions of the agonists or antagonists. In the example above, one or both of the pronator muscles would be used if supination was not desired when the biceps brachii was contracting.

It is important to assess which type of contraction muscles (particularly the agonists) are undergoing in a movement. Generally, if a limb is being moved in the opposite direction to a resistance force such as gravity, the agonists are undergoing isotonic concentric contraction. However, if a limb is moving in the same direction as the resistance force (but under control), the antagonists are performing an isotonic eccentric contraction. If *no movement* is apparent, but the muscles are contracting, then isometric contraction is likely to be occurring.

Think of flexion of the leg at the knee as you prepare to take a shot in soccer. During the initial movement, the hamstrings would be called the agonists and the quadriceps would be called the antagonists. As your leg moves for your foot to strike the ball, the muscles carry out the opposite action. The hamstrings are activated and become the antagonists to slow or stop the movement, and the quadriceps become the agonists, as they are responsible for producing knee extension to apply force to the ball.

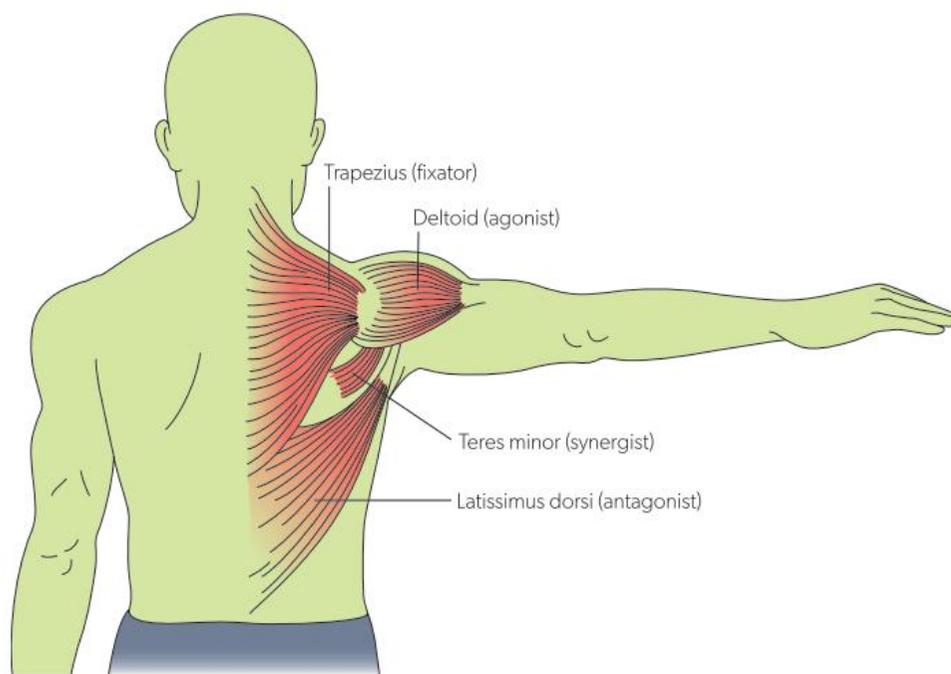
Now consider the action of taking a drink while running a marathon, as shown in Figure 7.



▲ Figure 7 When drinking a sports drink, the biceps brachii are acting as the agonists to flex the lower arm. The brachioradialis (located in the forearm) and the brachialis (located in the upper arm) are both synergists that aid in this motion.

Muscles perform a variety of roles in movement. For example, think of a gymnast performing arm abduction in the rings competition.

- The deltoid is the agonist as it is responsible for the abduction movement.
- The latissimus dorsi is the antagonist as it resists abduction.
- The trapezius is one of the fixator muscles as it is holding the scapula in place.
- The teres minor acts as a synergist as it contracts to eliminate any unwanted joint action of another muscle.



▲ Figure 8 The roles of muscles during a gymnast's performance on the rings

In summary, the muscle primarily responsible for a movement is called the agonist, and muscles that assist in this action are called synergists. A synergist that makes the insertion site more stable is called a fixator. A muscle with the opposite action to the prime mover is called an antagonist. Antagonists must relax to allow a movement to occur, or contract at the same time as the agonists to control or slow down a (joint) movement.

Reciprocal inhibition

When an agonist contracts to move a body segment, it is usual for the antagonist (the muscle with the opposite concentric contraction action) to relax. This means that the agonist is not being opposed by any muscle torque acting in the opposite direction to that of the motion. This reflex is called **reciprocal inhibition** and is an automatic action controlled by neurons. When the agonist motor neuron is stimulated, the motor neuron to the antagonist is inhibited, preventing it from contracting strongly. During sport and exercise, these signals are very important to ensure maximum torque around the joints when the agonist muscles contract.

It is a common misconception to think that when the agonist muscles contract concentrically, the antagonist muscles contract eccentrically. In most



Key terms

Insertion The end of a skeletal muscle that attaches to the bone being pulled.

Origin The end of the muscle attached to a fixed bone.

Agonist A muscle whose contraction is responsible for producing a movement.

Antagonist A muscle that opposes the action of an agonist.

Synergist A muscle whose contraction helps an agonist in an action.

Fixator A muscle that assists an agonist by preventing or reducing movement at another joint.

movements, this would be counterproductive as the antagonist muscles would be producing a torque in the opposite direction to motion, thus lowering the net torque around the joint. So, for example, during the upward phase of a biceps curl, the biceps brachii muscle contracts concentrically and the triceps brachii (the antagonist muscle) *relaxes*. During the downward phase (if slow and controlled), the biceps brachii muscle contracts eccentrically and the triceps brachii is still *relaxed*.

However, occasionally it is necessary for both agonist and antagonist to contract at the same time (for example, to control balance or to make a joint “stiffer” when learning a task). This is called co-activation and, in this case, reciprocal inhibition is overridden by the voluntary nervous system.

ATL Thinking skills

Movements are often the result of several skeletal muscles acting as a group rather than acting alone. Most skeletal muscles are arranged in opposing (antagonistic) pairs at joints.

For example:

- flexors ↔ extensors
- abductors ↔ adductors.

Within opposing pairs of muscles, one muscle, called the prime mover or agonist, contracts to cause an action while the other muscle—the antagonist (anti = against)—stretches and gives way to the effects of the agonist. With an opposing pair of muscles, the roles of the agonist and antagonist can switch for different movements. For example, while extending the forearm at the elbow, the triceps brachii is the agonist, and the biceps brachii is the antagonist. However, the roles of the two muscles reverse during flexion of the elbow.

Can you think of another example when the roles of the agonist and the antagonist reverse?



Linking question

How does malnutrition affect muscular function? (A.2.2)

Consider:

- can malnutrition be **either** inadequate **or** excessive caloric/nutrient intake?
- insufficient protein intake and muscle strength/weakness
- nutrient deficiency and muscle atrophy
- inadequate intake of carbohydrates and muscle endurance
- muscle recovery after exercise
- electrolytes and muscle cramps.



Linking question

How do different types of muscle fibre affect our ability to exert forces in a sporting environment? (B.1.4, B.2.1)

Consider:

- slow-twitch (type I) muscle fibres, resistance to fatigue and endurance
- type I muscle fibres, contraction speed and power
- fast-twitch (type IIa) muscle fibres and resistance to fatigue
- type IIa muscle fibres, contraction speed, endurance and power
- fast-twitch (type IIx) muscle fibres, contraction speed, muscle force and power
- type IIx muscle fibres and time to fatigue
- interplay between slow-twitch and fast-twitch muscle fibres
- other factors, such as technique, training, nutrition or mental preparation.

Mechanics of muscle contraction

When a muscle is viewed under a microscope, thousands of long, cylindrical muscle fibres can be seen lying parallel to one another. Looking at these more closely reveals smaller structures called **myofibrils** which have light and dark bands and give the muscle the striated appearance that was mentioned earlier. Myofibrils contain **thin filaments (actin)** and **thick filaments (myosin)**. Overall, there are two thin filaments for every thick filament. Filaments do not extend the entire length of a muscle fibre—they are arranged in functional units called **sarcomeres**.

As mentioned in the introduction to the chapter, when seen under a microscope, muscle fibre sarcomeres appear striped or striated. These cross-striations are due to the overlap of actin and myosin proteins in the muscle fibre. Thick and thin filaments overlap to a greater or lesser extent, depending on whether the muscle is contracted, relaxed or stretched. The detail of the muscle fibres and sarcomeres is shown in Figure 9.

Key terms

Myofibrils The contractile elements of skeletal muscle.

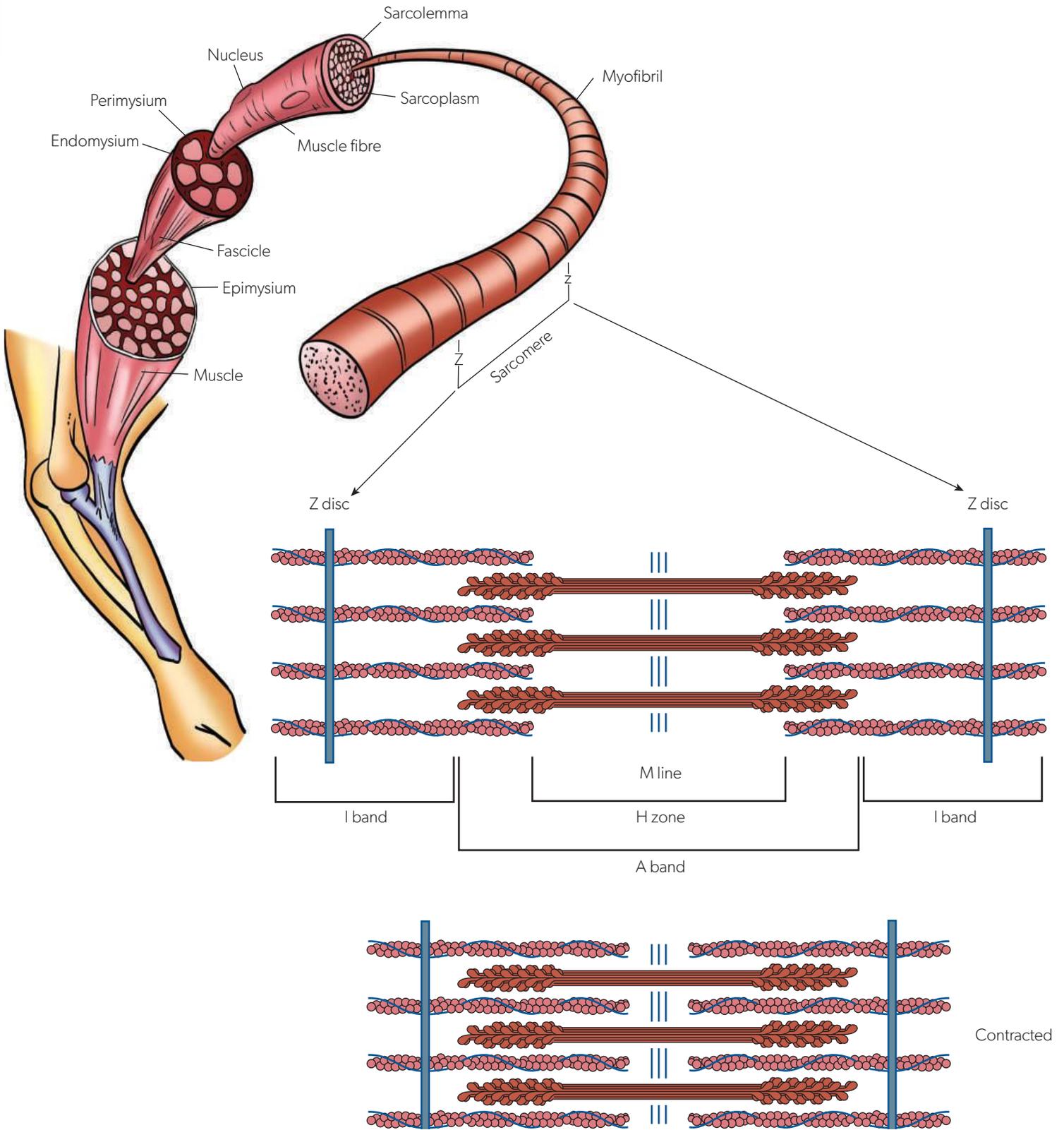
Z discs Separate one sarcomere from the next.

A band The middle part of the sarcomere that extends the length of the thick filaments. Towards each end of the A band is a zone of overlap (both thick and thin filaments).

I band Part of a sarcomere that contains thin filaments, but no thick filaments. A Z disc passes through the centre of each I band.

H zone Part of a sarcomere that contains thick but not thin filaments.

M line Part of a sarcomere consisting of proteins that hold the thick filaments together at the centre of the H zone.



▲ Figure 9 Muscle fibre and sarcomeres

The sliding filament theory

Muscular contraction starts with an electrical impulse, generated either voluntarily from the brain or by reflex, which travels along a motor neuron to the neuromuscular junction of the motor unit. At the neuromuscular junction or motor endplate, there is a space between the end of the neuron and the muscle fibres. This is called a synapse. When the signal reaches this synapse, a chemical called acetylcholine is released. This changes the electrical state of the muscle and causes a signal called the action potential to travel along the muscle fibres.

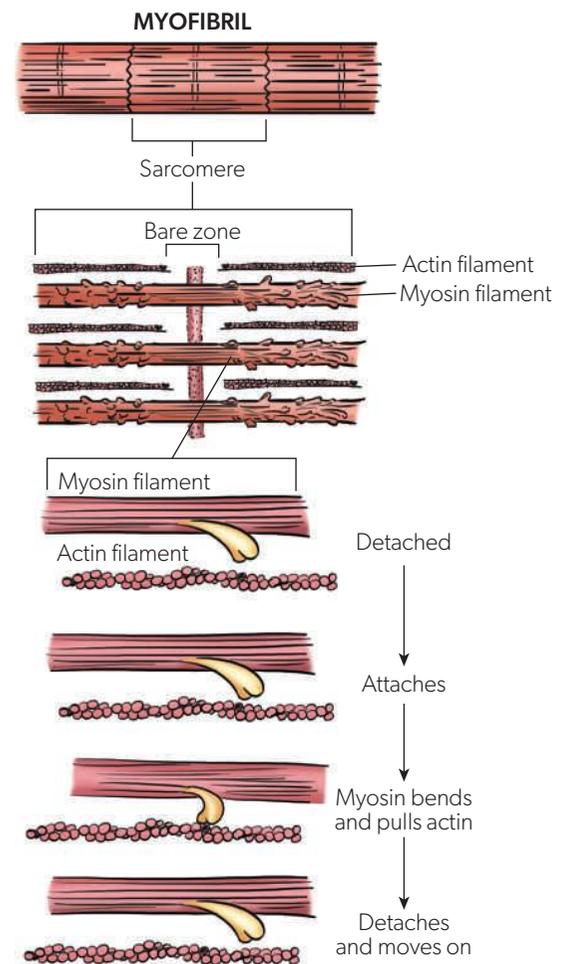
The action potential travels through the muscle fibres down the T-tubules, and stimulates the sarcoplasmic reticulum to release calcium ions (Ca^{2+}). This opens the binding sites on the actin molecules and the heads of the myosin molecules move out towards these sites. The heads of the myosin molecules are shaped a little like golf clubs and it is the ends of the heads that attach to the actin. Attached to the myosin head is the chemical ATP and this is split chemically into adenosine diphosphate (ADP) and phosphate. At the same time, the head of the myosin “bends”, thus sliding the actin along a little relative to the myosin.

The myosin is then released from the actin and fresh ATP can join the myosin head. If the electrical signal is still present, fresh calcium will also be available, and the myosin heads can bind to the next sites on the actin. Thus the actin has been pulled along parallel to the myosin. This happens repeatedly while the neural signal is active, thus the muscle contracts by the sliding of the actin relative to the myosin. This is known as the **sliding filament theory** and was first proposed by Huxley in 1957. Muscle fibres are made up of many thousands of actin and myosin molecules, and the sliding of all of these makes the muscle contract.

When the nerve is no longer stimulated, acetylcholine is removed by acetylcholine esterase, calcium goes back into the sarcoplasmic reticulum, and the myosin heads move back to their resting positions away from the actin.

The cross-bridge cycle

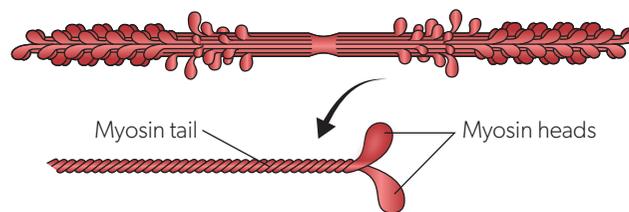
The **cross-bridge cycle** (or *contraction cycle*) refers to the repeating sequence of molecular events that occur between the myosin heads (cross-bridges) and the actin filaments during muscle contraction. At the onset of muscle contraction, when the myosin cross-bridges are activated, they bind with actin, and the myosin head tilts and drags the thin filament towards the centre of the sarcomere. The tilting of the myosin head is called the **power stroke**. Pulling the thin filament past the thick filament shortens the sarcomere and generates muscle force. When the muscle fibres are not contracting, the myosin head remains in contact with the actin molecule but bonding is blocked (by tropomyosin). After the myosin head tilts, it immediately breaks away and rotates back to its original position, and attaches to a new site further along the actin filament. The repeated attachments and power strokes cause the filaments to slide past one another, hence the *sliding filament theory*.



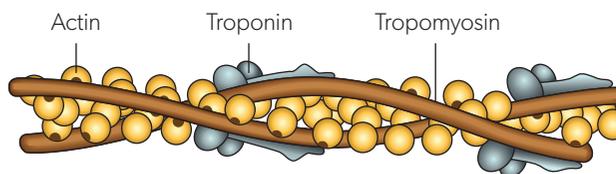
▲ Figure 10 The sliding of many thousands of actin and myosin molecules makes the muscle contract

Roles of troponin and tropomyosin

Myosin tails form the shaft of the thick filament, and the myosin heads project outwards towards the surrounding actin. The myosin and the actin generate force during muscle contraction. Although referred to as an actin filament, each thin filament is actually composed of three different protein molecules: actin, **tropomyosin** and **troponin**. Tropomyosin and troponin work together along with calcium ions to maintain relaxation or initiate contraction of the muscle. In a resting state, tropomyosin molecules cover the myosin-binding sites on the actin molecules, preventing the binding of the myosin heads. When a nerve impulse (or action potential) leads to the release of calcium ions from the sarcoplasmic reticulum, the calcium ions bind with troponin on the actin molecules. Troponin initiates contraction by moving the tropomyosin molecules off the myosin-binding sites on the actin molecules. The myosin heads can attach to the binding sites on the actin molecules, resulting in muscle contraction. Therefore, an increase in calcium ion concentration starts muscle contraction, whereas a decrease stops it. The complex sequence of events that triggers a muscle fibre to contract is called *excitation–contraction coupling* because it begins with the excitation of a motor nerve and results in contraction of the muscle fibres. Troponin and tropomyosin help switch muscle contraction on and off.



(a) One thick filament (above) and a myosin molecule (below)



(b) Portion of a thin filament

▲ Figure 11 Detail of a sarcomere

ATL Research skills

During the “power stroke”, does the myosin head rotate away from or towards the centre of the sarcomere?

Control of muscle force

When a muscle is signalled to contract, the CNS will usually control the force of contraction so that the body segment will move appropriately. This might require a very large force (such as in the quadriceps muscles during kicking) or a small force (such as when writing). The control of the muscle force can be carried out by recruiting the motor units in two ways.

The size principle is when smaller motor units are recruited first, and only when larger forces are required are large motor units stimulated. However, in activities that require very large forces, this principle may not be effective. Therefore, the frequency of motor unit innervation can also be varied, with a higher rate of activation causing a higher force in the muscle. This is called frequency or rate coding of motor unit recruitment.



Linking question

How can knowledge of the sliding filament theory be applied to optimize nutrient intake and timing, to enhance muscle function, recovery and performance in athletes and active individuals?

(A.2.2.1, A.2.2.2)

Consider:

- amino acids, muscle repair and recovery post-exercise
- glycogen stores and the role of ATP in powering muscle contractions
- timing of nutrient intake
- hydration, muscle function and performance
- micronutrient considerations (such as calcium, magnesium and potassium)
- nutrient intake and timing strategies based on their specific goals and type of sport/exercise requirements.



Linking question

How can technology be utilized to support our understanding of microscopic phenomena? (NOS, Tool 2)

Consider:

- microscopes, cells, molecules and atomic structures
- imaging techniques and observing cellular processes, protein interactions and sub-cellular structures
- spectroscopy and determining the chemical composition, molecular structures and dynamic behaviour of molecules
- DNA sequencing technologies and the study of genes (such as genetics of responders and non-responders)
- computers and simulations, experimental observations and theoretical understanding, and virtual environments
- analytical data analysis tools and algorithms to process, analyse and interpret big data (such as patterns, correlations and trends of microscopic phenomena).

Practice question

Calcium is required to help with muscle contraction. Explain how an athlete's muscle contracts quickly once calcium ions bind to troponin. (6 marks)

Summary

- Muscles are stimulated by nerves to contract.
- Energy is required for muscle contraction to occur.
- Muscles are organized into motor units, each containing a neuron together with muscle fibres.
- Type I, type IIa and type IIx motor units have different speeds of contraction, forces of contraction, resistance to fatigue and neuron diameters.
- A motor nerve impulse that results in muscle contraction is called excitation–contraction coupling.
 - An action potential causes calcium ions to be released from the sarcoplasmic reticulum.
 - Calcium ions bind with troponin.
 - Troponin moves the tropomyosin molecules off the myosin-binding sites on the actin molecules, allowing the myosin heads to bind to them.
 - The myosin head pulls the thin filament (actin) past the thick filament (myosin).

AHL

Check your understanding

After reading this chapter, you should be able to:

- explain how muscle fibres and motor neurons combine to form motor units
- describe how motor units are innervated to create muscle forces
- outline different muscle contraction types
- describe how muscles usually function in pairs
- explain the sliding filament theory of muscular contraction.

AHL

Self-study questions

1. Outline, and give examples of, how concentric and eccentric contractions differ.
2. Outline the relation between muscle force development and the recruitment of type I and type II motor units.
3. Distinguish between functions of the three types of muscle.
4. Explain how the sliding filament theory accounts for muscle contraction.
5. How do calcium ions and ATP contribute to muscle contraction and relaxation?

AHL



Data-based question

Beetroot juice (BRJ) supplementation has been reported to enhance skeletal muscle contraction. A study (randomized, double-blind crossover design) assessed the effect of BRJ supplementation on power output during concentric (CON) and eccentric (ECC) muscle contractions during a half-squat in 18 active adult males. The experimental group (BRJ supplementation) were compared with a placebo group (no BRJ supplementation), and the mean and peak (\pm SD) power outputs are shown in Table 1.

▼ Table 1

	Placebo group	BRJ supplementation group
Mean concentric power (watts)	644 (\pm 153)	750 (\pm 173)
Mean eccentric power (watts)	572 (\pm 131)	684 (\pm 154)
Peak concentric power (watts)	1,075 (\pm 205)	1,251 (\pm 249)
Peak eccentric power (watts)	1,005 (\pm 176)	1,195 (\pm 265)

Source: Adapted from Rodríguez-Fernández et al. (2021).

1. Distinguish between eccentric and concentric muscle contraction during the half-squat exercise. (1 mark)
2. Identify which group and type of muscle contraction produced the highest peak power. (1 mark)
3. Explain the differences found between mean power and peak power during muscle contraction. (3 marks)

B.1.4 Levers in movement and sport

Syllabus understanding

B.1.4.1 Three different classes of levers, both within and outside the human body, work to create movements.

ATL Thinking skills

Think about where door handles are usually located on doors. Why do you think this is?

Introduction

Levers are rigid rods that can rotate about a fixed pivot, or fulcrum, when force is applied. A lever is a simple machine.

Tendency for rotation in either direction depends on the:

- magnitude of forces applied
- distance between the fulcrum and the line of action of the force.

In human movement, bones act as levers when muscle contraction generates tension and tendency for rotation. This chapter will describe:

- the differences between the three types of levers both within and outside the human body
- the use of mechanical advantage as a way to assess the efficiency of a lever.

Parts of a lever

Levers consist of the following parts:

- a rigid rod
- a **fulcrum** (axis)
- a **load force**
- an **effort force**.

The perpendicular distance at which a force acts from the axis of rotation (fulcrum) is called the **moment arm**.

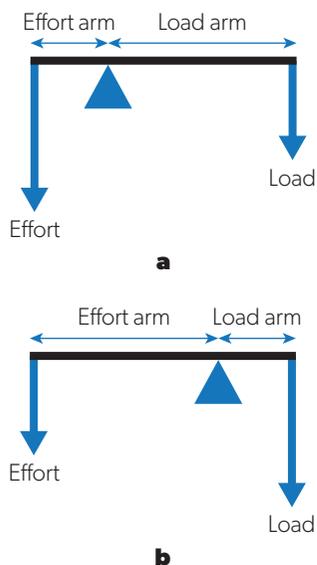
The distance at which the load (sometimes called the resistance force) acts from the fulcrum is called the **load arm**.

The distance at which the effort acts from the fulcrum is called the **effort arm**.

Mechanical advantage of a lever

A lever has a **mechanical advantage** (MA). This is how much the effort force is multiplied by to overcome the load. It can be calculated as the effort arm divided by the load arm. Therefore, the MA of a lever is a measure of its efficiency in terms of the amount of effort required to move a particular resistance, and is given by:

$$MA = \frac{\text{magnitude of effort}}{\text{magnitude of load}}$$



▲ **Figure 1** In **a** the effort moment arm is shorter than the load moment arm, so more effort is required to overcome the load. Whereas in **b** the effort moment arm is longer than the load moment arm, so less effort is required to overcome the load.

This can also be expressed as:

$$MA = \frac{\text{length of effort moment arm}}{\text{length of load moment arm}}$$

Any MA greater than 1.0 is regarded as very efficient.

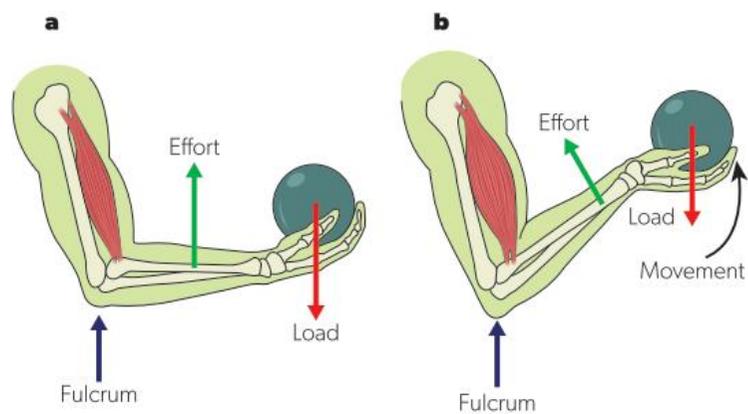
Activity 1

Which of the following statements are true?

1. When MA = 1, the effort arm does not equal the load arm.
2. When MA = 1, the effort arm equals the load arm.
3. When MA is greater than 1, less effort is required to overcome the load force.
4. When MA is greater than 1, more effort is required to overcome the load force.
5. When MA is less than 1, more effort is required to overcome the load force.
6. When MA is less than 1, less effort is required to overcome the load force.

Activity 2

Explain why more effort is required for the arm curl at position (a) compared with position (b).



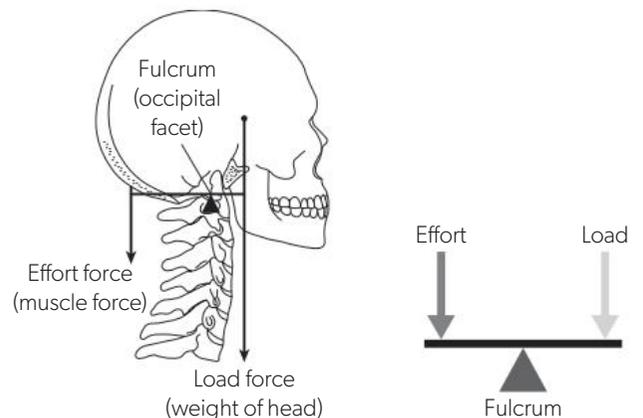
▲ Figure 2

Types of lever

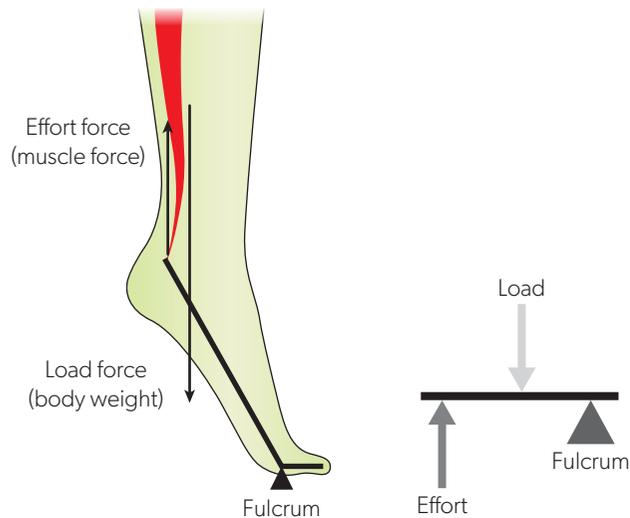
Levers can be classified into three types depending on the positions of the effort force and load force relative to the fulcrum: first-class levers, second-class levers and third-class levers.

First-class levers have the effort force and the load force on opposite sides of the fulcrum. The effort arm may be smaller than, equal to or greater than the load arm. These are fairly rare in the human body—an example would be the muscles of the neck providing the effort force to overcome the load force caused by the weight of the head.

Second-class levers have the effort force and load force on the same side of the fulcrum, but with the effort arm longer than the load arm (the effort force is further away from the fulcrum than the load force). This means the MA is greater than 1, and a small effort force can overcome a large resistance. This is common in machines such as wheelbarrows, in which larger loads can be carried close to the fulcrum (the wheel) by applying relatively small forces at the ends of the handles. However, this type of lever is very rare in the human body, and the only example that is commonly suggested is when the calf muscles contract to provide the effort force when standing on the toes in plantarflexion. This would suggest that the human body has not evolved to use its limbs as levers to overcome very large load forces.

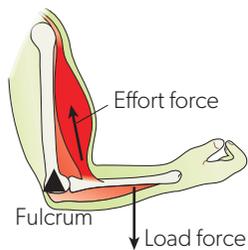


▲ Figure 3 Example of a first-class lever in the human body

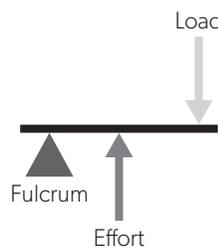


▲ Figure 4 Example of a second-class lever in the human body

Third-class levers also have the effort and load forces on the same side of the fulcrum, but the effort arm is smaller than the load arm (the effort force is closer to the fulcrum than the load force). The MA, therefore, is less than 1, and this might seem counterproductive as large effort forces are required to overcome small load forces. However, there is another advantage to this arrangement. A small movement of the lever near the fulcrum is magnified by the length of the lever, so that the end of the lever moves through a greater angle, and with a greater angular velocity. Thus, the advantage is in range of motion and speed. This type of lever is very common in the human body, as shown in Figure 5 where the biceps brachii is providing the effort force at the elbow joint to hold a weight at the hand (the load). Therefore, the lever systems in the human body seem to have evolved to favour range and speed of motion.



▲ Figure 5 Example of a third-class lever in the human body



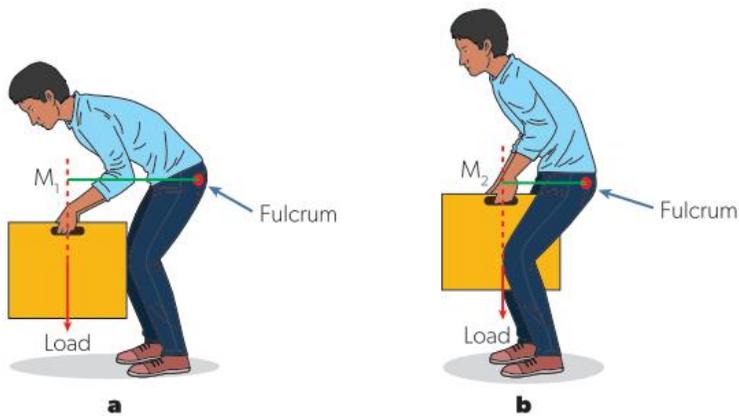
A first-class lever may have a MA greater or less than 1.0.

Every second-class lever has a MA greater than 1.0 because the length of the effort moment arm will always be greater than the length of the load moment arm.

In contrast, every third-class lever has a MA less than 1.0 because the length of the effort moment arm will always be less than the length of the load moment arm.

For example, imagine trying to lift a really heavy box. You have a lever, which is basically a long stick. There are three important parts of the lever: the effort, the fulcrum and the load. The effort is the force you apply to the lever to lift the box. The fulcrum is the point where the lever pivots or turns. The load is the weight of the box that you want to lift.

Depending on where these three parts are positioned, the lever can give you either an *advantage* or a *disadvantage* in lifting the load. If the fulcrum is closer to the load than to the effort, then you have a MA. It means it is easier for you to lift the heavy box. You can use less effort to move the load. On the other hand, if the fulcrum is closer to the effort than to the load, then you have a mechanical disadvantage. It means it is harder for you to lift the load. You need to apply more effort to move the heavy box. Therefore, the position of the fulcrum relative to the effort and the load determines whether you have an advantage or disadvantage in lifting things with the lever.



▲ Figure 6 The length of the load moment arm (M_1) for position **a** is greater than the length of the load moment arm (M_2) for position **b**

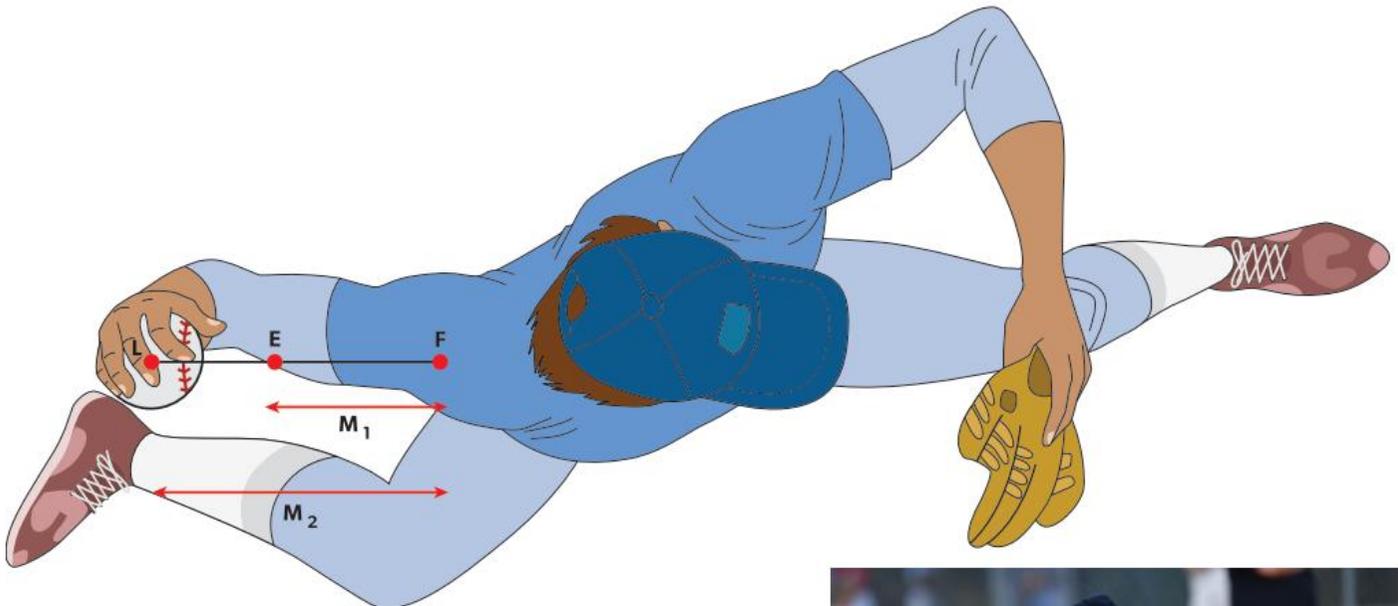
Key point

In the human body, the bones of the skeleton act as levers that are rotated about joints by muscles to bring about movement. Most of the muscles operate within first- or third-class lever systems. Like the third-class levers, most of the first-class lever systems of the body have MAs less than 1.0 because the tendons of the muscles that operate within them are inserted close to the joints and consequently have short moment arms in relation to the moment arms of the load forces they are required to overcome.

Levers inside the body used to project an object

Think of throwing a baseball. One important lever in our body is our arm. It acts like a lever when we want to throw something.

- **Effort:** Your muscles are the effort in this case. They provide the strength and power to move your arm and throw the ball.
- **Fulcrum:** The fulcrum is the shoulder joint.
- **Load:** The load is the ball you want to throw. It is the thing you want to project outside your body.



▲ Figure 7 F is the fulcrum at the shoulder joint, E is the effort at the insertion of the pectoralis major muscle, and L is the load (the baseball). Therefore, M_1 is the effort moment arm and M_2 is the load moment arm.

The longer the lever (our arm), the more distance and speed we can achieve when throwing, assuming all other variables (for example, technique) are equal.





Activity 3

1. Explain why an athlete with shorter arms has an advantage compared with an athlete with longer arms when performing the dumbbell exercise in weightlifting (assuming they are both technically proficient).
2. Explain why an athlete with longer arms has an advantage compared with an athlete with shorter arms when throwing the discus (assuming they are both technically proficient).

Levers outside the body used to enhance performance

Levers outside our bodies can make us better at physical activities and sports. Imagine you are swinging a baseball bat. The bat is the lever (outside our body) and this is how it helps.



▲ **Figure 8** In baseball, the bat functions as an external lever

- The effort is the force or power you put into swinging the bat.
- The fulcrum is the turning point or the centre of the lever. In sports, it is usually the joint where the lever attaches to your body. In this case, when you swing a baseball bat, your shoulder acts as the fulcrum.
- The load is the object you want to hit (the baseball).

Depending on how you position your body and use the lever, you can enhance your movement and sport performance. If you position the fulcrum closer to the load and away from the effort, you can generate more power and speed. In baseball, if you position your hands closer to the bat's end (load) and away from your body (effort), you can swing the bat faster and hit the ball harder. If you position the fulcrum closer to the effort and away from the load, you can gain more control and accuracy and hit the baseball with better accuracy. Thus, by understanding how to use levers, you can improve your movement and sport skills. It is all about finding the right balance and position to maximize power, speed, control and accuracy to enable us to perform better in sports.



Activity 4

In any training exercise such as a pull-up or sit-up, the muscles involved are required to overcome a certain amount of resistance to perform the exercise. The size of the moment of resistance and, therefore, the training effect on the muscles, can be varied in three ways:

- altering the moment arm of the weight of the body part that is moved
- increasing the load by adding weights to the body part that is moved
- altering the line of action of the load.

How can you change the moment of resistance to make it (a) easier and (b) harder to perform the pull-up, sit-up and push-up exercises?



Activity 5

When you flex your knee, where are the fulcrum and load? Where is the muscle that provides the effort located?



Linking question

How can changing external levers (such as the pole length in a pole vault) affect skill acquisition? (C.2.1)

Consider:

- time to adapt to a shorter/longer pole (for example, change in grip position)
- force and coordination (for example, longer pole needs more strength and coordination to control)
- timing to coordinate movements and spatial awareness during skill execution
- psychological effects on athletes (for example, confidence, focus of attention and concentration).



▲ Figure 9 Principles of levers are important in a pole vault

Practice question

The diagram shows a volleyball player serving right-handed. Which is an example of a first-class lever during the acceleration phase of the serve?

(1 mark)



▲ Figure 10

- Extension of the right elbow
- Flexion of the left elbow
- Plantarflexion of the right ankle
- Extension of the left knee

Summary

- In producing movement, bones act as levers, and joints function as the fulcrums of these levers.
- Levers can be classified into three types, depending on the positions of the effort force and the load force relative to the fulcrum.
- When a lever operates at a mechanical advantage (MA), a smaller effort can move a heavier load.
- When a lever operates at a mechanical disadvantage, a larger effort is required to move a lighter load.

Check your understanding

After reading this chapter, you should be able to:

- understand the principles of levers and MA
- distinguish between first-, second- and third-class levers.

Self-study questions

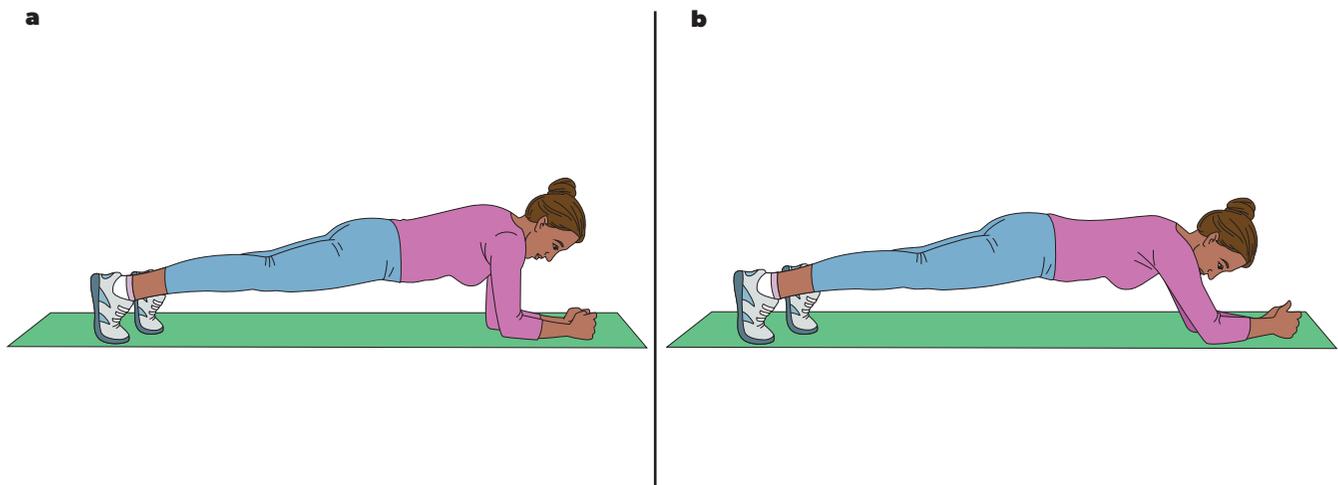
1. Outline the differences between the three types of levers.
2. Outline how mechanical advantage can be calculated.
3. Identify the fulcrum, effort arm and load arm in push-ups (on toes).
4. Describe how you can make the push-ups (on toes) exercise easier.
5. Explain how the effort arm and load arm change when performing push-ups against a wall.

Data-based question

A study compared core muscle activation of the traditional prone plank with a modified version performed with a long lever (long-lever plank), using surface electromyography.

The study involved 19 participants (mean \pm SD age 23.3 ± 4.0 years), who had been performing abdominal exercise for two years (twice per week).

They performed the two variations of the plank for 30 seconds in a randomized order with a 5-minute rest between exercise bouts (Figure 11).



▲ Figure 11 Two variations of the plank

Table 1 shows the mean (\pm SD) electrical activity (percentage of maximal voluntary activation, MVC) of the upper rectus abdominis, lower abdominal stabilizers and the lower external oblique muscles.

▼ Table 1

Muscle	Mean electrical activity (percentage MVC)	
	Traditional plank	Long-lever plank
upper rectus abdominis	21% \pm 14%	82% \pm 68%
lower abdominal stabilizers	29% \pm 26%	93% \pm 59%
lower external oblique	48% \pm 30%	98% \pm 63%

Source: Adapted from Schoenfeld et al. (2014).

1. Identify which exercise and plank position had the highest standard deviation. (1 mark)
2. Calculate the difference in mean electrical activity for the lower abdominal stabilizers. (2 marks)
3. Explain the difference found between the two plank positions. (3 marks)



B.2

Forces, motion and movement

How can the laws of motion be applied to explain the movement of bodies in sport and exercise, and be used to improve performance?

Newton's three laws of motion help explain how and when a force creates a movement and can be used to analyse linear and angular momentum in sport. Human movement (and projectile motion) is affected by the fluid in which sport and exercise are performed. For example, the motion of a runner is affected by air movement, and a swimmer by water or the air-water interface. Our understanding of movement in sports and physical activities can be enhanced by movement analysis, including a "phases of movement approach".

B.2.1 Newton's laws of motion

Syllabus understandings

B.2.1.1 Linear and angular motion can be analysed using Newton's laws of motion.

B.2.1.2 A collision results in a change in momentum in the colliding bodies.

B.2.1.3 The force of friction is determined by the coefficient of friction.

B.2.1.4 Work results from the application of a force over a distance.

AHL

Introduction

The movements of the body (and of sporting equipment) are underpinned by Newton's laws of motion, which relate forces to motion. It is not possible to analyse sporting techniques or physical activity without an understanding of Newton's laws of motion—whether you want to improve performance, reduce the risk of injury or develop new techniques.

Terms such as “force”, “power”, “velocity” and “energy” all have specific meanings in science. Understanding these definitions—and those of some other mechanical quantities—will help you carry out accurate and informative analyses of human movement.

Mechanical science is the noblest and above all other, the most useful, seeing that by means of it, all animated bodies which have movement perform all their actions.

Leonardo da Vinci (1452–1519)

An introduction to kinematics

Kinematics is the study of motion. Motion is the “change in position of a body or object”. This might be a change in the position of the body's limbs, moving the body from one place to another or both together.

Motion can be:

- linear (in a straight line), such as an ice hockey puck sliding over the ice
- curvilinear (in a curve), such as a shot-put travelling through the air
- angular, or rotational (around an axis), such as a gymnast rotating around a high bar
- general (linear and angular motion together).

The most common type of motion of the human body in sport and exercise is general. This is because at almost all synovial joints in the body, one segment rotates around another. This means that, even if we want to run in a straight line, we must rotate our limbs while travelling linearly.

Key terms

Vector A measurement that has both size and direction.

Scalar A measurement that only has size.

Measurements and position

Vector and scalar measurements

A measurement that has both size and direction is known as a **vector**. A measurement that only has size is known as a **scalar**.

The difference between scalars and vectors is important in biomechanics. It affects how measurements are combined (for example, by adding, subtracting, multiplying or dividing). If the direction of two vectors is the same, their sizes can be combined together. But if there are different directions, this must also be taken into account. Scalars can simply be added, subtracted, multiplied and divided.

Position

The position of an object or body is usually given by its coordinates. **Coordinates** are a measurement of distance from an origin (for example, in metres) and are often given in two dimensions (horizontal and vertical) or three dimensions (horizontal, vertical and lateral).

Two-dimensional coordinates are often named x and y (horizontal and vertical), while three-dimensional coordinates are usually called x , y and z .

There are two systems for giving three-dimensional coordinates. In the first x is horizontal, y is vertical, z is lateral while in the second x is horizontal, y is lateral, z is vertical.

Angular coordinates are given by a measurement of angles around one or more axes.

Linear kinematics

Linear kinematics looks at motion in a straight line.

Linear displacement and linear distance

If a body or object changes its position it undergoes a **displacement**. This is given in terms of how far and in which direction the end position is from the start position. The displacement is often expressed as how far the body or object has moved horizontally, vertically and laterally. Therefore, displacement is a vector quantity because it has size and direction.

The size of linear displacement is called **distance**. Distance is a scalar quantity and has no direction. Therefore, it does not matter in which direction the object or body moves, only how far it goes.

Linear displacement is usually given by the symbol s . Linear distance is usually given by the symbol d . The SI unit for the size of displacement is metres (m).

The direction of a displacement can be specified in degrees ($^{\circ}$) or radians (rad) from a particular direction, or may be along a coordinate axis (horizontal, vertical or lateral).

Linear velocity

Velocity is a change in displacement divided by the time taken for the change to take place. It has size (how fast) and direction, so it is a vector quantity. Linear velocity is usually given by the symbol v . Sometimes the symbol u is used.



Activity 1

What is the overall linear distance and displacement covered after a 400 m event completed in the first lane of a competitive running track?

Note: the length of the first lane of a competitive running track is 400 m.

This definition of velocity can be written as:

$$v = \frac{\Delta s}{\Delta t}$$

where v is velocity, s is displacement, t is time and Δ means "difference in".

The size of linear velocity is called **speed**. It is a scalar quantity as it does not have any direction.

The SI unit for speed and velocity is metres per second (m s^{-1} or m/s).

As with linear displacement, the direction of velocity may be specified in degrees or radians from a particular direction, or may be along a coordinate axis (horizontal, vertical or lateral).

Linear acceleration

Acceleration is a change in velocity divided by the time taken for the change to take place. It also can be linear or angular. It has size and direction and is a vector quantity.

Acceleration is a change in speed, a change in direction or both. If you are running around a bend at constant speed, you are accelerating. Acceleration should therefore not just be used to indicate a change in speed, but also a change in direction.

Linear acceleration is usually given by the symbol a and can be expressed as:

$$a = \frac{(v - u)}{t}$$

where v and u are final and initial velocities, and t is the time for the velocity change.

The SI unit for acceleration is metres per second per second (m s^{-2} or m/s/s), and the direction may be specified in degrees or radians from a particular direction, or may be along a coordinate axis (horizontal, vertical or lateral).

Key point

The symbols usually used for the different types of movement in linear kinematics and the SI units used are summarized in Table 1.

▼ Table 1 Different types of movement in linear kinematics

Movement	Symbol	Unit
linear displacement	s	metres
linear distance	d	metres
linear velocity	v, u	metres per second (m s^{-1} or m/s)
linear acceleration	a	metres per second per second (m s^{-2} or m/s/s)

Angular kinematics

Angular kinematics is a branch of physics that deals with the motion of objects that rotate or spin around an axis. This has applications across many sports, such as the rotation of the body of a figure skater during jumps and spins, and the

rotation of a golf club during swings. By understanding the principles of angular kinematics, athletes and coaches can improve their performance and reduce the risk of injury.

For example, when a soccer player kicks the ball, their leg rotates around the hip joint. Angular kinematics is used to analyse the rotation of the leg during the kick. The spin of the soccer ball after it is kicked is also an example of angular kinematics. The spin affects the trajectory of the ball and can make it curve or swerve in the air.

Let's consider swimming as another example of the application of angular kinematics. When a swimmer performs a flip turn, their body rotates around the longitudinal axis. Angular kinematics can be used to analyse the rotation of the swimmer's body during the turn.

In baseball, when a baseball pitcher throws a curveball, the ball spins around its axis. This spinning motion is another example of angular kinematics. Baseball pitchers can use their knowledge of angular kinematics to throw different types of pitches, and batters can use their understanding of velocity to time their swings to improve their performance.

In the game of cricket, the length of a cricket bat can also affect the application of these angular kinematics concepts. For example, a longer cricket bat can increase the angular velocity of the bat during a swing, which can result in a faster ball speed when hitting the ball. However, a longer bat can also increase the moment of inertia, which can make it harder to swing the bat quickly. By understanding the principles of angular kinematics, displacement and velocity, cricket players and coaches can improve their performance and better understand the physics of the game of cricket.

Angular displacement

Angular displacement is the difference between start and end positions when a body moves around an axis with angular motion. Angular displacement is a vector quantity so has size and direction and is represented by the symbol θ (Greek lower-case theta). The SI unit for the size of angular displacement is usually degrees or radians, and the direction is anticlockwise or clockwise around the axis.

Angular velocity

Angular velocity is the change of angular displacement divided by the time taken. It is also a vector quantity and is represented by the symbol ω (Greek lower-case omega).

The SI unit for the size of the angular velocity is degrees per second ($^{\circ}\text{s}^{-1}$ or $^{\circ}/\text{s}$) or radians per second (rad s^{-1} or rad/s), and the direction is usually clockwise or anticlockwise about an axis.

Sometimes the angular velocity of an object will be expressed as:

$$v = \omega r$$

where ω is the angular speed and r is the radius (distance of the object from the axis).

One full rotation equals 2π radians, so another way of expressing this is as:

$$v = \frac{2\pi r}{T}$$

where T is the period (time taken for a full rotation).

Angular acceleration

Angular acceleration is the change of angular velocity divided by the time taken for the change to take place.

It is a vector and is given by the symbol α (Greek lower-case alpha).

The SI unit for the size of the angular acceleration is degrees per second squared ($^{\circ}\text{s}^{-2}$ or $^{\circ}/\text{s}^2$) or radians per second squared (rad s^{-2} or rad/s^2), and the direction is often clockwise or anticlockwise about an axis.

Key point

The symbols usually used for the different types of movement in angular kinematics and the SI units used are summarized in Table 2.

▼ Table 2 Different types of movement in angular kinematics

Movement	Symbol	Unit
angular displacement	θ	degrees ($^{\circ}$) or radians (rad)
angular velocity	ω	degrees per second ($^{\circ}\text{s}^{-1}$ or $^{\circ}/\text{s}$) or radians per second (rad s^{-1} or rad/s)
angular acceleration	α	degrees per second squared ($^{\circ}\text{s}^{-2}$ or $^{\circ}/\text{s}^2$) or radians per second squared (rad s^{-2} or rad/s^2)

Instantaneous and average kinematics

As velocities and accelerations (linear and angular) involve division by time, the values obtained will depend on the duration over which the measurement is made. The time may be long (for example, over a whole race), or very short (fractions of a second). As the time gets shorter and shorter, it approaches zero. In mathematics, the study of these continuous changes over time is called calculus.

Velocity and acceleration measured over a very short ("instant") period of time are called **instantaneous velocity** and **instantaneous acceleration**, and may be calculated in two ways.

If the relationship between the displacement and time is known mathematically (by an equation), calculus allows the exact calculation of an equation for the velocity (and similarly, if the equation between the velocity and time is known, an equation for the acceleration can be found).

Alternatively, you can draw a graph of *displacement* against *time*. The velocity is the gradient of the slope of this graph at any point. This is usually found by drawing a *tangent* to the displacement–time graph. Similarly, the same method can be used to get acceleration from a velocity–time graph.

Velocity and acceleration calculated over a longer period of time are usually called **average velocity** and **average acceleration**.

Average velocities and accelerations are much simpler to calculate than instantaneous velocity and acceleration.

- To find average velocity, divide change in displacement by the time taken.

$$\text{average velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

- To find average acceleration, divide change in velocity by the time taken.

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

An introduction to kinetics

Kinetics looks at the forces involved in the movement of an object or body. As with kinematics, we can look at linear kinetics for movements in a straight line or angular kinetics for movement around an axis.

Force

Force is sometimes described as a push or a pull. However, this is rather simple and so a better definition and understanding are needed.

Force is the mechanical interaction that goes on between two objects or bodies. It may involve contact (such as friction) or it may act at a distance (such as gravity). A force changes or tries to change the motion of the objects.

The **resultant motion** of an object is determined by the sum of the forces acting on it. When an athlete moves, the resultant motion is determined by the sum of the forces acting on them. For example, when a trampolinist jumps or bounces on a trampoline, the resultant motion of the trampolinist is determined by the sum of the forces acting on them, including the force of the trampoline pushing them up and the force of gravity pulling them down. Additionally, the resultant motion of the trampolinist is determined by the direction and magnitude of these forces, which can affect the height and speed of their jump or bounce. By understanding the principles of forces and motion, trampolinists (and their coaches) can adjust their technique to maximize the force of the trampoline and minimize the force of gravity, which can result in higher and more impressive jumps and bounces and, importantly, more time in the air to perform their high-flying acrobatics, such as twists and somersaults.

Gravity

In 1687, Sir Isaac Newton published his *Principia*, which set out to understand how objects changed their motions. Building on the work of other scientists, such as Galileo, Kepler and Halley, he realized that there is an attractive force between objects that is related to their masses (the amount of material in them) and inversely proportional to the square of the distance between them.

The force of **gravity** acts between all objects with mass. Gravity causes the elliptical orbits of the planets around the Sun, but is also the reason for the attraction between the Earth and all bodies and objects near to it or on its surface.

ATL Thinking skills

Astronauts orbiting the Earth are still subject to Earth's gravity (that is why they are orbiting rather than travelling off into space) and so are not in "zero gravity". It is simply that their spacecraft is moving as fast as they are and so they are in "free fall" all of the time and thus have no force between them and the floor.

Mass and weight

Mass is the amount of material in a body or object. It is usually measured in kilograms (kg). This is not the same as weight.

Weight is the effect of the force of gravity on mass. This means that, for example, the mass of an object on the Moon is the same as on the Earth, but its weight is less (because the Moon's gravity is less than that of the Earth). On Earth, the force of gravity always acts between an object and the Earth and is directed towards the centre of the Earth, so there is *always* a force acting vertically on us.

Newton's laws of motion

In his *Principia*, Newton also stated the three laws that relate forces to the change of motion. Although today we know that Newton's laws of motion do not work well when considering motion near the speed of light or when looking at subatomic particles, these laws are accurate when analysing the forces and motion on our bodies or everyday objects.

Newton's first law of motion

Newton's first law of motion can be stated as:

An object will remain at rest or continue with constant velocity unless acted on by an unbalanced force.

This means that bodies or objects stay where they are or keep moving unless acted on by an unbalanced force. This law is sometimes known as the law of inertia.

For a body to be at rest (standing still) on the Earth, there must be a force balancing the weight, acting in the opposite direction (upwards). This force often comes from supports or the ground and is called the reaction force. If an object is travelling at constant speed in a constant direction, the forces on it must also be balanced.

Thus, a true understanding of a force is that it is something that *changes* (or tries to change) a body or object's motion and not something that *causes* motion.

Newton's second law of motion

Newton's second law of motion relates the change in motion (acceleration) to the force causing that change. It can be stated as:

The acceleration (for a body/object of constant mass) is proportional to, and in the same direction as, the unbalanced force applied to it.

This law is sometimes known as the law of acceleration.

This is sometimes written as: "Force is equal to mass multiplied by acceleration":

$$F = ma$$

where m is mass and a is acceleration.

ATL Thinking skills

An example of Newton's first law of motion in sport is when an ice hockey puck is stationary on the ice. The force of the weight of the puck is balanced by the upward force from the ice, so it is at rest. However, when a player hits the puck, an unbalanced external force is applied to it so it accelerates in the direction of the hit. It then travels across the ice, being slowed slightly by friction, until another external force (another player's stick or the side walls of the arena) changes its motion again (for example, to stop it).



▲ Figure 1

ATL Thinking skills

Newton's second law can be illustrated by considering the different forces required to accelerate a table tennis ball and a soccer ball. To give the soccer ball the same acceleration as a table tennis ball, the player must apply a larger force because the soccer ball has a greater mass than the table tennis ball.



▲ Figure 2

Thus, a body or object's change of motion is directly related to the size of the (unbalanced) force causing the change, and in the direction of the applied force. The change in motion is also inversely related to the mass of the object. Therefore, heavier objects will accelerate less for the same force, and to accelerate heavy objects, a large force is needed.

As we have seen, acceleration is change in velocity divided by the time taken. So Newton's second law of motion could be rewritten as:

$$F = \frac{m(v - u)}{t}$$

where v and u are final and initial velocities and t is the time for the velocity change.

The force of gravity acting on an object (weight) can be expressed as:

$$F_g = mg$$

where m is the mass of the object and g is the acceleration caused by gravity.

Newton's third law of motion

The third law of motion explains the forces between two objects. It can be stated as:

When one body or object applies a force to another, the second body or object will apply a force equal in size but opposite in direction to the first body or object.

This law is often called the law of reaction. This law is sometimes phrased as "for every action there is an equal and opposite reaction."

There are several important aspects to the understanding of this law.

- The two forces are on two *different* bodies or objects (not on the same body/object).
- The forces on the objects are exactly the same size, regardless of the masses of the objects.
- The *effects* of those forces may be different if the bodies/objects are of different masses—this is due to Newton's second law of motion.
- The forces happen at exactly the same time—one does not occur later in response to the other.

ATL Thinking skills

Newton's third law is very important when a sprinter starts a race from the blocks. They must push backwards and downwards with large forces onto the blocks. According to Newton's third law, the blocks will push back onto the sprinter with the same force, but in the opposite direction (forwards and upwards). As the blocks are connected to the ground (which has a much larger mass than the athlete), the ground will not move backwards, but the athlete will move forwards and upwards out of the blocks as soon as they raise their arms from the ground.



▲ Figure 3

Key points

Newton's first law Bodies or objects stay where they are or *keep moving* unless acted on by an unbalanced force (law of inertia).

Newton's second law Force is equal to mass multiplied by acceleration (law of acceleration).

Newton's third law For every action there is an equal and opposite reaction (law of reaction).

ATL Thinking skills

Newton's laws of motion applied to ice hockey

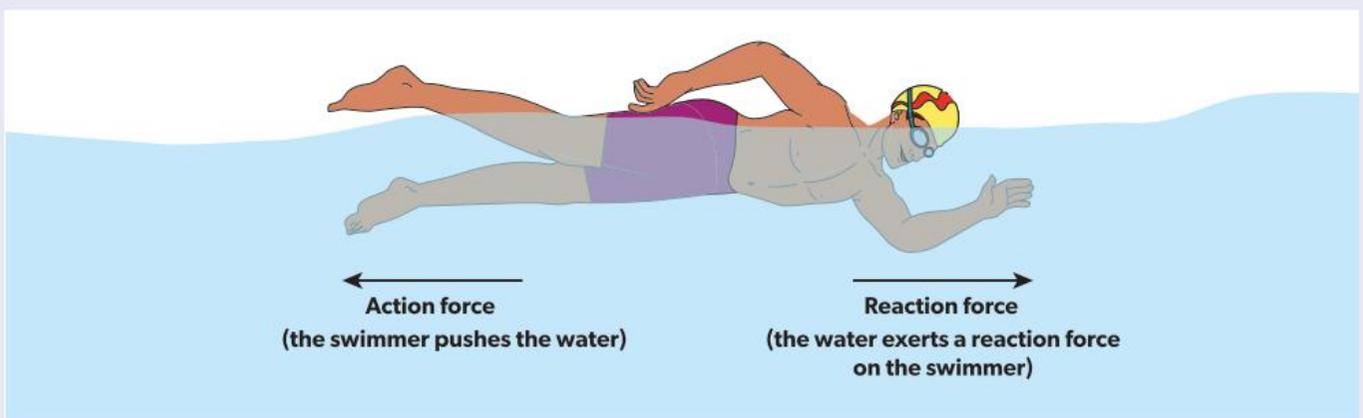
- Newton's first law of motion: a hockey puck will remain at rest on the ice or continue to move at a constant speed in a straight line unless acted upon by a force, such as a player's stick hitting it.
- Newton's second law of motion: a hockey player must apply more force to a heavier puck to achieve the same acceleration as with a lighter puck.
- Newton's third law of motion: when a hockey player hits the boards, the force of the impact is equal and opposite to the force the player exerts on the boards.

Newton's laws of motion applied to swimming

- Newton's first law of motion: a swimmer will remain at rest in the water or continue to move at a constant speed in a straight line unless acted upon by a force, such as a swimmer's arms and legs pushing against the water.
- Newton's second law of motion: a heavier swimmer must apply more force to the water to achieve the same acceleration as a lighter swimmer.
- Newton's third law of motion: when a swimmer pushes against the water with their arms and legs, the water pushes back with an equal and opposite force, propelling the swimmer forwards.



▲ Figure 4 The boards exert an equal and opposite force on the player



▲ Figure 5 The water exerts a reaction force on the swimmer



▲ Figure 6 Wrestlers maximize their stability by minimizing the height of their centre of mass, and maximizing their base of support

Applying Newton's laws of motion

There are several principles to consider when applying Newton's laws.

Principle of stability

The following factors affect the stability of an object.

- the height of the centre of mass relative to the supporting surface (a lower centre of mass provides greater stability)
- the size of the base of support (a larger base provides greater stability)
- the position of the line of gravity relative to the base of support (a line of gravity that is within the base of support provides greater stability)
- the mass (a larger mass provides greater stability).

ATL Thinking skills

How stability can positively impact basketball performance

- When a basketball player is dribbling the ball, they need to maintain their balance and stability to avoid losing control of the ball and to be able to change direction quickly.
- By maintaining good stability, a basketball player can generate more force and power in their movements, such as jumping higher for a rebound or making a quick change of direction to get past a defender.
- Stability also helps basketball players to resist external forces, such as a defender trying to push them off balance, and to recover quickly from unexpected movements or contact with other players.

How instability can negatively impact basketball performance

- Instability can increase the risk of injury in basketball players.
- Maintaining good balance is essential for basketball players to control their bodies, minimize mistakes and rapidly change direction in a limited area.



▲ Figure 7 Stability in basketball

Principle of summing joint forces

When you play sports, your muscles create forces to make movements, such as running, jumping or throwing. These forces act on your joints, allowing you to perform a wide range of movements.

Each joint in your body can experience multiple forces acting on it simultaneously. For example, when you jump to play an attacking shot in volleyball, your leg muscles push down on your knee joint to propel you upwards, while your feet push against the ground to push you off the surface. The principle of summing joint forces is about understanding how these forces combine or interact at a joint.

Imagine a group of friends are pulling in a tug of war competition. If everyone in a team pulls in the same direction, their forces combine and make it easier to move the opposing team.

As an individual athlete, when the forces from your muscles add up in the same direction, they make your movements more powerful (for example, you can jump higher when playing an attacking shot in volleyball). The principle of summing joint forces in sport biomechanics helps us understand how the forces created by our muscles combine at our joints, affecting our movements and performance in sports.

But be careful! Sometimes, if you use too much force or perform a movement with poor technique, it can put extra pressure on your joints, which can lead to injury.

Principle of linear momentum and linear impulse

Linear momentum is the property an object has due to its movement. It is calculated by the mass of the object (m) multiplied by the velocity at which it is moving (v). Momentum is a vector since it has size and direction, and it is measured in kg m s^{-1} .

It is usually given by the symbol p , and can be expressed as:

$$p = mv$$

Linear impulse is force multiplied by the time that the force acts for. Impulse is also a vector. It is usually given by the symbol J :

$$J = F\Delta t$$

where F is force and Δt means "change in time".

There is an important relationship between linear impulse and linear momentum. Linear impulse is the change in linear momentum. This means that the size and direction of the change in momentum of a body or object depend on the force applied to it and the time for which that force acts. If the force is large and the time is also large, there will be a significant change in momentum. As the mass of a body or object does not usually change, this will equate to a change in velocity.

Activity 2

Newton's second law of motion can be expressed as:

The acceleration experienced by an object when acted upon by a force is directly proportional to the size of the force, inversely proportional to the mass of the object and takes place in the direction of the force.

Therefore, the greater the force applied to an object, the greater will be the acceleration of the object, and the greater the velocity of the object will be when the force is removed. For example, the more force that a shot-putter can apply to the shot before release, the greater the velocity of the shot will be at release and, other things being equal, such as the height of release and angle of trajectory, the further the shot will travel.

However, from Newton's second law the amount by which the velocity of an object can be increased depends not only on the size of the force applied but also on the length of time the force can be applied for. It follows that in order to give a shot maximum velocity, it is necessary to apply as much force as possible for as long as possible.

What sports techniques do athletes use to ensure they apply force to the shot (or the discus) for as long as possible?

ATL Thinking skills

Impulse–momentum relationship in sport

During take-off, a high jumper must change their horizontal motion into vertical motion to jump over the bar. This means the horizontal linear momentum they have from the approach must be converted to vertical linear momentum. This is done by applying a large vertical force down on the ground, and thus, by Newton's third law, receiving the same ground reaction force acting upwards.

To gain the greatest vertical momentum, this force must be applied for as long a time as possible. Therefore, the high jumper places their take-off leg in front of them, landing on the heel. The time taken for the body over the take-off foot, combined with the flexion and extension of the knee, means that the muscles can apply a very large force over a long period of time, thus maximizing the vertical linear impulse and gaining a large vertical linear momentum.



▲ Figure 8

Principle of impulse direction

Imagine you are playing soccer and you need to kick the ball to score a goal. The principle of impulse direction in sport biomechanics is like understanding how to kick so it goes exactly where you want it to go. Think of impulse as a “pushing force” that you apply to the ball. The direction of this “pushing force” is essential because it determines which way the ball will move.

Now imagine you have a toy car, and you want to make it move forward. You give it a gentle push from behind, and it goes straight ahead. But if you push it from the side, it will move sideways instead. That is because the direction of your push affects the direction that the car moves.

In sports involving a ball, such as soccer or basketball, understanding impulse direction helps athletes control the ball and make it go where they want. So, the principle of impulse direction in sport biomechanics is all about applying the right amount of force in the right direction to make the ball go where you want it to go, whether shooting a basketball into the hoop or scoring a goal in soccer.

Principle of angular movement

Torque

If a force is applied to an object that is free to rotate around an axis, as long as the force is applied so that it does not act through the axis (centre of rotation), it will create a **torque** (sometimes called the moment of the force). The force that is applied is called an **eccentric force**.

The size of the torque created depends on three factors:

- the size of the force
- the direction of the force
- how far the force is applied from the axis of rotation.

Torque is very important because almost all segments of the human body rotate about axes within the synovial joints. The way in which the muscles are anatomically arranged relative to the joints plays a large part in determining how much torque can be created around each joint. This is closely linked to the principle of levers—rigid rods (such as the bones) that are rotated about axes such as the joints (chapter B.1.4).

Moment of inertia

The **moment of inertia** is how difficult it is for a body or object to rotate about an axis. It is measured in kg m^2 . It depends on the mass of the body or object, and its mass distribution around the axis. More mass further away from the axis gives a greater moment of inertia and makes it more difficult to rotate. More mass nearer the axis of rotation makes it easier to rotate. The human body has different moments of inertia depending on the axis of rotation and the body position.

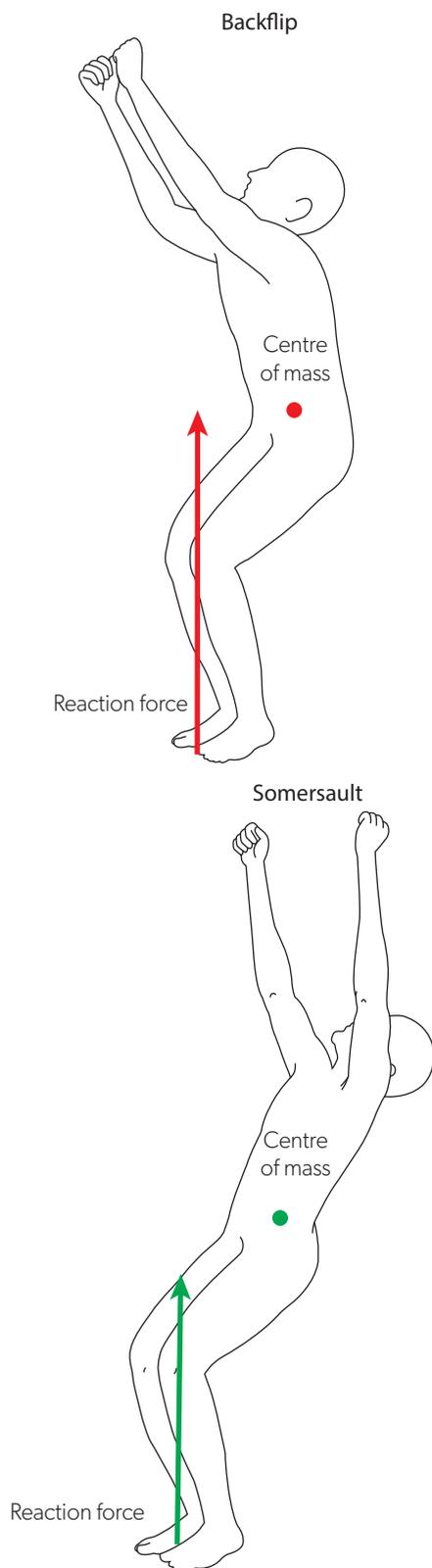
Angular momentum

Angular momentum is a measure of the amount of (or potential for) rotation. It is generated by the torque resulting from the application of an eccentric force to an object that is free to rotate around an axis. The eccentric force may come from another object (such as the ground or a sporting implement), another body or a segment of the body via the muscles.

ATL Research skills

In 1952 at the Helsinki Olympic Games, the winner of the shot-put, Parry O'Brien of the USA, demonstrated a new technique that has since been used by many Olympic champions.

Research the “O'Brien” technique and explain why its advantage is that as a result of the impulse of the force applied to the shot in the movement across the circle, the shot will be moving fairly quickly in the direction intended to achieve maximum distance.



▲ **Figure 9** Gymnast generating angular momentum in a backflip (top) and back somersault (bottom) by creating ground reaction forces (arrows) not directed through the centre of mass (circles)

Angular momentum is a vector quantity as it has size and direction, and it is measured in kg m s^{-1} .

It is often represented by the letter L and can be expressed as:

$$L = I\omega$$

where I is moment of inertia and ω is angular velocity.

Angular momentum of the human body is often generated by using the muscles and limbs to apply a torque to the ground, which applies the same torque back (refer to Newton's third law). As the body has a much smaller moment of inertia than the Earth, the body will rotate much more. This is important in sports such as gymnastics for creating the rotation necessary to perform somersaults, twists and other rotational movements. The angular momentum may also be created by applying and gaining a torque to apparatus such as a vaulting table or beam.

This often means a force must be applied to the ground or apparatus so that the reaction force does not travel through the individual's centre of mass (the axis for airborne rotations).

Many other sports require rotational movements—swinging a golf club, throwing a javelin or kicking a football, for example—so generation of angular momentum is an important principle here as well.

Conservation of angular momentum

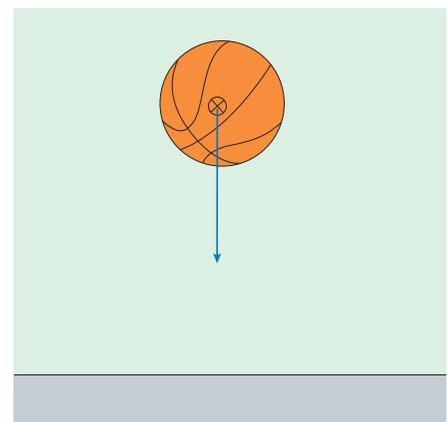
Newton's first law of motion can be expressed angularly as:

A rotating body will continue to turn about its axis with constant angular momentum unless an external unbalanced torque (moment) is applied to it.

Therefore, once the angular momentum has been generated, it will stay constant unless there is an interaction with another object or body that creates a torque to change it.

During human airborne flight in sports such as gymnastics, diving, long jump and high jump, the only forces acting are gravity and air resistance (drag). As the speed of the flight is fairly low (less than 15 m s^{-1} even in long jump) and the human body has considerable mass, the effect of air resistance (drag) is very small. Therefore, the only major force acting is gravity acting through the centre of gravity.

However, the axes of rotation in flight are also through the centre of gravity. Therefore, the force of gravity does not create a torque as it goes through the axis of rotation (that is, the distance of the force from the axis of rotation is zero). This means that there is no rotational effect of the force of gravity while the body is in flight. Therefore, according to Newton's first law, the angular momentum must stay the same (it is conserved) during the flight. For example, if you drop a ball from a height of 1 m, the speed of the flight will be low and air resistance will be negligible. The force of gravity applied



▲ **Figure 10** When you drop a ball, gravity acts through the centre of mass and there is no rotation

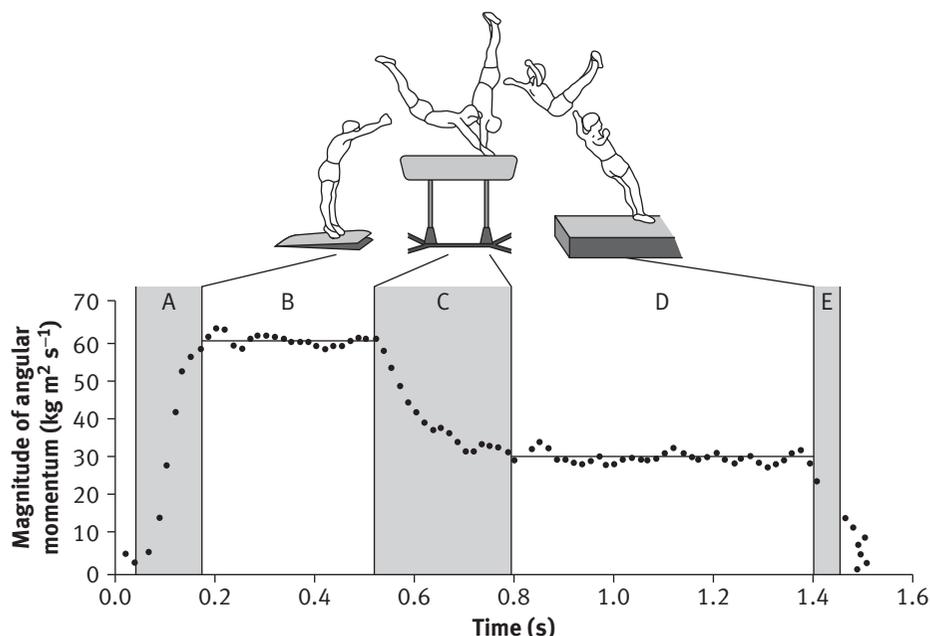
passes through the centre of mass (at zero distance from the axis of rotation) and does not create rotation (torque).

Angular momentum is comprised of moment of inertia multiplied by angular velocity. Therefore, during flight, if the moment of inertia is reduced, the angular velocity must increase to keep the angular momentum constant. This is why when a gymnast “tucks” during a somersault (by bringing their arms and legs towards the centre of gravity and reducing the moment of inertia), they will rotate faster. Similarly by the same principle, when the gymnast “opens out” prior to landing (increasing the moment of inertia) their rate of rotation will decrease.

A common misconception is that these changes in rotational speed (angular velocity) are due to decreases or increases in air resistance—this is untrue.

Figure 12 illustrates angular momentum as a gymnast completes a Yamashita vault. Solid black dots show the magnitude of angular momentum. Angular momentum only changes when the gymnast is in contact with the ground or the box and stays constant in the airborne phases.

- During phase A, the gymnast is in contact with the ground and the angular momentum in the clockwise direction is increasing, reaching values greater than $60 \text{ kg m}^2 \text{ s}^{-1}$.
- During phases B and D, the gymnast is in the air (not in contact with the ground or the box) and angular momentum remains constant.
- During phase C, the gymnast's arms are in contact with the box and the momentum is decreasing as the angular velocity of the gymnast is reduced.
- During phase E, the gymnast is in contact with the ground on landing and the angular momentum decreases to zero.



▲ Figure 12 Angular momentum in a Yamashita vault



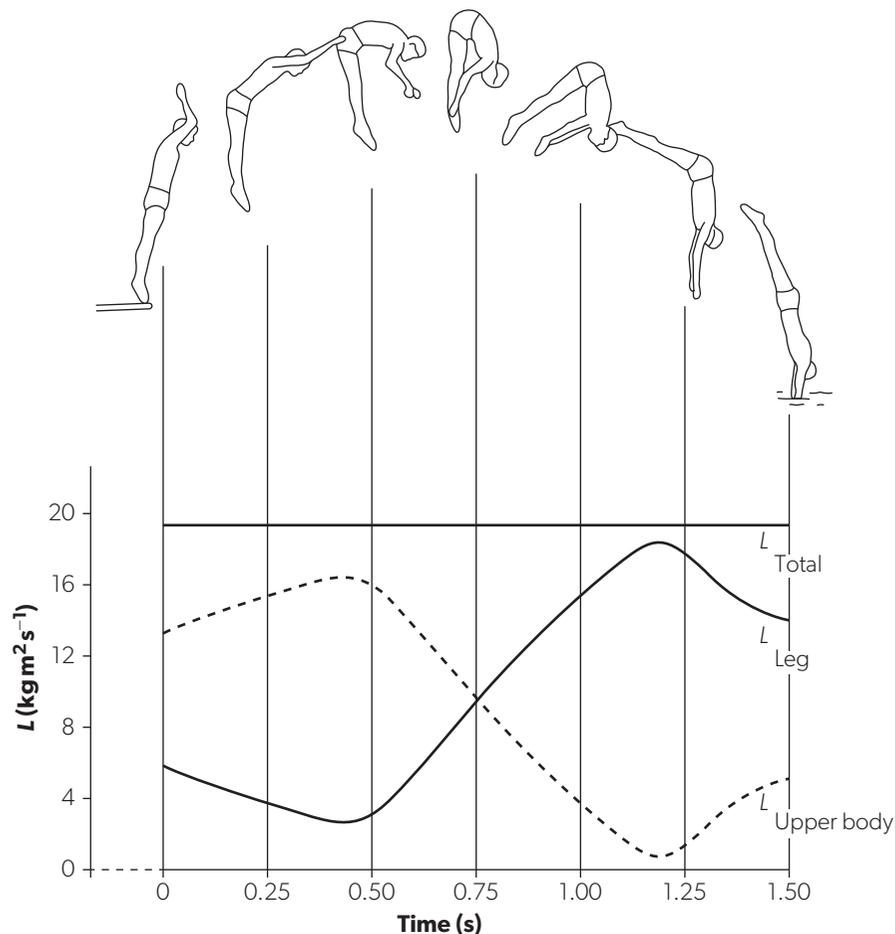
▲ Figure 11 In figure skating, athletes bring their arms closer to or further away from the axis of rotation (the vertical axis) to control their angular velocity (rate of rotation)

Transfer of angular momentum

As angular momentum cannot be created or destroyed unless there is an external torque, once an athlete is in the air, it is not possible to change the amount of angular momentum of the whole body.

This means that if one part of the body increases its angular velocity (for example, by muscle contraction), another part of the same body must slow down (reduce its angular velocity) to make sure the angular momentum of the whole body stays the same. However, when the first part then slows down, the second part will speed up again.

This transfer of angular momentum between the different segments of the human body when airborne is used in activities such as the piked dive (Figure 13). As the diver is flexing their hips to achieve a piked position (0–0.5 seconds), their upper-body angular velocity increases, and as a consequence the angular momentum of the upper body increases too. Since the angular momentum of the total body is conserved, the angular momentum of the lower body during the same period of time (0–0.5 seconds) decreases. The greater the angular momentum of the upper body, the lower for the lower body.



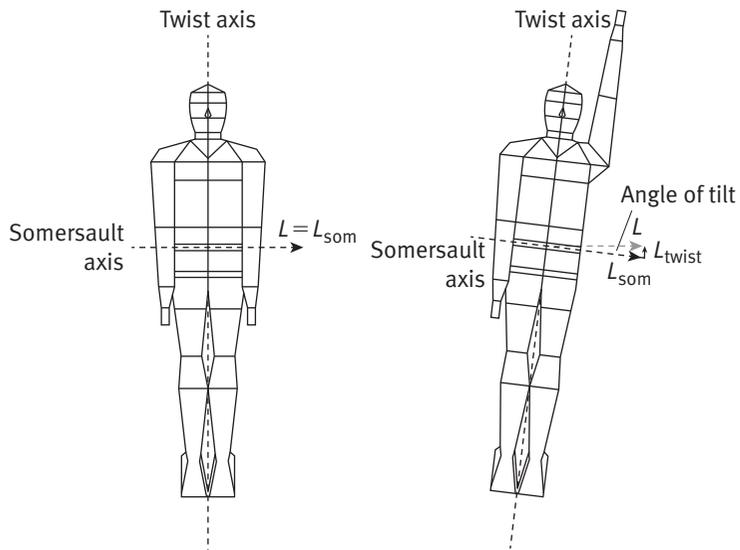
▲ Figure 13 Angular momentum in a piked dive

Trading angular momentum

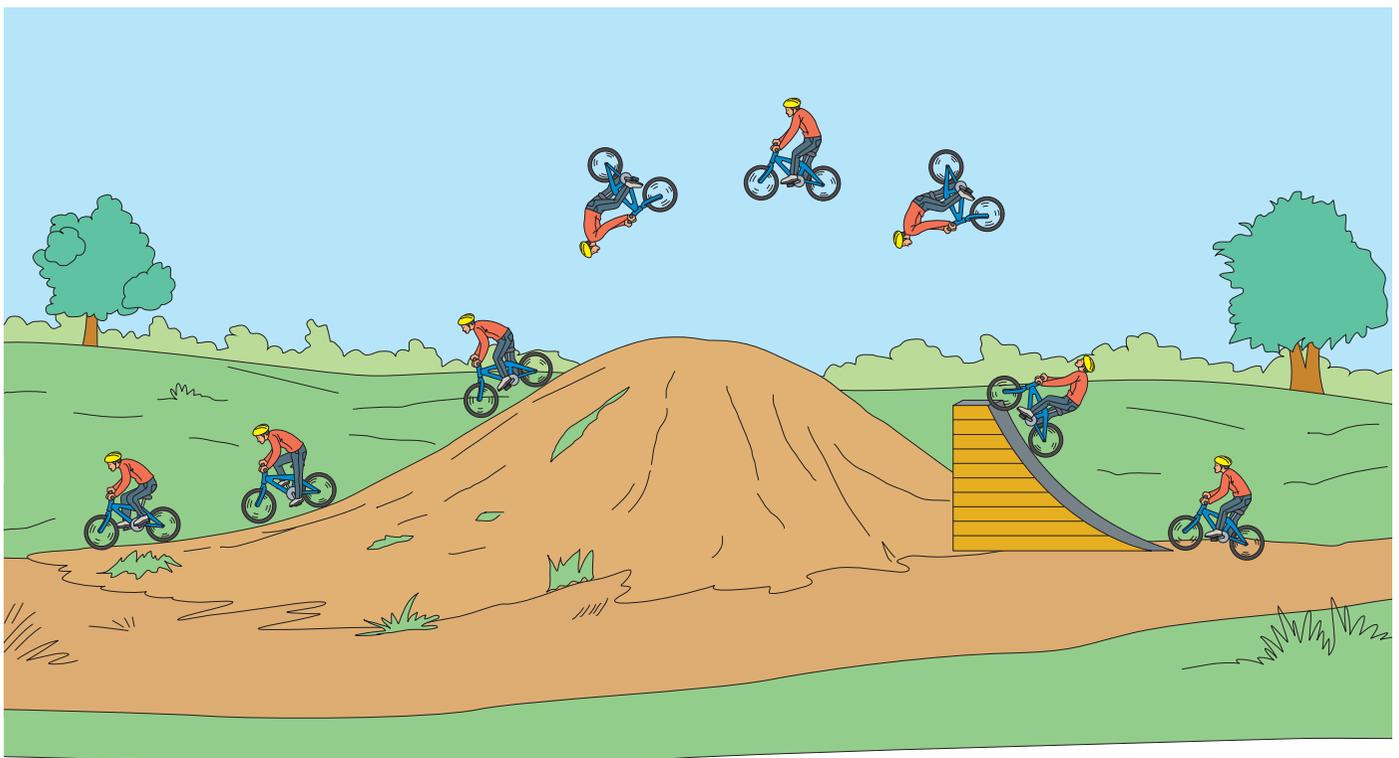
As angular momentum is a vector quantity, if an athlete is rotating about one axis (for example, if they are somersaulting) and they introduce rotation about another axis (such as tilting) by movements of body segments using the muscles, then

the combination of the two vectors is rotation around a third axis (twisting). In gymnastics, this is often used to create twisting in somersaults.

This allows the trading of some of the somersault angular momentum for twisting (Figure 14).



▲ Figure 14 Trading of angular momentum—creating twist by introducing tilt while somersaulting



▲ Figure 15 Cyclists can use their brakes to adjust their rotation when in the air. Since there is no contact with the ground and angular momentum remains constant, braking allows a transfer of angular momentum from the wheel to the cyclist.



Linking question

How can coaches use Newton's laws to improve the performance of their athletes? (B.2.1)

Consider:

- law of inertia, body positioning, balance/stability and conserving energy (for example, coach athletes to avoid unnecessary movements and move efficiently)
- law of acceleration, power, strength and speed (for example, coach athletes to enhance their power-weight ratio)
- law of action-reaction and generating power (for example, coach athletes to transfer energy from legs to arms during throwing)
- impulse and momentum (increase impulse to generate greater momentum; for example, coach athletes to take longer strides when running)
- Newton's laws, identifying areas for technical improvement, feedback, and injury prevention.

Collisions

A **collision** occurs when two or more objects come into contact with (exert forces on) each other during a short period of time.

Conservation of linear momentum

During collisions between two bodies or objects, the total linear momentum of the objects involved is conserved (stays the same). This is a direct result of Newton's second and third laws, as the forces between the objects will be the same, as will the time of the collision. Therefore, the linear momentum changes will be the same for the two objects.

However, some energy is lost in the collision due to heat and sound energy. There is an experimental law formulated by Newton that states that the difference in velocities of the two objects is directly related to the difference in velocities before the collision. The variable that quantifies this relationship is called the **coefficient of restitution** (C_R) and is mainly dependent on what materials the objects colliding are made of (although it does depend slightly on the initial velocities of the objects—this is why it is an experimental law). The more elastic the objects in the collision, the closer to 1 the coefficient of restitution will be and the less energy will be lost in the collision.

The coefficient of restitution C_R of two objects a and b can be expressed as:

$$C_R = \frac{v_b - v_a}{u_a - u_b}$$

where v_a and v_b are the final velocities of the objects, and u_a and u_b are the initial velocities of the objects.



Global impact of science

Coefficient of restitution—cheating in ball games?

Because the coefficient of restitution depends on the material of the objects in the collision, it is sometimes possible to change this to your advantage in ball games. For example, the properties of many sports balls depend on their temperature (because the balls are made of rubber or may contain air). So by raising the temperature of the ball, it may be possible to increase the coefficient of restitution, thus giving the ball a higher velocity after collision with a racket or club.

In some sports, such as squash, this is legal and a warm-up serves to increase the temperature of the ball. However, in other sports this is illegal. For example, in the 1950s, some professional baseball teams kept baseballs in a freezer to cool them. This would reduce the coefficient of restitution and make them less elastic. If the home team were playing against a team who were renowned for hitting home runs, this could reduce the number of runs scored by the visitors. Therefore, balls for baseball matches (and other sports such as tennis) are now kept in containers whose temperature is closely monitored by the governing authorities.

In 2008, the governing bodies of golf (the USGA and R&A) made particular designs of clubs illegal. Golf club manufacturers had been making clubs (particularly drivers) with contact surfaces that had a very high coefficient of restitution (sometimes called “trampoline club faces”), and thus the ball could be hit faster and would travel further. The governing bodies, therefore, put an upper limit on the coefficient of restitution of the driver club face, to ensure fairness between players and to prevent golf courses from having to be lengthened to cope with the increased driving distances.



Activity 3

The coefficient of restitution can be experimentally measured by dividing ball velocity after collision by ball velocity before collision. Can you design an experiment to assess the coefficient of restitution of a golf club?

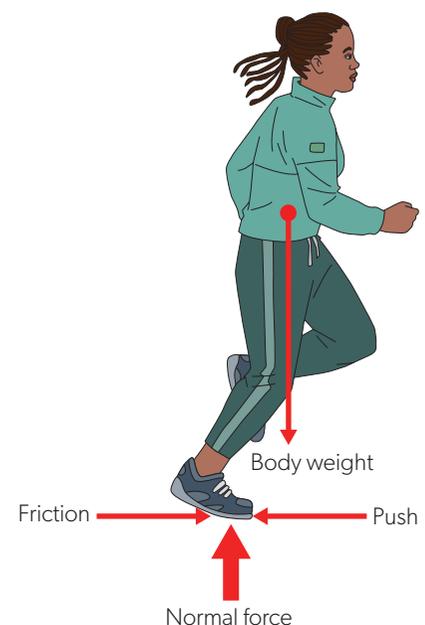
Note: assume we can use a ball cannon to fire golf balls at a specific speed and in a specific direction. We can also measure ball velocity before and after collision with the use of a high-speed video camera.

Friction

Friction is a force that acts against the motion of two surfaces that are in contact. The direction of frictional force is parallel to the plane of contact of the two surfaces.

For example, consider Figure 16.

When you walk or run, the surface of your shoes meets the surface of the ground. When you apply a pushing force, friction acts in the opposite direction, parallel to the surface of the ground. Figure 16 also shows the forces of body weight (the force of gravity) and the normal force (the force that the ground exerts on the body).



▲ Figure 16 The direction of the friction acting in opposition to the pushing force

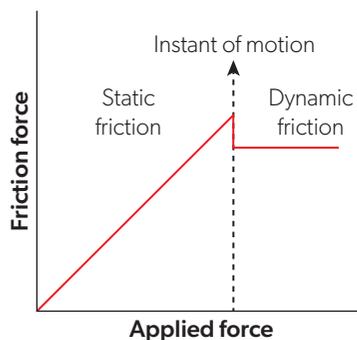
ATL Thinking skills

Figure 17 shows a blister on an athlete's foot after completing a race.

Are such blisters the result of static friction or dynamic friction?



▲ Figure 17



▲ Figure 18 When the force applied to a stationary object is sufficient to overcome static friction, the object begins to move

Key points

- The direction of friction is opposite the direction of the applied force.
- The magnitude of friction is proportional to the normal force between the two surfaces and is affected by the characteristics of the surfaces in contact.
- Static friction reaches its maximum value before the surface of an object starts to move.
- Dynamic friction is lower than static friction.

There are two types of friction:

- static or limiting friction
- dynamic friction.

Static friction

Static friction refers to the force acting between two surfaces that are not moving relative to each other.

The **coefficient of static friction** (μ_s) is a scalar quantity that reflects the characteristics of the surfaces in contact. For example, steel on ice will have a low coefficient of static friction, whereas rubber on the ground will have a high coefficient of static friction. Values range between zero and one, but can sometimes be higher. Overall, the greater the interaction between the interfacing surfaces, the greater the size of the coefficient of static friction.

The coefficient of static friction (μ_s) is equal to the ratio of the force of friction (F_f) to the normal reaction force, F_N :

$$\mu_s = \frac{F_f}{F_N}$$

where μ_s is the coefficient of static friction, F_f is the force of friction and F_N is the normal reaction force.

Sometimes this equation is written with a “less than or equals sign” to show that the friction force increases depending on the applied force:

$$F_f \leq \mu_s F_N$$

The maximum value of static friction is reached before the surface of an object starts to move across the surface of the other.

Dynamic friction

When the force applied to a stationary object is sufficient to overcome static friction, the object will begin to move.

Once the object is in motion, the magnitude of the friction force will be lower than it was when the object was static. The frictional force between surfaces that are moving relative to each other is called **dynamic friction** (Figure 18).

When an object is in motion, we consider the coefficient of dynamic friction (μ_d), which is given by:

$$\mu_d = \frac{F_f}{R}$$

where μ_d is the coefficient of dynamic friction, F_f is the force of friction and R is the normal reaction force.

This can also be written as:

$$F_f = \mu_d F_N$$

Friction and sports performance

Both maximizing and minimizing frictional force can be used to improve performance in sports.

In sports such as badminton, athletes aim to start, stop and change direction as quickly as possible. To support this, badminton shoes are designed to have a high coefficient of friction (Figure 19).

Similarly, gymnasts apply chalk to bars and rings to increase the coefficient of friction. This allows them to apply more force without slipping.

In other sports, athletes seek to decrease friction to improve performance. For example, downhill snow skiers wax their skis to decrease the coefficient of friction.



▲ Figure 20 Skiers apply wax to their skis to reduce friction



▲ Figure 19 Badminton shoes are designed to increase friction

Work and power

Work

Work results from the application of a force over a distance. When work is done, energy is transformed from one form to another. Work done is usually represented by the letter W and can be expressed as:

$$W = Fd$$

where F is force and d is distance.

For example, when lifting a weight, you apply a vertical force to oppose the force of gravity. The work done is the force you apply multiplied by the distance over which you apply it (the distance you lift the weight). The energy you use is transformed to the gravitational potential energy of the weight.

Power

Power is defined as the rate at which work is performed. It is usually represented by the letter P .

$$P = \frac{\Delta W}{\Delta t}$$

where ΔW means "change in work done" and Δt means "change in time".

ATL Research skills

▲ **Figure 21** As marathon world records have tumbled in recent years, there has been debate over the role played by “super shoes”

Ethiopia's Tigst Assefa broke the marathon female world record in Berlin in 2023 with a time of 2 hours 11 minutes 53 seconds, taking 2 minutes 11 seconds off the previous record. Kenyan Kelvin Kiptum also broke the marathon male world record at the Chicago marathon in 2023. Both Assefa and Kiptum were wearing models of what have been described as “super shoes”. Research “super shoes” and how much of an advantage athletes could gain by wearing them.

Activity 4

In many sports it is necessary for participants to create a certain amount of friction between their feet and the playing surface, or between their hands and some implement such as a club, racket or pole (in pole vaulting), to prevent slipping.

1. How is this achieved by mountaineers, baseball players, soccer players, squash players, golfers, and track and field athletes?
2. What would be the effect of an indoor playing surface (for example, a volleyball or basketball court) being highly polished? Would this increase or reduce the coefficient of friction between shoes and the playing surface?
3. Give two reasons why too much friction between shoes and a playing surface can be an issue.
4. Can you think of an activity where skilful performance depends on reducing the friction between shoes and the floor to a certain extent?
5. Why do skiers wax the underside of their skis?
6. What role does synovial fluid play in the knee joint during weight-bearing human movement?
7. Why do blisters sometimes form in the hands or feet following participation in rock climbing or running a marathon?

Power can be calculated as the product of force and velocity:

$$P = Fv$$

where F is force and v is velocity.

Power is a measure of the rate at which work is done. Measuring power output can therefore be a measure of work intensity. Muscular power is the explosive aspect of muscular strength—the product of strength and the velocity of movement.

Power output in sport

Although absolute strength is an important component of many different types of sports performance, muscular power is the functional application of both strength and speed of movement, and an athlete's muscular power is a key component for successful performance in many sports and competitive activities. It is therefore valuable to understand how to optimize power output through correct technique and design of equipment.

Activity 5

Power is the product of force and velocity, and is one of the key distinguishing features between successful and average athletes.

1. Which sports require large power outputs?
2. How does an athlete train for power?

Optimizing power by adjusting technique: imagine you're learning to trampoline. When you bounce off a trampoline, if you bend your knees and use your legs to push off as hard as possible (maximize force) and as fast as possible (maximize knee extension angular velocity), you will go higher than if you just bounce and push off with moderate force and at a moderate knee extension angular velocity or if you bounce without bending your knees. So, in sports, using the correct technique means doing the movements in the best way possible to make the most of your strength and speed.

Optimizing power by using effective sports equipment: imagine you are riding a bike. The shape and materials of the bike can affect how fast and efficiently you can pedal. Research findings (Burns, Kram, 2020) indicate that cycling shoes with clip-in pedals allow an increased average and maximum sprint output when compared with running shoes with flat pedals or running shoes with toe clips. So, the effective design of sports equipment can help enhance your sport performance.

When you use the correct technique and have well-designed sports equipment, it is like having a secret recipe for successful performance!

ATL Thinking skills

Can you think of how to optimize power through correct technique in your favourite sport?

In a sport that you do not participate in, can you think of how the effective design of equipment used in that sport helps improve performance?



Linking question

Can the use of heated runners in bobsleigh, or a sharkskin swimsuit in a swimming pool, be considered an unfair advantage? (NOS, B.2.2)

Consider:

- if specialized equipment, such as heated runners or sharkskin swimsuits, enhances performance beyond an athlete's natural abilities
- whether these technologies are affordable for all athletes (will all athletes have access to such equipment?)
- the importance of maintaining the integrity of the sport and ensuring a level playing field for all athletes
- if the focus should be more on the human element of sports/competition and individual effort and achievement.

Practice question

Explain how Newton's laws of motion apply in a team sport. (4 marks)

Summary

- Linear kinematics involves motion in a straight line and consists of linear displacement, linear velocity and linear acceleration.
- Angular kinematics is concerned with rotation and consists of angular displacement, angular velocity and angular acceleration.
- Newton's three laws of motion relate how forces change motion.
- The impulse–momentum relationship is important when understanding changes of motion.
- Angular momentum measures the amount of rotation a body or object has.
- In the absence of an external torque (for example, in low-speed flight such as jumping), angular momentum remains constant.
- Friction is a force that acts parallel to the interface of two surfaces that are in contact during the motion (or impending motion) of one surface as it moves over the other.
- The coefficient of static friction is a dimensionless scalar quantity equal to the ratio of the force of friction and the normal reaction force. When the object is in motion, we consider dynamic friction.
- To improve performance in sports we seek either to maximize or to minimize frictional force.

AHL

Check your understanding

After reading this chapter, you should be able to:

- outline Newton's three laws of motion
- apply Newton's laws to analyse linear and angular motion
- understand conservation of momentum in collisions
- interpret values for the coefficient of restitution in collisions
- distinguish between the coefficient of static friction and the coefficient of dynamic friction
- explain the influence of friction on sports performance
- understand the relationships between force, work done and power
- outline how power output can be optimized in sport.

AHL

Self-study questions

- Using sporting examples, outline Newton's three laws of motion.
- Distinguish between distance and displacement, and speed and velocity.
- List the factors that affect the stability of an object.
- Explain how we can maximize vertical momentum in a vertical jump.
- Describe how a gymnast can increase the rate of rotation during a somersault.
- Explain how we either maximize or minimize frictional force to improve performance, in a sport of your choice.
- Describe how a gymnast can generate enough angular momentum to perform a somersault.
- Explain how we can assess the coefficient of restitution of a basketball.
- Distinguish between static and dynamic friction.


 AHL

Data-based question

Table 3 shows data from Usain Bolt's world record 100 m run in 2009 in Berlin.

▼ Table 3

Displacement / m	10	20	30	40	50	60	70	80	90	100
Time / s	1.89	2.88	3.78	4.64	5.47	6.29	7.10	7.92	8.75	9.58

- Calculate the average velocity for each 10 m interval using the displacement and time differences for each 10 m. (2 marks)
- What was his maximum average velocity (in m s^{-1}) and where in the race did he reach it? (2 marks)
- How would you work out the instantaneous velocities from a graph of *displacement* against *time*? (2 marks)
- Try to find out what his maximum instantaneous velocity was using a smooth displacement–time graph. How would you then find out the instantaneous acceleration at any time? (4 marks)

B.2.2 Fluid mechanics

Syllabus understandings

B.2.2.1 The path of a projectile through air is determined by different factors and forces.

AHL

B.2.2.2 Environmental conditions such as temperature, humidity, air pressure, wind, salinity of water and altitude affect the external forces acting on an object.

B.2.2.3 The forces, buoyancy, lift and drag acting on a body as it moves through a fluid (air or water) have a measurable effect on its path. A projectile travelling through a fluid may be affected by Bernoulli's principle, the angle of attack and the Magnus effect.

Introduction

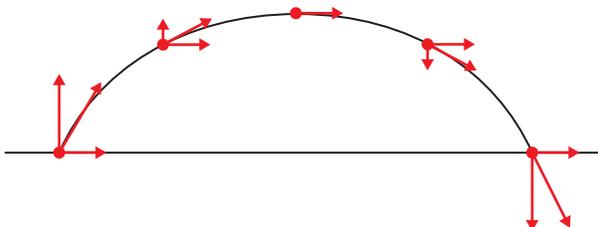
Humans and objects moving through a fluid, either gas or liquid, experience external forces resisting their motion. It is important for us to know the direction of the external resistive forces, their magnitude and how environmental conditions might affect them. Such forces are applied when the objects are either in flight (for example, in diving) or translating in contact with the ground (such as cycling). The units for forces are in Newtons (N).



▲ Figure 1 A cyclist and a diver experiencing external resistive forces

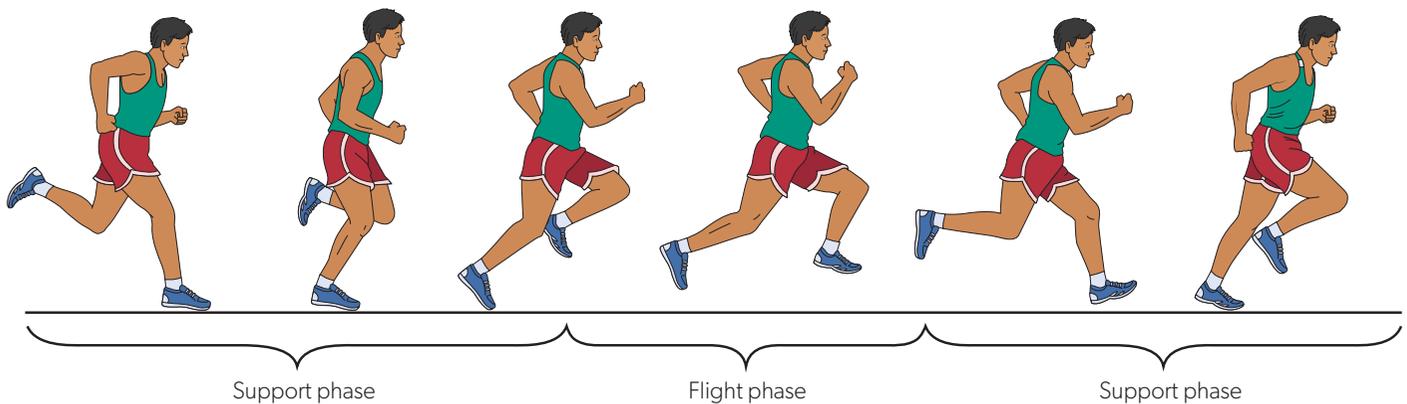
Projectile motion

A **projectile** refers to the motion of an object that has been projected into the air or dropped and where the only forces acting on it are gravity and air resistance. When the influence of air resistance is negligible, and the only force acting is gravity, the horizontal component of velocity remains constant and only the vertical component of velocity changes (Figure 2).



▲ Figure 2 Projectile motion when the influence of air resistance is negligible

In sport, there are numerous cases where either implements or the human body is projected in the air. A football in flight, a golf ball in flight, or a volleyball in flight are all projectiles. Similarly, the human body in long jump or even when running (during the flight phase) is a projectile (Figure 3).



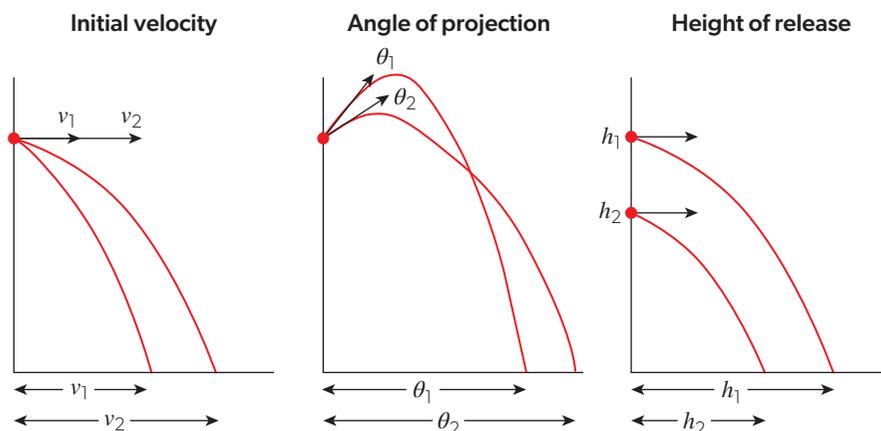
▲ **Figure 3** The body is a projectile during the flight phase of running

The pathway of the projectile and the overall distance travelled (range) depend on:

- initial conditions of projection
- gravity
- air resistance.

The initial conditions of projection include the:

- initial velocity
- angle of projection
- height of release.



▲ **Figure 4** The initial conditions of the projectile affecting the flight path, including maximum height and the range. v = initial velocity; θ = angle of release; h = height of release

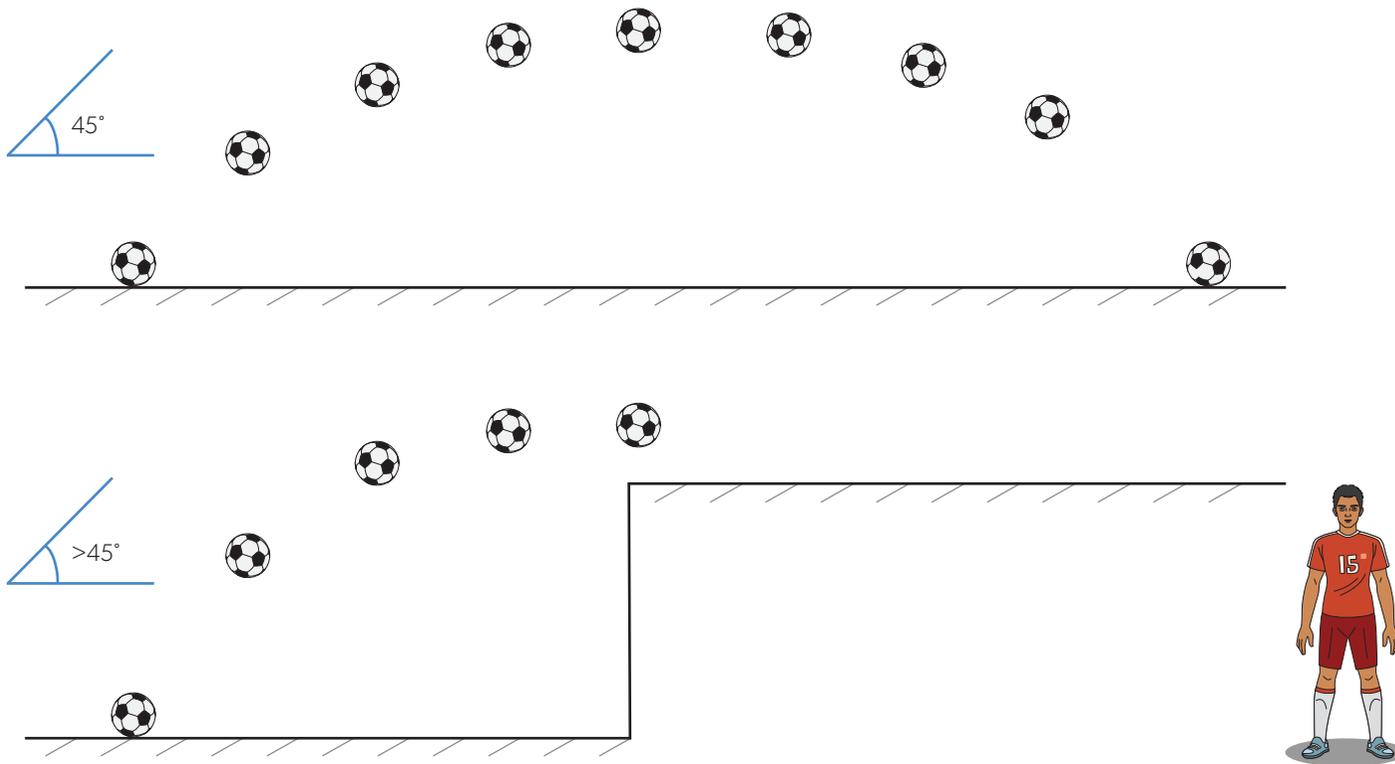
Initial velocity

The flight path of a projectile is primarily affected by the initial velocity. The projectile's range is related to the square of the initial velocity. So, a small increase in initial velocity will increase the range considerably.

Angle of projection

The angle of projection is most significant for the maximum height of the flight (for example, to get a volleyball serve over the net) and for accuracy (for example, in a basketball free throw).

The angle of projection also significantly affects the range. When the projection height is the same as the landing height, an angle of projection equal to 45° will maximize the range. But if the landing height of the projectile is higher than the projection height, the optimal release angle is greater than 45° (Figure 5).



▲ Figure 5 The optimal release angle depends on the projection height and the landing height

Height of release

The height of projection also affects the projectile range; the higher the height of projection, the longer the range (Figure 4). The projection height might be important to beat an opponent (for example, a basketball jump shot or volleyball spike), or to maximize the range of values possible for the initial velocity or angle.

Optimum angle of projection

To achieve maximum range, the optimum projection angle depends on the initial velocity and, more importantly, the projection height.

- If the projection height is above the landing area or target (for example, in shot-put), the optimum projection angle is below 45° .
- If the projection height is below the landing area or target (for example, in a basketball free throw), the optimum projection angle is above 45° .

- If the projection height is the same as the landing height (for example, a goal kick in soccer), the optimum angle is 45° .

However, these optimum angles depend on the size of the air resistance in flight as well as other complex factors such as the strength and speed of contraction of human muscles. This is why long jumpers take off at 18° – 27° , rather than 45° . Table 1 shows typical projection angles for common sporting activities.

▼ Table 1

Action	Initial velocity (m s^{-1})	Typical angle of projection ($^\circ$)	Comments
long jump take-off	10–11	18–27	leg muscles are not strong enough or quick enough to produce 45° without losing velocity
high jump take-off	4–5	40–48	a lower velocity, so jumpers have a higher angle of projection
shot-put	11–15	35–42	lower than 45° as projection height is above landing area
basketball free throw	7.0–7.5	50–60	depends on projection height; above 45° as even tall athletes are below basketball hoop height
tennis first serve	50–60	–3 to –15	angles are negative as ball is served down into court
golf drive	70–90	10–20	angle is low because backspin causes a lift force to make the ball stay in the air longer

Centre of mass

The **centre of mass** is the mathematical point around which the mass of a body or object is evenly distributed. The centre of mass depends on the distribution of the material in a body or object. This will be affected by the density of the body or object and also by its shape.

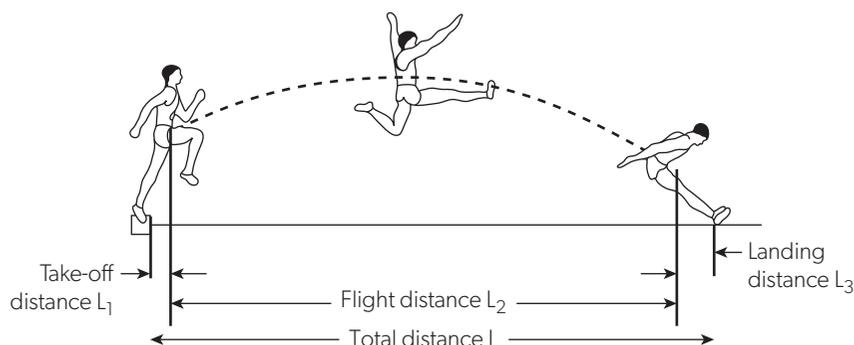


▲ Figure 6 Centre of mass is important for a high jumper to consider

As the centre of mass is a mathematical, imaginary point, it does not need to lie within the material of the body or object. For example, the centre of mass of a boomerang is in the space between the arms and not in the material. For the human body, this can also be true, particularly in sporting actions such as high jump or pole vault when clearing the bar.

Knowing the position of the centre of mass is important for three reasons.

- It determines the stability of static positions. If the vertical projection of a line downwards from the centre of mass lies within the base of support (for example, between the feet when standing), then the position of the body or object is stable and, if disturbed by an external force, it will return to its original position. This is the principle behind many balance activities.
- It is the axis for all free airborne rotations of the body or object, for example, somersaulting in diving.
- The centre of mass acts as the reference point when considering whole body or object translation. For example, when performing the long jump in athletics, the trajectory of the centre of mass during take-off, flight and landing is crucial for understanding the distance jumped (Figure 7).



▲ Figure 7 Components of centre of mass in the long jump

Hay et al. (1986) measured the distances of phases L_1 , L_2 , L_3 of long jumps by four athletes.

▼ Table 2 Distances of the phases of four long jumps

Athlete	Take-off distance (m)			Total distance jumped (m)
	L_1	L_2	L_3	
1	0.46	7.77	0.56	8.79
2	0.37	7.80	0.22	8.39
3	0.53	7.50	0.32	8.35
4	0.25	7.45	0.36	8.06

Measurement

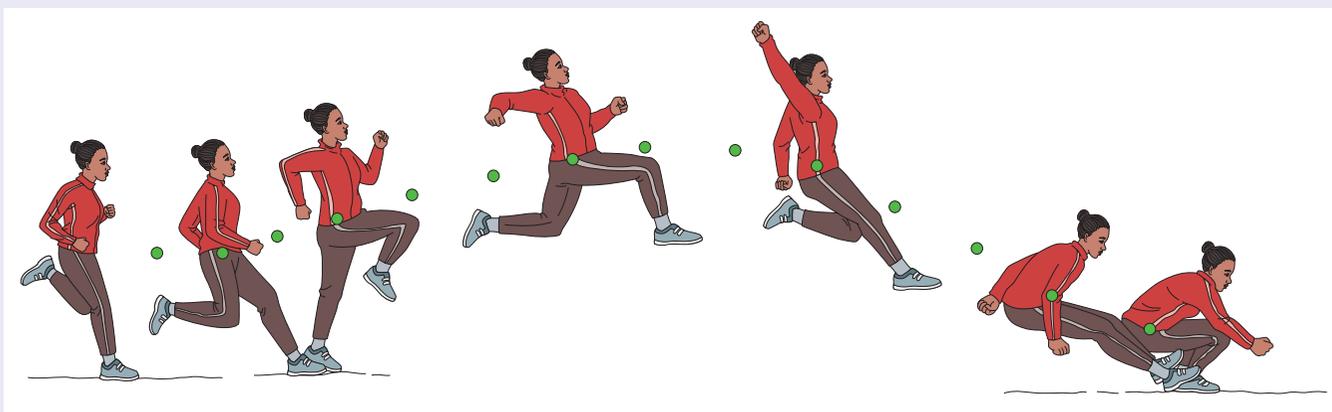
The centre of mass may be measured in several ways (for example, calculations from segmental positions and masses, reaction board, suspension of an object or model). It can probably only be measured to an accuracy of 1–2 millimetres for the human body, due to errors introduced by breathing, blood circulation and inaccuracies in segment densities and positions.

ATL Thinking skills

Once the human body has been projected into the air, the athlete cannot change the pathway of the flight. Figure 8 shows the pathway of the centre of mass. The green dots indicate the location of the centre of mass during the jump; by connecting the dots we can trace the projectile path. In this case, the force applied is gravity and air resistance is considered negligible.

During the flight, the athlete can move the different segments of the human body, such as the arms or the legs, or even change the inclination of the core. However, the pathway of the centre of mass will not be affected.

Why is it that any actions after taking off do not affect the pathway of the flight?



▲ Figure 8 Projectile pathway of the body's centre of mass

Air resistance

Both the overall pathway and the range of the projectile are affected by air resistance. In particular, the ratio of weight to air resistance influences the object's flight path.

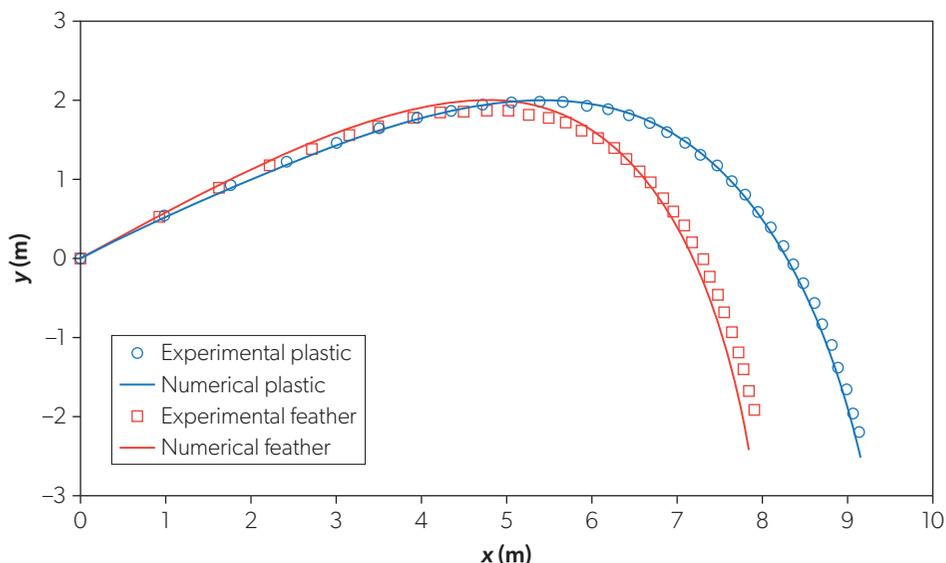
Faster-moving objects experience more air resistance, which means that air resistance is more of a factor for projectiles moving quickly than for projectiles moving slowly.

- For slow-moving objects, the magnitude of air resistance is small in comparison with the force of gravity acting on the object, so the object follows a typical projectile flight path.
- For fast-moving objects, air resistance is higher, and the pathway of the flight is affected; increased air resistance will cause a faster deceleration.

For example, in badminton, the shuttlecock moves at high velocities, reaching a maximum of 117 ms^{-1} (or 421.2 km h^{-1}). Due to high air resistance compared with its weight, the shuttlecock will decelerate quickly. The shape of the projectile pathway is affected and is not symmetrical (Figure 9).

Figure 9 shows the results of an experiment to measure projectile pathways for two different types of shuttlecock made from different materials (Darbois Texier et al., 2012). The difference in projectile pathways is primarily due to the different masses of the shuttlecocks. The feather shuttlecock has less mass than the synthetic shuttlecock, so the effect of air resistance is greater.

The graph includes both the projectile pathways recorded during the experiment (experimental plastic; experimental feather) and the theoretical projectile pathways proposed by the researchers' model (numerical plastic; numerical feather).



▲ Figure 9 Projectile pathways of feather and synthetic shuttlecocks illustrating the greater effect of air resistance on a lighter object



Linking question

How can graphs provide evidence of systematic and random errors?

(NOS, Tool 3, Inquiry 3)

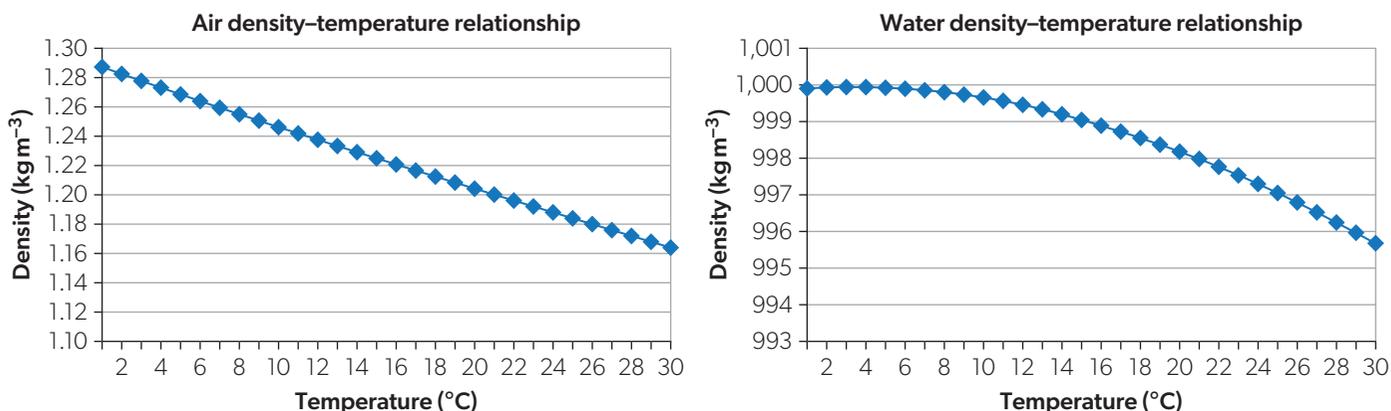
Consider:

- how graphs help visualize consistent bias or deviation from the expected pattern
- how graphs show scattered data points that do not follow a specific pattern or trend.

The effect of environmental conditions

Environmental conditions, such as temperature, humidity, wind, air pressure, salinity of water and altitude, affect the forces acting on an object.

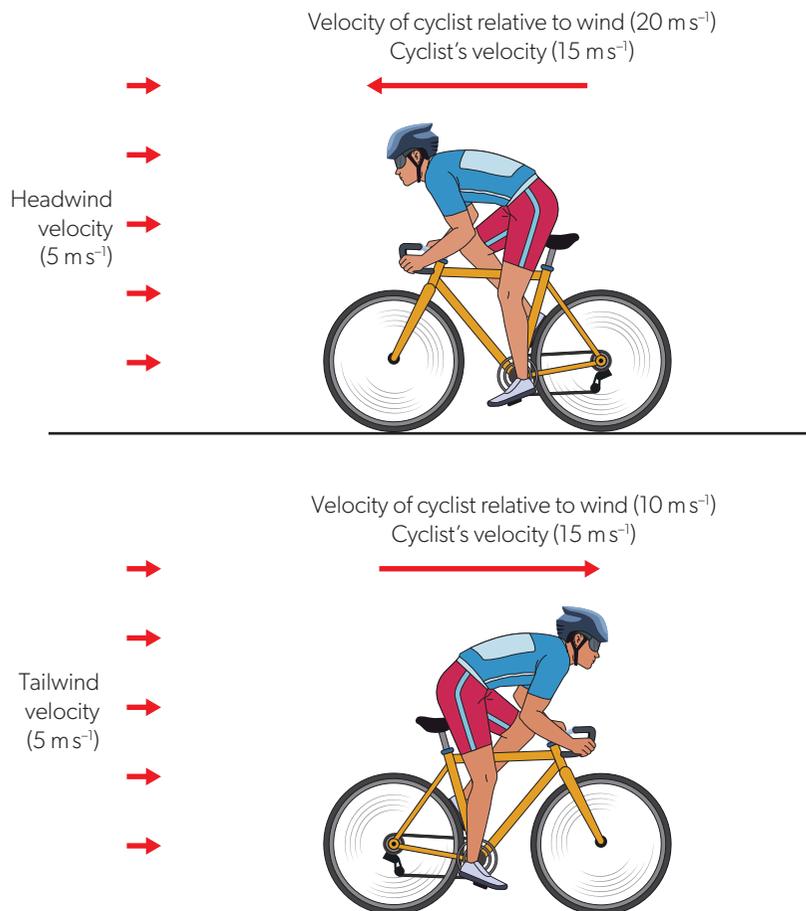
For example, temperature affects the density of air and water (Figure 10). But, considering that there is only small variation in density values when temperature ranges between 0 and 30°C (temperatures in which athletes usually perform), the effect on forces will be minimal.



▲ Figure 10 The effect of temperature on fluid density (air and water)

However, wind speed significantly affects fluid forces and is an important factor to consider for many sports.

Figure 11 shows the difference in relative velocity depending on whether a cyclist is cycling in the same or opposite direction as the wind. Relative velocity takes into account the movement of the body with respect to the fluid. It can be calculated by subtracting the vector of the velocity of the fluid from the velocity of the object.



▲ Figure 11 Relative velocity of a cyclist with either a headwind or a tailwind

ATL Thinking skills

In sports, the athlete, the venue and any pieces of sports equipment are all affected by physical principles, such as aerodynamic forces. Projectile motion is influenced by air density. Therefore, in sports requiring precise timing, accuracy and position of a projectile, such as ball sports, sports involving throwing or ski jumping, skills may be adversely affected by a change in air density. Consider the trajectory of a ball in soccer and how it could vary depending on the air density at different altitudes. Remember, as altitude increases, air density decreases.

- Suggest how variation in soccer ball trajectories at different altitudes could affect the anticipation skills of a soccer player.
- How could variations in the flight characteristics of the ball influence free kick strategy when playing at higher altitudes?



Experiments

Humidity can affect projectile motion in sports, particularly in outdoor sports where the projectile (for example, a soccer ball sent high into the penalty box from a corner kick) is affected by the air. Humidity affects air density, which, in turn, affects the drag force acting on the projectile. As humidity increases, air density decreases, which can cause the projectile to experience less drag and travel further. Therefore, humidity can affect the projectile motion in sports by affecting air density.

What variables would you control when conducting a study to investigate the effect of humidity on the flight of a baseball?

ATL Thinking skills

The relationship between air pressure and the distance travelled by a projectile is inversely proportional. This means that as air pressure increases, the distance a projectile will travel decreases, and vice versa.

In some sports, the air pressure in a ball determines how much it bounces. For instance, the air pressure in a basketball determines how much it bounces during dribbling or when it hits the backboard/rim from an attempted shot. Basketball players prefer a consistent air

pressure in the basketball to help maintain control when dribbling and accuracy in their shots and passes.

- Why might a golfer consider air pressure when adjusting their shots for optimal distance and accuracy?
- Why might a tennis coach use tennis balls with a lower air pressure when coaching beginners?
- Why might an Olympic thrower in discus or javelin prefer to compete during days with low air pressure when attempting a world record?

ATL Research skills

Salt water constitutes most of the water on the planet. The U.S. Geological Survey estimates that more than 96% of Earth's water is saline (salty) ocean water. The salinity of water can have an impact on swimming performance. The higher the salt content of the water, the more buoyant you will be. One of the saltiest bodies of water on the planet is the Dead Sea, which has a salinity of about 34%, compared with the ocean's average 3.5% salinity (nearly 10 times as saline). For many swimmers, especially those learning to swim who may struggle to find the right

body position, bodies of water with higher salinity may make swimming easier. This is because if a swimmer is not having to work so hard to stay afloat, they can put more energy into moving forward faster. In contrast, fresh water lacks the high salinity of oceans and seas, requiring swimmers to work harder to maintain good body alignment and a high position in the water.

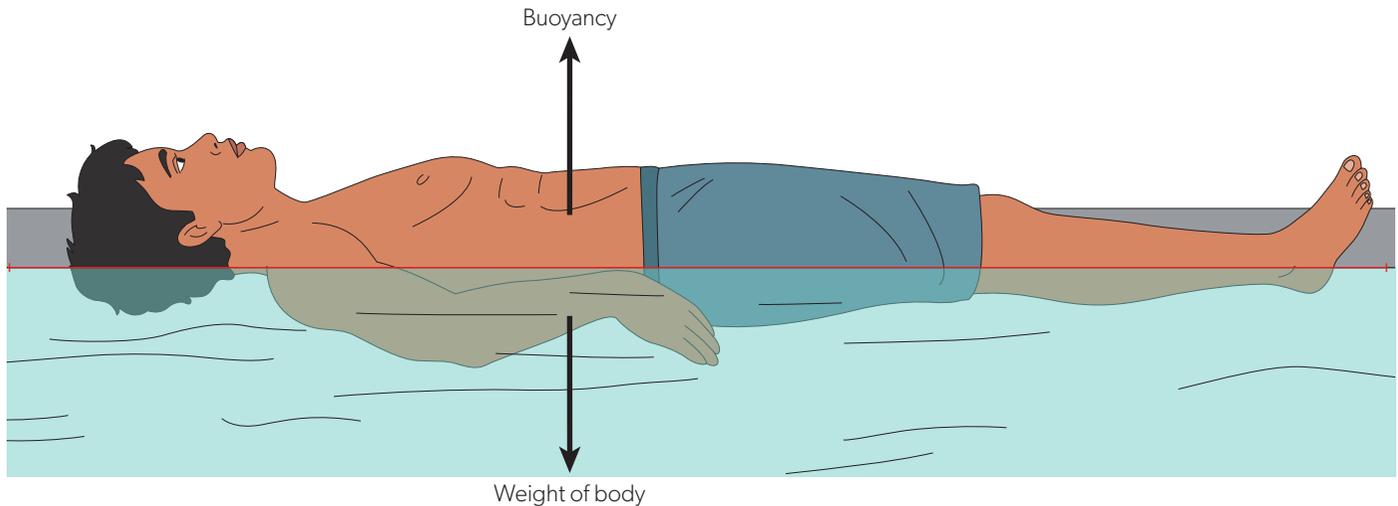
Research the optimal salinity level for competitive swimming, and why this is.

Buoyancy

Buoyancy is a force acting vertically on objects immersed or partially immersed in a fluid (Figure 12). According to Archimedes' principle, the magnitude of the buoyant force is equal to the weight of the volume of the fluid displaced by the object. The weight of the displaced fluid depends upon:

- the density of the fluid
- the volume of fluid displaced.

For an object to float, the buoyancy force must be greater than or equal to the weight of the object.



▲ Figure 12 Buoyancy

Drag force

As a body or object moves, it moves through a resistive medium, for example:

- air (such as projectile motion)
- water (such as swimming).

The effects of the medium on the motion of the object must be considered. Air and water are both fluids. The same principles apply for movement through either medium.

When the body or object moves through the fluid, it experiences a force in the direction opposite to its motion. This force is called air (or water) resistance or **drag**. The force opposes the direction of motion because the motion of the object is trying to push apart the molecules of the fluid. The forces between the molecules resist, and apply a force to the object.

There are several different types of drag, including surface drag, form drag and wave drag.

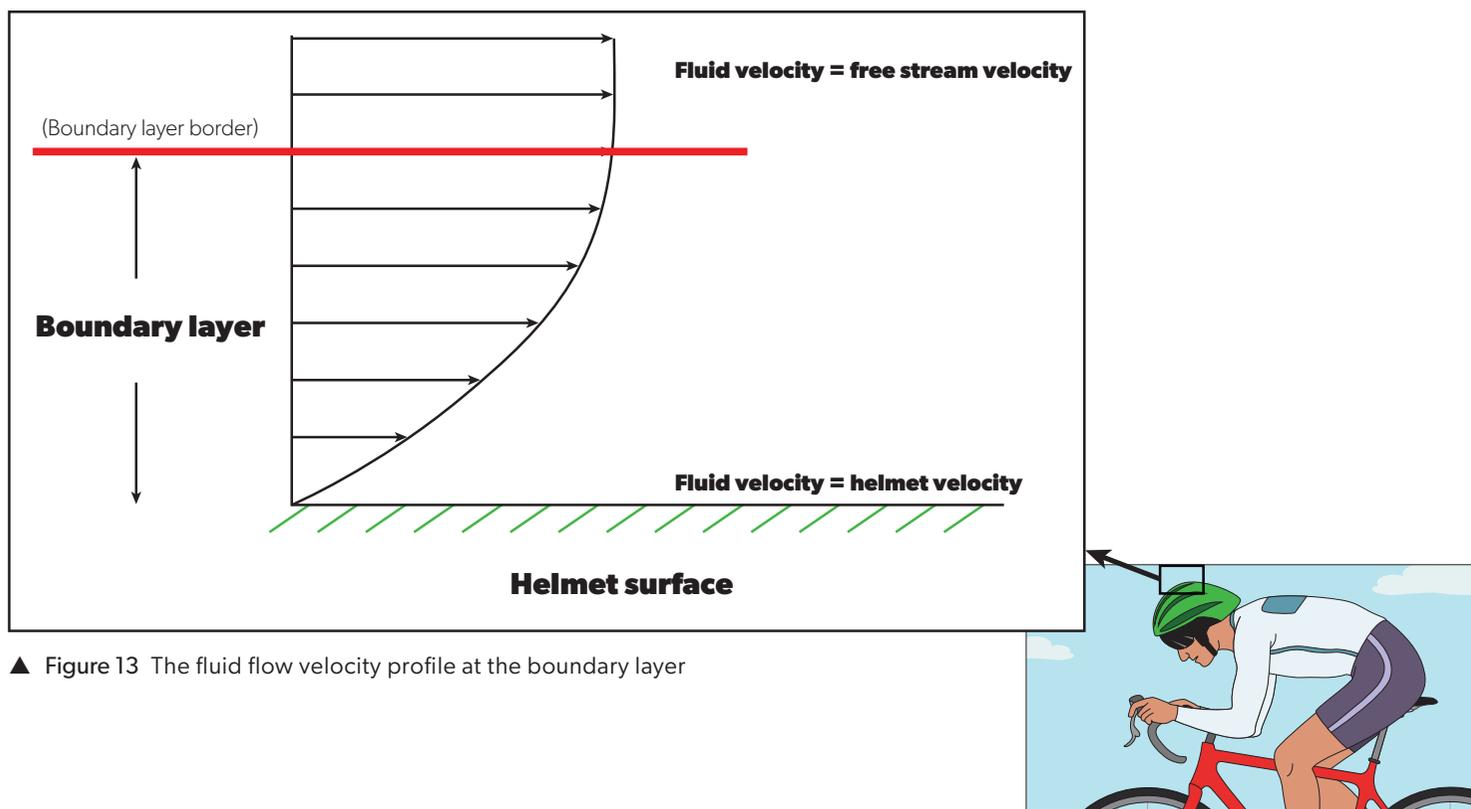
Surface drag

Surface drag (also known as frictional or skin drag) is caused by the interaction between the surface of the body or object and the fluid molecules. This type of drag is affected by:

- the velocity of the object relative to the fluid (a faster-moving object has to push apart more molecules per second)
- the surface area of the body or object (a larger object will be contacting more fluid molecules)
- the nature of the surface of the body or object (a smoother surface will push apart molecules more easily)
- the density of the fluid (denser fluids have more molecules to push apart).

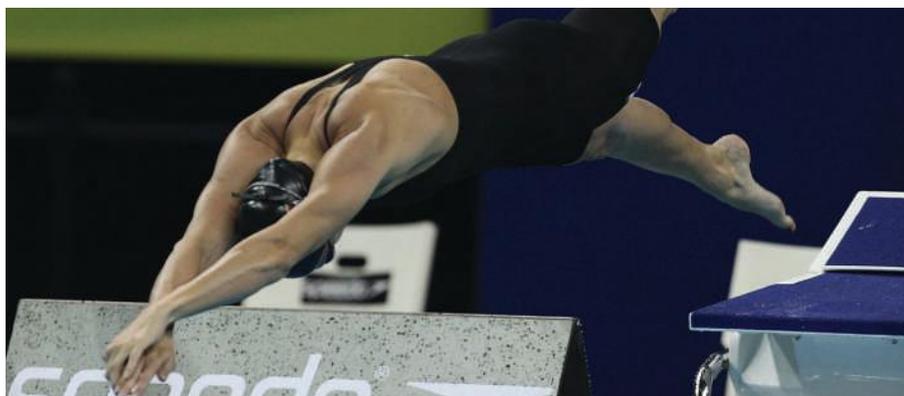
Where the surface of the object meets the fluid, the velocity of the fluid particles becomes equal to the velocity of the object. As the distance from the surface increases, the flow velocity increases until it reaches the free stream velocity (velocity of the fluid unaffected by the interaction).

This layer of fluid that experiences a change in velocity due to its proximity to the object is called the **boundary layer** (Figure 13).



▲ Figure 13 The fluid flow velocity profile at the boundary layer

Swimmers aim to minimize surface drag by minimizing the frictional effect that their skin has on water particles as they move in the water. This can be achieved by improving the smoothness of their body surface, removing skin hair or adjusting the tightness of their clothing (Figure 14).



▲ Figure 14 Swimsuit designed to minimize surface drag

Form drag

Form drag (also known as pressure drag) occurs when an object moves through a fluid. As an object moves through fluid, the fluid particles are pushed to the sides of the object and follow its curvature. However, the flow does not remain attached to the surface for the whole length of the object, and separates. After the boundary layer has separated from the surface, a circular flow forms, leading to an area of low pressure at the rear of the object, sometimes called the “wake”. This causes a difference in pressure between the front and the rear of the object (Figure 15).

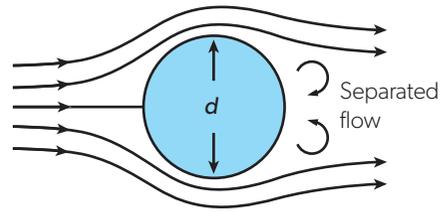
The size of the separated flow is larger when the boundary layer separation occurs closer to the front of the object. The distance between the front of the object and the location where the separation point occurs (and, therefore, the amount of form drag) is affected by:

- the frontal area of the body or object (a larger frontal area has to push apart more molecules)
- the shape of the object or body (a streamlined shape such as a rugby ball or American football travelling end-on experiences less drag than a spherical ball as the fluid molecules are parted more easily by the pointed end of the rugby ball)
- the relative velocity to the fluid of the body or object.

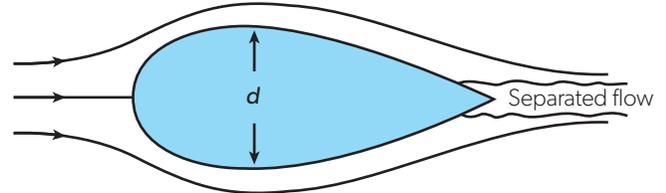
Form drag is highly related to velocity. As the relative velocity to the fluid of the object increases, the form drag increases. This is because the boundary layer thickness is reduced, and the point of separation occurs closer to the front of the object.

Form drag increases also when the frontal area of an object is greater, for example, when a swimmer is not efficiently streamlined in relation to the gliding direction (Figure 16).

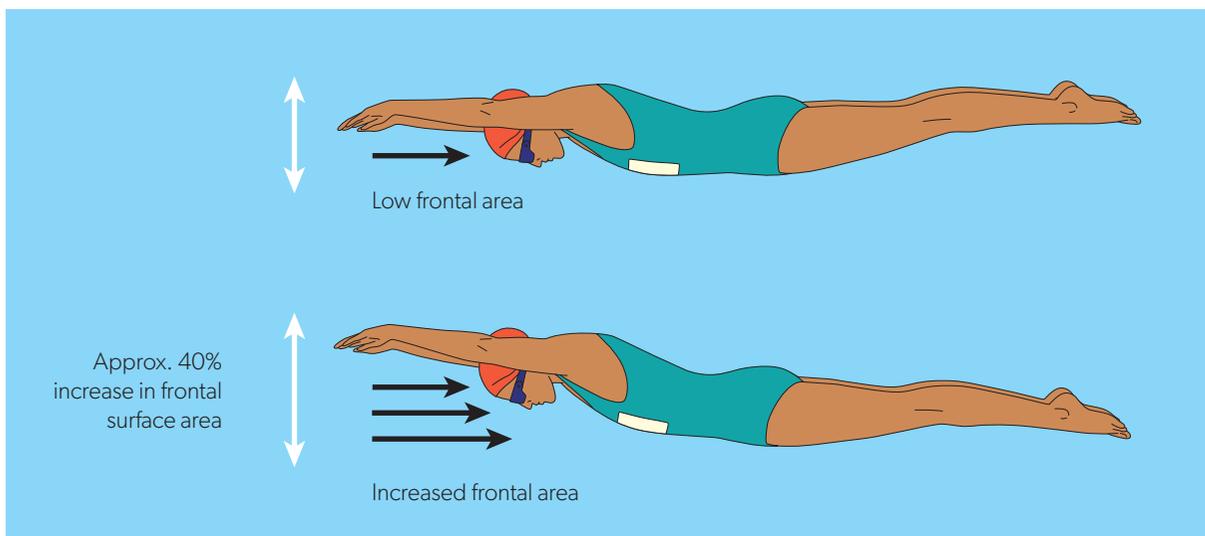
Sphere



Streamlined object



▲ Figure 15 Boundary layer separation

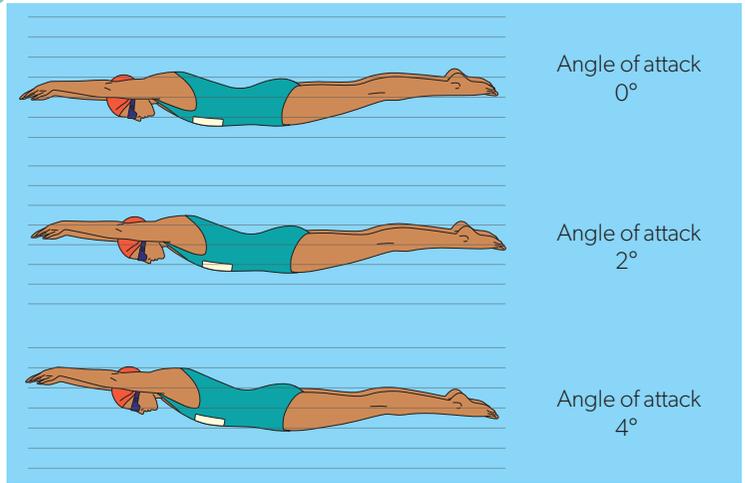


▲ Figure 16 The frontal surface area increases significantly when the swimmer is not efficiently streamlined

Activity 1

In the glide phase of starts and turns, swimmers adopt a streamlined position (Figure 17). The angle between the swimmer's body and the travelling direction is called the **angle of attack**. It is calculated by measuring the angle between the cord linking the wrist with the ankle joint centres and the horizontal.

An increase in the angle of attack affects the swimmer's frontal surface area. This change is expected to affect the magnitude of resistive forces experienced.



▲ Figure 17 Angle of attack

The following equation can be used to compute drag:

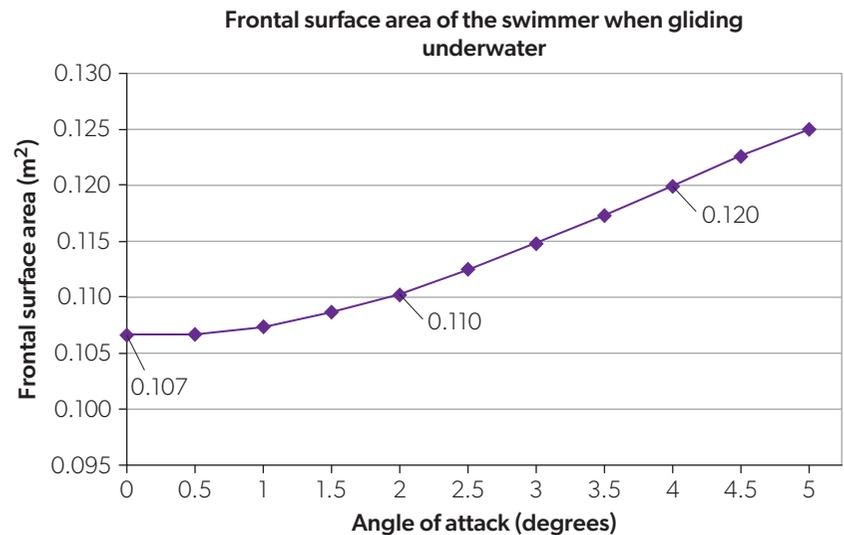
$$F_{\text{drag}} = \frac{1}{2} C_d A \rho v^2$$

Where C_d is the coefficient of drag (a variable affected by the shape and surface roughness of the body or object), A is the projected frontal area of the body or object, ρ is the fluid density and v is the relative velocity of the moving object (that is, the velocity of the object in relation to the fluid).

Using the data for frontal surface area in Figure 18, calculate the drag force experienced when the swimmer is gliding underwater at an angle of attack equal to 0° , 2° and 4° .

Assume that the gliding velocity (v) is 2 m s^{-1} , the density of the water (ρ) is 996.53 kg m^{-3} and the drag coefficient (C_d) is 0.278.

$$F_{\text{drag}} = \frac{1}{2} C_d A \rho v^2$$



▲ Figure 18 Frontal surface area of the swimmer when gliding underwater

World records have been achieved by minimizing the frontal surface area exposed to the flow. In 2015, AeroVELO's team reached the highest speed for a human-powered vehicle (114.17 km h^{-1}) in a bike designed to have minimal frontal area (Figure 19).



▲ Figure 19 AeroVELO (2015) reached a maximum speed of 114.17 km h^{-1}

Wave drag

Wave drag is the opposing force caused by the object making waves in the fluid. This is particularly important in motion through water, such as swimming, canoeing, rowing or sailing.

When a swimmer moves close to the surface of the water, the fluid level rises and waves begin to form. Consecutively, the water level lowers in an attempt to get back to equilibrium as a result of gravitational forces that in this case act as a restoring force. This way, a series of waves are formed. Due to this mechanism, energy is transferred from the athlete to the water, and consequently the velocity of the athlete decreases. Part of the athlete's kinetic energy is lost in displacing water and consequently forming waves.

As swimming speed increases, the size of the waves formed (in terms of both the wavelength and wave amplitude) increases. For competitive swimmers, the most efficient swimming speed is that which generates waves with a wavelength equal to the length of their body. This is known as "hull speed". Any further increase in speed will result in the swimmer being trapped in the interim space between crests of waves.

Wave drag is also related to swimming depth. Swimming below the water surface decreases wave drag. Hence, to improve performance, athletes swim underwater for the maximum allowed length after the start of the race and after turns.

Drag: a summary

Drag is the force, or forces, acting to oppose the motion of an object through a fluid medium such as air or water. The overall drag acting on an object can be considered as the sum of the surface, form and wave drag contributions.

$$F_{\text{total}} = F_{\text{surface}} + F_{\text{form}} + F_{\text{wave}}$$

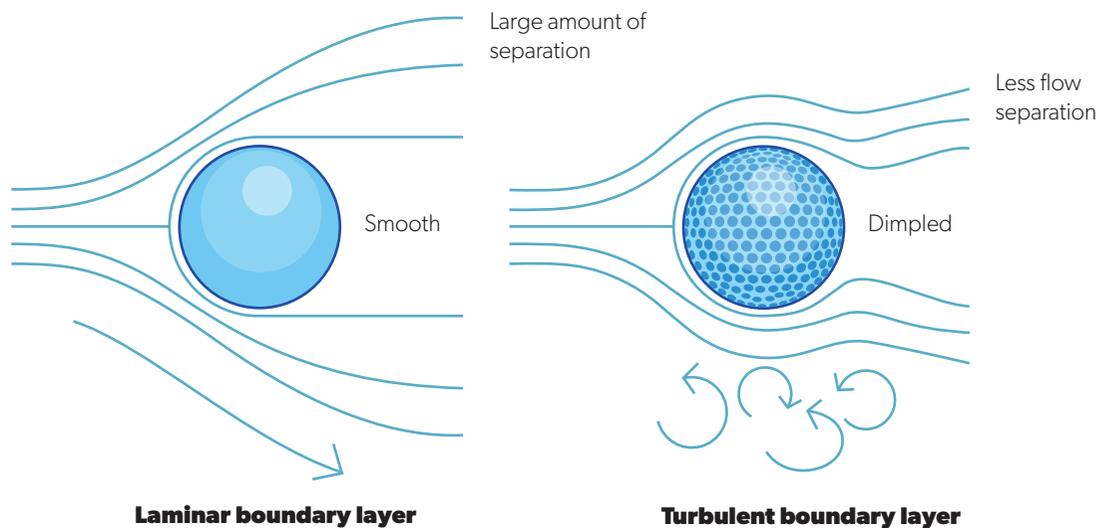
Laminar and turbulent flows

The flow of fluid at the boundary layer can be **laminar** or **turbulent** depending on the size, shape and velocity of the object as well as the density and viscosity of the fluid.

Normally, boundary layers have all the molecules moving in the same direction and are called laminar boundary layers. However, if the body or object is moving very fast or if the surface is rough enough, the molecules of the boundary layers get mixed up. Then they are called turbulent.

Paradoxically, a turbulent flow causes less surface drag than would be expected so the body or object is not slowed down as much. Experiments demonstrated that animals such as dolphins, which reach high velocities in the water, can maintain a fully attached turbulent boundary layer.

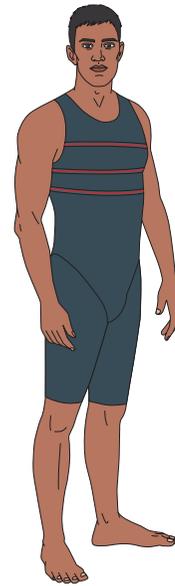
It was found that a turbulent boundary layer delays the separation of the flow and consequently reduces form drag, regardless of whether this is a dolphin or a human. This is why golf balls have dimples—they make the boundary layers turbulent, thus the ball is not slowed down as much and travels further.



▲ Figure 20 Laminar and turbulent flow around a smooth ball and a dimpled golf ball

Since the size of the wake is directly related to the amount of form drag (and, therefore, gliding performance) it is beneficial to a swimmer to maintain a turbulent (and not separated) boundary layer throughout the length of their body. The reduction in form drag seems to outweigh any increase in surface drag. To find solutions that would help swimmers decrease form drag and improve performance, sport scientists have made efforts to induce turbulence in the boundary layer.

Researchers added turbulators (wires wrapped around the circumference of the body) to the surface of a full-body swimsuit. They found that drag decreased by 13%–16% when three turbulators were used (Figure 21). These research findings were used by companies to bring a revolutionary full-body swimsuit to the market that could assist swimmers to improve their performance. Similar attempts are popular for equipment used in other sports such as the dimples in golf balls (Figure 20).



▲ Figure 21 Turbulators added to the surface of a swimsuit

Global impact of science

High-tech swimsuits, swim caps and goggles allowed improvement of swim times and numerous world records. Would you consider the use of innovative equipment an unfair advantage?

Consider that many athletes hold binding contracts with sportswear companies and cannot use products released by third-party companies.

Effect of pacers on drag

Athletes travelling in groups experience reduced form drag when positioned in the leading athletes' wake, which is known as "drafting". Research has showed more than 25% drag reduction of a trailing cyclist.

This effect was used when Eliud Kipchoge completed a marathon event in less than two hours while running behind a group of pacers (Figure 22a). Similarly, Denise Mueller-Korenek achieved a speed record by cycling behind a motor vehicle with a large frontal area (Figure 22b).



a



b

◀ Figure 22 a Eliud Kipchoge completed a marathon event in less than two hours while running behind a group of pacers in a formation. b Denise Mueller-Korenek reached a speed of 296.01 km h^{-1} while cycling behind a motor vehicle.

Experiments

Which position is best when you are participating in a long-distance race with a group of “pacers”? At the back of six “pacers” in a 1-2-3 formation, as done by Eliud Kipchoge (Figure 22a), or an alternative strategy such as “in-line drafting” where you are positioned second, third or fourth behind a group of “pacers”, as shown in Figure 23?

Consider how you could investigate this question. Include which other variables should be taken into account. For example, anthropometric differences or other external factors (such as weather conditions, sports equipment, surface or altitude).



▲ Figure 23 “In-line drafting” pacers

Lift force

When fluid is moving (or a body or object is moving through it), the pressure it exerts *reduces* as its velocity *increases*. This is known as the **Bernoulli principle** after the Dutch-Swiss scientist Daniel Bernoulli. The principle states that the pressure exerted by a fluid is inversely related to its velocity. When applied to a body or object, this means that faster fluid flow reduces the pressure on the body or object. If there is uneven speed flow on each side of the body or object, then there will be an uneven pressure on either side. This means the body or object will move from high to low pressure, thus changing its motion.

This principle explains how a **lift force** is generated and how aeroplanes can fly. Lift force is a force acting at right angles to the direction of motion. If an object or body is experiencing a lift force, it will rise or stay in the air longer than if there was no lift force. If it is experiencing negative lift, it will drop faster than with no force.

Lift is generated in asymmetrical objects; for example, by an aircraft wing. The wing is shaped differently on its top and bottom surfaces, leading to pressure differences above and below it. As the wing is shaped to speed up the flow over the top surface, the result is lower pressure above the wing and higher pressure below it, forcing the wing (and the aeroplane) upwards. The same effect happens to sails on a boat, but as the sail is vertical (rather than horizontal), the force is directed sideways and forwards.

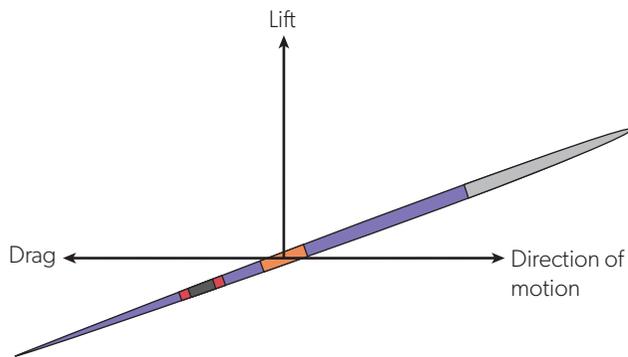
It is also possible to gain lift force if an object is angled up or down relative to its motion through the fluid. In such cases, airflow follows different paths on either side of the object, resulting in higher fluid velocity on one side of the object and lower fluid velocity on the other side. From Bernoulli’s principle we know that the pressure exerted by a fluid is inversely related to its velocity. This means that, as a fluid moves faster, it produces less pressure (and as a fluid moves slower, it produces greater pressure). This difference in pressure generates a lift force towards the area of low pressure. For example, a javelin usually goes further if it is angled slightly upwards relative to its motion (although this is complicated by the effect of any wind).

Key term

Lift force A force acting perpendicular to the direction of motion of an object when travelling through a fluid.

Key point

The Bernoulli principle states that the pressure exerted by a fluid is inversely related to its velocity.



▲ Figure 24 Lift is acting perpendicular to the direction of motion



Activity 2

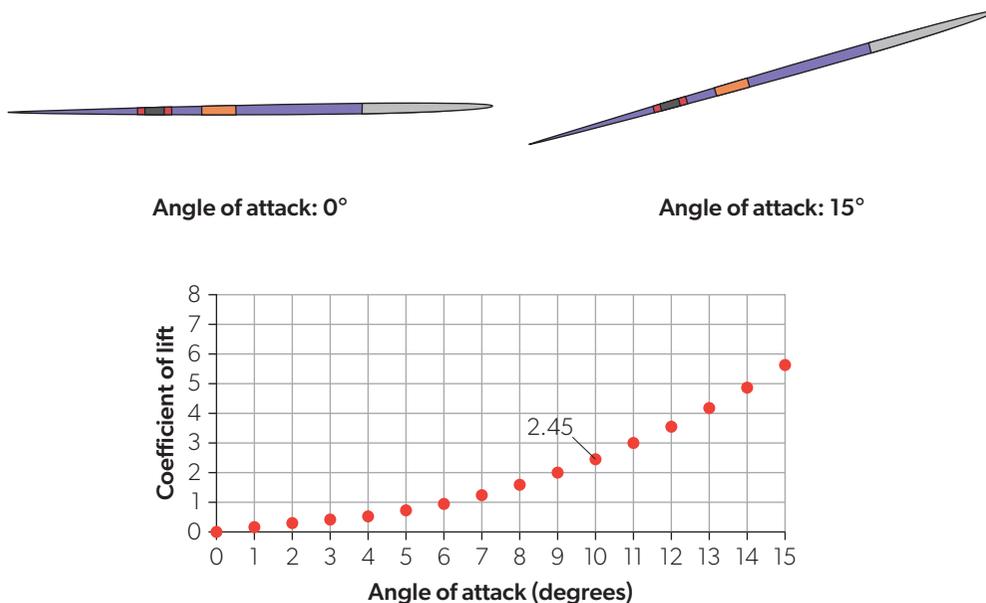
The following equation can be used to compute lift:

$$F_{\text{lift}} = \frac{1}{2} C_d A \rho v^2$$

where C_d is the coefficient of lift, A is the projected frontal area of the body or object, ρ is the fluid density and v is the relative velocity of the moving object (that is, the velocity of the object in relation to the fluid).

Figure 25 displays the coefficient of lift of the lift force acting on a javelin travelling at a speed of 25 m s^{-1} . The measurements were taken with the use of a wind tunnel while the angle of attack ranged between 0° and 15° .

1. Calculate the lift force when the angle of attack is equal to 10° and the frontal surface area is 0.00845 m^2 . Assume that air density is equal to 1.225 kg m^{-3} and the velocity of the javelin is 25 m s^{-1} .
2. Explain why the lift force is equal to zero when the javelin is horizontally aligned (the angle of attack is equal to 0°).



▲ Figure 25 Coefficient of lift for a javelin travelling at 25 m s^{-1} according to angle of attack



Activity 3

Bernoulli principle—try it yourself

To demonstrate the Bernoulli principle that generates the lift for aeroplane wings, you simply need a sheet of A4 or letter-size paper.

Hold the paper lightly with the index finger and thumb of each hand at both of the short sides—about 3 cm from one of the long sides. Then, hold the long side about 1 cm below your bottom lip and let the paper hang down.

Now, blow hard downwards and forwards over the curve of the hanging paper. You should find that the loose end of the paper rises when you blow over the paper (it may require some practice to get right).

Because you have increased the velocity of the airflow over the top of the paper, the pressure decreases in line with the Bernoulli principle. The loose end of the paper moves upwards, from the higher pressure below the paper towards the lower pressure above it.

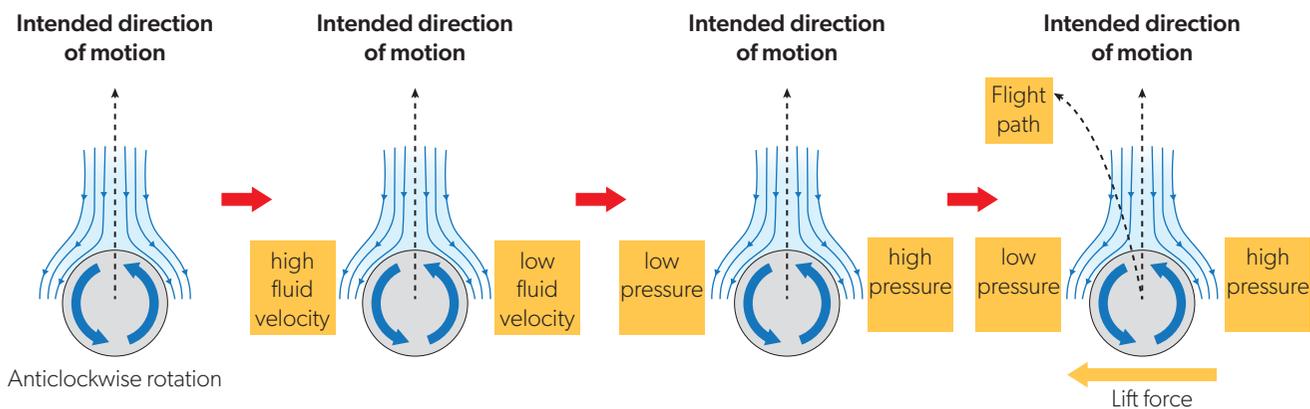
Magnus force

When a body or object is rotating while moving through the air (for example, a spinning ball), the air is dragged around by the rotation of the ball. This causes an increased velocity on one side of the object and a decreased velocity on the other. Therefore, by Bernoulli's principle, there are uneven pressures on the ball and the ball deviates from its motion. The lift force caused by this pressure difference (due to rotation) is called the **Magnus force**.

If the axis of rotation (spin) is horizontal and at right angles to the direction of travel, this will cause backspin or topspin and the ball will go up or down. However, if the axis of rotation (spin) is vertical and at right angles to the direction of travel, this will create sidespin and the ball will deviate left or right. The axis of rotation may be in a more complex direction and thus the spin may be a combination of topspin and sidespin or backspin and sidespin.

Golf clubs are designed to create backspin of the golf ball during impact. In the ball's subsequent flight, this backspin will keep the ball in the air longer, and thus the range will be further. Topspin is not required during golf (apart from possibly during putting) as this would bring the ball down quicker and thus decrease the distance travelled. The angled faces of golf clubs and the surface grooves mean that the ball gains backspin when it contacts the club and thus achieves a longer flight. In other sports, such as tennis and table tennis, topspin or backspin may be applied to the ball by the path of the racket and the angle with which the face contacts the ball.

Therefore, when an object is rotating while travelling through a fluid, fluid particles are dragged around by the rotating object. As a consequence, fluid velocity increases on one side of the object and decreases on the other. This difference in fluid velocity will lead to a difference in pressure between the two sides of the object and the generation of lift force in the direction of low pressure (Figure 26).



Anticlockwise rotation

▲ Figure 26 Lift force due to spin (Magnus effect)

Skilled football players can use spin to bend the flight path of the ball and score from a free kick or corner kick.

ATL Thinking skills

Marta Cox's swerving soccer free kick at the Women's 2023 World Cup

In soccer, when a direct free kick is awarded, players often attempt to score a goal. Usually, the defensive team positions a wall to "cover" an area of the goal to prevent the player taking the kick from scoring there. However, some players, such as Panama's Marta Cox, have perfected the skill of curving the ball around or over the wall to hit areas of the goal not covered by the goalkeeper. To do this, the kicker must create rotation of the ball at impact so that the Magnus force will bend its flight.

Marta Cox was successful at the 2023 Women's World Cup because she can generate sidespin and topspin so the ball not only swerves sideways in flight, but also "dips" and thus travels beyond the reach of the goalkeeper. Her free kick for Panama (their first ever Women's World Cup goal) against France in the 2023 World Cup showed Cox's skills at their peak.



▲ Figure 27 Marta Cox

Activity 4

In small groups, discuss the following and be prepared to explain **why** for any agreed group response.

- If reducing drag on the athlete's body or equipment in sports like swimming, cycling and skiing results in faster speeds and better results, does this create an uneven playing field if some athletes or teams have access to advanced technologies that others do not?
- Will the pursuit of reducing lift and drag in sports create a "tech race" where the focus shifts more towards technology than the athletes' skills and abilities?
- Does manipulating the environment and the moving object in ways that provide significant advantages have ethical implications around equal opportunity and the spirit of fair competition?
- Does pushing the limits of equipment, the environment and human capability lead to safety concerns in high-speed sports?
- Is there a need for sporting bodies and regulatory authorities to establish rules and standards governing the use of lift and drag manipulation techniques to ensure that sports remain fair and safe for all participants?
- Is it important to strike the right balance between technological advancements that manipulate the environment and/or the moving object and maintaining the integrity of the sport to ensure a safe, level playing field and a positive sporting environment?



Global impact of science

Aerodynamic resistance is the highest resistive force in cycling, particularly when travelling at high speeds (at velocities over 20 mph, approximately 80% of the total resistance is attributed to aerodynamic resistance). Road cyclists aim to decrease aerodynamic resistance and improve performance by optimizing their position and the equipment they use, such as their helmet.

Wind tunnels (Figure 28), large structures allowing airflow direction and velocity to be controlled, are used to test the interaction between objects and the fluid and can be used to assess the magnitude of aerodynamic resistance while cycling in various positions. Forces are measured by attaching the bike on a force balance (Figure 29).

Can access to and use of wind tunnels to identify optimal aerodynamic positions for elite road cyclists be considered an unfair advantage?



▲ Figure 28 Cycling wind tunnel facilities (Silverstone sports engineering hub)



▲ Figure 29 Bicycle attached to the force balance



Linking question

How can friction and drag be used to enhance training? (A.1.3)

Consider:

- resistance training in water or on sand
- speed and agility training with resistance bands and parachute-like devices
- resistance bands and technique development
- injury prevention and rehabilitation
- reducing stress on joints (such as low-impact exercises in a swimming pool).

Practice question

Describe how a long jumper can manipulate the factors that affect projectile motion to increase their distance jumped during a competition. (4 marks)

Summary

- The pathway of the projectile and the overall distance travelled depend on the initial conditions of projection, gravity and air resistance.
- When a body moves through a fluid medium it experiences resistive forces.
- Surface drag is the result of the interaction between an athlete's skin or an object's surface and the fluid particles. Form drag is caused by the boundary layer separation that results in differential pressure between the front and the rear of the object. Wave drag is caused by the formation of waves on the water surface.
- Lift forces are caused by an object's shape and its orientation to the air and/or the spin imparted to it.
- When an object is rotating while travelling through a fluid, fluid particles are dragged around by the rotating object. As a consequence, fluid velocity increases on one side of the object and decreases on the other. This difference in fluid velocity will lead to a difference in pressure between the two sides of the object and the generation of lift force in the direction of low pressure.

AHL

Check your understanding

After reading this chapter, you should be able to:

- identify the factors that affect projectile motion
- identify the forces acting on a body as it moves through a fluid
- explain the differences between surface drag, form drag and wave drag
- define lift force
- explain the effect of Bernoulli's principle
- describe angle of attack and outline its importance
- explain the Magnus effect.

AHL

Self-study questions

1. Outline the three factors that determine the motion of an object when it is thrown into the air.
2. What are the forces acting on a body as it moves through a fluid?
3. What are the directions of the drag and the lift force?
4. Explain how the following factors affect the drag force on an object moving through the air:
 - o shape
 - o frontal area
 - o velocity of the object
 - o density of the air.
5. Describe the boundary layer.

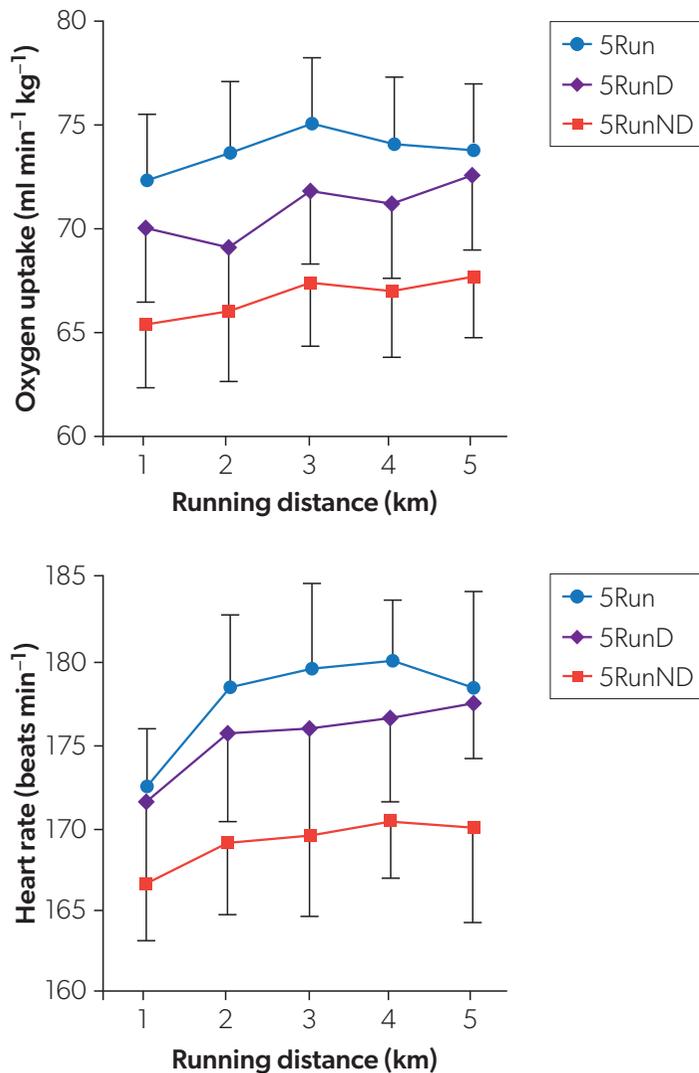
AHL

Data-based question

The term “drafting” describes the tactic of performing a mode of activity in a sheltered position. A study investigated changes in oxygen uptake and heart rate in triathletes during a 5 km run in three trials, simulating one component (5 km run) or two components (20 km cycle, 5 km run) of a short course triathlon (750 m swim, 20 km cycle, 5 km run), one week apart.

- 5 km run (i.e. no swimming or cycling) = 5Run
- 5 km run after drafting behind another cyclist (i.e. no swimming and after drafting during the cycle stage) = 5RunD
- 5 km run following cycling with others (i.e. no swimming and after no drafting during the cycle stage) = 5RunND

The mean (\pm SD) responses for oxygen uptake and heart rate at each kilometre of the run are shown in Figure 30.



▲ Figure 30 Changes in oxygen uptake and heart rate in triathletes during a 5 km run; adapted from Brisswalter and Hauswirth (2008)

1. Identify which trial had the lowest heart rate at 3 km. (1 mark)
2. Calculate the difference in oxygen uptake at 1 km between the trials with and without drafting during the cycling stage. (2 marks)
3. Compare the oxygen uptake and heart rate responses between 4 km and 5 km for all three trials. (4 marks)

B.2.3 Movement analysis and its applications

Syllabus understanding

B.2.3.1 A “phases of movement” approach is used to break down and describe movements.

Introduction

Movement analysis requires the identification of the different phases of a physical task. Performance is observed or video recorded and biomechanical flaws or inefficient movement patterns are identified for each phase independently either to prevent injuries or to improve performance.

Phases of movement approach

Phases of movement can be categorized into different stages that help athletes and coaches understand and analyse the execution of specific skills.

- Preparatory phase
- Force production phase
- Critical instant
- Follow-through (for discrete skills) or Recovery phase (for continuous skills)

With **discrete skills** we refer to tasks and activities with a fixed beginning and end and short duration, for example, throwing a ball or jumping. **Continuous skills** are those tasks and activities that have no clearly defined beginning and end and a longer duration, for example, swimming or running.

Discrete skills

Preparatory phase

This is the initial stage where the athlete prepares mentally and physically for the skill execution. Athletes focus on body position, balance and positioning themselves optimally for the skill. Anticipation of the skill’s demands is a key component of this phase.

Force production phase

The force production phase involves the synchronized movement of the skeletal and muscular systems in producing the movement and force needed to perform the task. In discrete skills, such as a golf swing or a tennis serve, this phase encompasses the application of force to the object. For continuous skills, such as running, cycling or swimming, force production refers to applying force against the ground, pedals or water to move the body. Good technique, timing and coordination help maximize force application and performance.

Critical instant

The critical instant is the culmination of the preparation and force-producing phases, and is the specific moment within the skill execution that significantly



▲ Figure 1 Phases of movement of a traceur taking part in parkour

influences the skill's outcome. This instant determines the accuracy, power and effectiveness of the skill. This could be:

- the point of contact/impact in striking sports, such as tennis, baseball and cricket
- the moment where contact is lost with the surface in jumping sports such as diving, trampolining or volleyball
- the point of release, for example, when throwing a javelin.

Follow-through

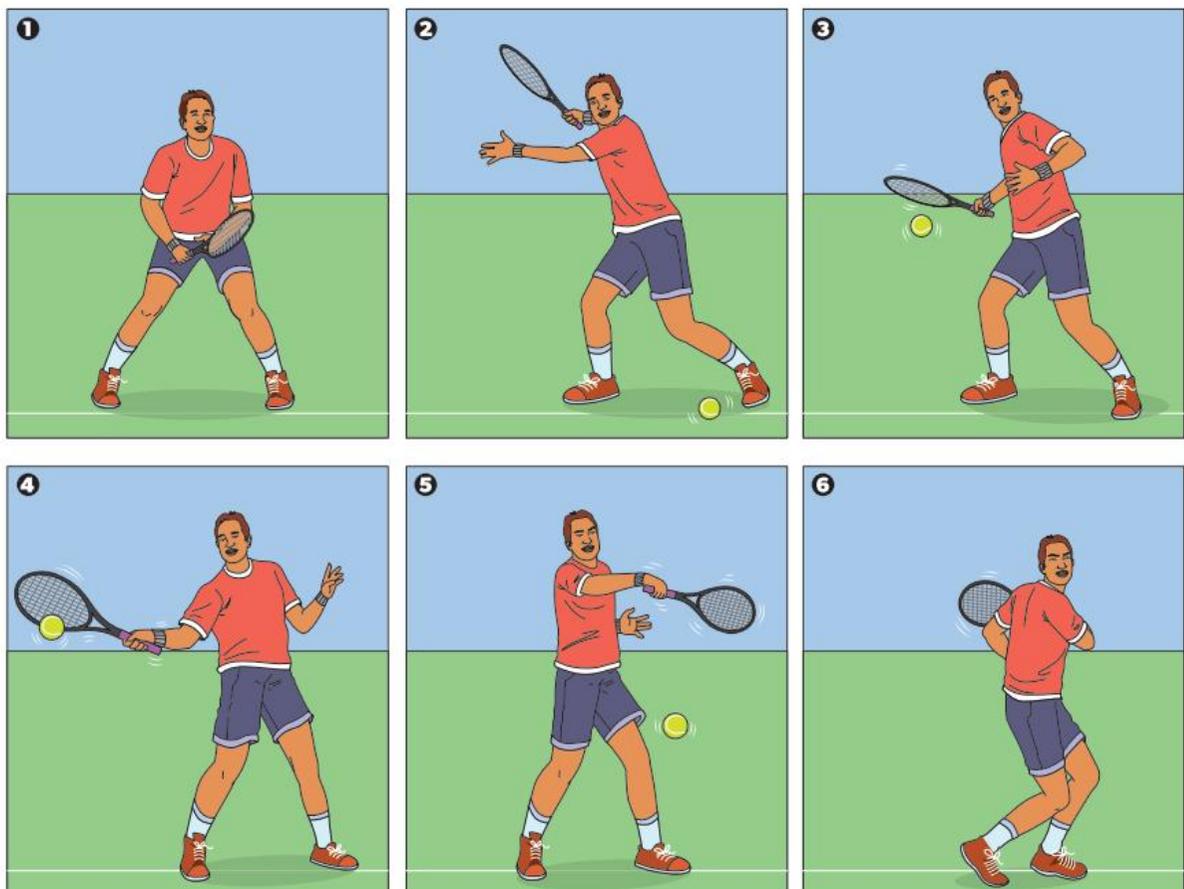
The follow-through occurs immediately after the critical instant in discrete skills. It involves continuing the motion and maintaining the correct body alignment and form. Follow-through helps prevent injury, enhance accuracy and improve the overall feel and control of the skill.

Discrete skill movement analysis example

As an example, consider the phases of movement of the forehand drive in tennis.

The forehand drive in tennis is a discrete skill with a distinct beginning and end. Phases of movement can be identified and performance can be observed independently for each phase. In Figure 2, the phases are:

- image 1: preparatory phase
- images 2–3: force production phase
- image 4: critical instant
- images 5–6: follow-through.



▲ Figure 2 The forehand drive in tennis

Continuous skills

For continuous skills, such as running, cycling or swimming, phases of movement are identified based on key events such as “heel strike” in running or “hand entry” in swimming. Each phase is analysed and inefficient movement patterns are identified.

The recovery phase takes place after the completion of one cycle or repetition of the movement. For example, in swimming, the recovery phase occurs after completing one stroke, as the swimmer positions their arms for the next stroke. A smooth and efficient recovery is essential for maintaining momentum and rhythm in continuous skills.

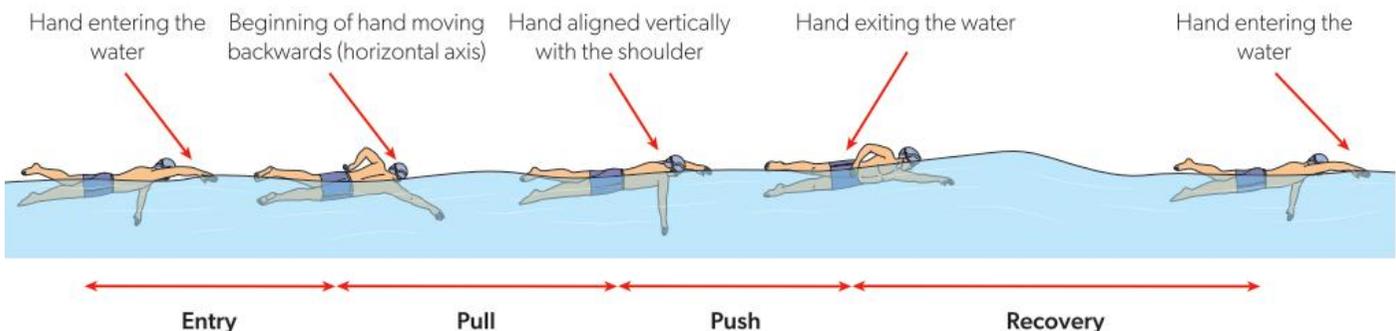
Continuous skill movement analysis example

As an example, consider the phases of movement in front crawl swimming.

An arm stroke in front crawl swimming is a complete arm action, for example, from right hand entrance to right hand entrance. Each arm stroke is divided into four phases, with the positions of the hand and the shoulder on the horizontal axis used to identify the beginning of each phase.

- **Entry** phase begins when the hand enters the water.
- **Pull** phase begins when the hand starts moving backwards (on the horizontal axis).
- **Push** phase begins when the hand is aligned vertically with the shoulder.
- **Recovery** phase begins when the hand exits the water.

Analysis of the phases could include looking at time variables (such as the duration of each phase) or spatial parameters (such as joint angles or the distance covered in each phase).



▲ Figure 3 Arm stroke cycle in front crawl swimming

Benefits of movement analysis for health and safety

Movement analysis can help identify biomechanical flaws or inefficient movement patterns that may contribute to the risk of injury. By understanding the phases of movement, healthcare professionals can collaborate with sports coaches (and athletes) to design targeted injury prevention programmes, corrective exercises and rehabilitation protocols to address specific weaknesses or imbalances. Video analysis, biomechanics and motion capture technologies are often used to assess and quantify the different phases of movement precisely.

Benefits of movement analysis for sporting performance

Movement analysis allows coaches to identify technical flaws in athletes' movements. By breaking down skills into phases, coaches can provide targeted feedback and design training interventions to enhance technique, consistency and efficiency in sports-specific movements.

Other examples of the application of movement analysis to health, safety and sporting performance include:

- optimizing biomechanics to improve power, speed and performance
- developing tactical insights of games players to develop effective strategies and improve decision-making
- injury management, assessing progress and readiness for an athlete to resume their sporting activities
- helping to track and manage an athlete's workload, and reduce the risk of overuse injuries.



Linking question

How does movement analysis help a coach design a training programme, or a physiotherapist design a rehabilitation programme?

(A.3.1, B.3.1, B.3.2)

Consider:

- assessing movement efficiency and athlete needs analysis
- identifying strengths and weaknesses
- correcting movement patterns or imbalances that may increase the risk of injuries
- techniques or modifications that can enhance performance
- objective data, feedback and tracking progress.



▲ Figure 4 Coaches can provide targeted feedback on athletes' movements

Practice question

Describe the key phases of movement in a sport of your choice (3 marks)

Summary

- Movement analysis is an effective way to prevent injuries or improve performance for either discrete or continuous skills.
- Performance is observed or recorded, phases of movement are identified and potential biomechanical flaws or inefficient movement patterns are highlighted.

Check your understanding

After reading this chapter, you should be able to:

- distinguish between discrete and continuous skills
- identify and describe the phases of movement
- explain the benefits of movement analysis.

Self-study questions

1. Is equipment required to complete movement analysis?
2. Identify the phases of a baseball throw.
3. Analyse the phases of a running gait cycle.

Data-based question 1

The physical demands of basketball were studied in 38 elite basketball players (aged 19 years). Video recordings of competitive matches were assessed using computerized time-motion analysis. The mean frequency and duration of different activities during the matches were recorded for three positions (guard, forward or centre), and these data are shown in Table 1.

▼ Table 1

	Position		
	Guard	Forward	Centre
Frequency			
sprint	67	56	43
jump	41	41	49
stand	141	149	150
Average time (s)			
sprint	1.9	2.1	2.2
jump	0.9	1.0	1.1
stand	2.2	2.2	2.4

Source: adapted from Abdelkrim et al. (2006).

1. Identify which position had the most jumps. (1 mark)
2. Calculate the difference in the mean jump time between guards and centres. (2 marks)
3. Discuss which position is the most physically demanding. (4 marks)

Data-based question 2

When assessing symmetry between limbs, the symmetry score is a way to measure how similar or different two limbs are. It is a number that tells us how much one limb differs from another limb in terms of angle. It is presented as a percentage, with 0% indicating perfect symmetry between limbs and a symmetry score greater than 0% indicating a difference between the two limbs. Higher symmetry scores mean a greater difference (that is, less symmetry). A study investigated the symmetry score for hip adduction, knee flexion and foot eversion, comparing healthy with injured female cross-country runners. The mean (\pm SD) symmetry scores are shown as percentages in Table 2.

▼ Table 2

	Healthy ($n = 15$)	Injured ($n = 7$)
Hip adduction (%)	7.2 (\pm 6.5)	9.6 (\pm 6.1)
Knee flexion (%)	3.0 (\pm 3.1)	3.8 (\pm 3.4)
Foot eversion (%)	16.4 (\pm 9.9)	12.1 (\pm 6.2)

Source: Wayner et al. (2023).

1. Identify which group of runners had the lower mean symmetry for knee flexion. (1 mark)
2. Calculate the difference between groups for their mean symmetry score for foot eversion. (2 marks)
3. Suggest **two** reasons why hip adduction and foot eversion have higher standard deviation scores in the healthy group of runners. (2 marks)
4. Deduce whether healthy runners have more or less limb symmetry compared with injured runners. (2 marks)



B.3

Injury

What are the primary causes of musculoskeletal injury, and how can they be prevented and treated?

Sport and recreation are encouraged as part of a healthy lifestyle across the lifespan and in all populations. While injuries are arguably predictable and preventable, it is likely impossible to eliminate all injuries in sport. Internal factors such as age, sex and body composition may influence the risk of sustaining injuries, and external factors, such as floor friction, may result in an athlete becoming even more susceptible to injury. Injury prevention strategies can reduce the number and severity of injuries. This topic is presented in two parts: causes of injury and interventions related to injury. Interventions related to injury include the use of protective equipment, warm-up and prehabilitation exercises, and injury treatment to promote healing and a safe return to activity.

B.3.1

Causes of injury

Syllabus understandings

B.3.1.1 The complex interaction of internal and external risk factors can predispose and make an individual susceptible to injury.

B.3.1.2 An acute trauma is caused by a sudden or excessive application of force, or by a force from an unexpected direction. A cumulative trauma is caused by the repeated application of force.

B.3.1.3 Chronic or overuse injuries are often related to technique.

AHL

Introduction

Physical activity has many benefits to a person's health and well-being.

However, physical activity can also expose a person to the risk of injury. It is important that we try to minimize these risks so that the benefits outweigh them.

Injury can be defined as a reduction or loss of bodily function or structure. There are several types of injury, each with a different mechanism or cause. Causes of injury can take place over different time periods.

A sports injury often requires a clinical diagnosis from a professional practitioner, such as a doctor, physiotherapist or physical therapist.

In sport science, the term **trauma** relates to the sensation of pain, discomfort or loss of function. This is often reported by the person exercising, for example, "I felt my muscle pull, and then it was very painful."

Injury can reduce a person's ability to exercise, which might demotivate them to improve their health through physical activity. Or, if a professional athlete is injured, their ability to compete may be affected; this could affect their ranking, sponsorship deals and even team promotions.

This chapter will discuss risk factors of exercise and injury, and how to reduce them, as well as defining common types and causes of injury.

Risk of injury

The causes of injury can be many and complex. However, all causes of injury can be related to the **risk of injury**. Risk is concerned with recognizing what could potentially happen to cause harm—in this case, an injury. Risk assessment aims to identify the likelihood of an event happening as well as the severity of the consequences should it happen. In the context of risk of injury, this means the chance of a hazard causing an injury and also how serious that injury could be.

magnitude of risk = likelihood of risk × severity of risk

To assess a risk, first you must quantify the likelihood and severity. These can be classified into five categories each. The categories of likelihood range from almost certain to rare (Table 1). The categories of severity range from negligible (no injury) to extreme (an injury leading to death or a permanent life-changing injury) (Table 2).

▼ Table 1 The likelihood of risk

Category	Classification
almost certain	<ul style="list-style-type: none"> expected to occur frequently in most circumstances more likely to occur than not
likely	<ul style="list-style-type: none"> there is a possibility that this could occur likely to occur
possible	<ul style="list-style-type: none"> may occur occasionally, has happened before on occasions reasonable chance of occurring
unlikely	<ul style="list-style-type: none"> not likely to happen but definite potential exists unlikely to occur
rare	<ul style="list-style-type: none"> will only happen in exceptional circumstances

▼ Table 2 The severity of risk

Category	Classification
negligible	no injury or minor injury requiring no first aid or treatment
minor	minor injury or illness requiring first aid, minor treatment
moderate	significant injury requiring medical treatment and/or counselling
major	major injuries, long-term incapacity or disability requiring medical treatment or counselling
extreme	incident leading to death or major permanent incapacity

Once you have assessed the likelihood and severity of an injury, it is relatively simple to then determine the overall risk. This can be classified into low, medium, high or very high (Table 3).

► Table 3
Classification
of risk

			Severity				
			negligible	minor	moderate	major	extreme
			1	2	3	4	5
Likelihood	almost certain	5	medium	high	high	very high	very high
	likely	4	medium	medium	high	high	very high
	possible	3	low	medium	medium	high	high
	unlikely	2	low	medium	medium	medium	high
	rare	1	low	low	low	medium	medium

Notice in Table 3 that there is no zero-risk category: even a risk that is of negligible severity and rare is classified as low risk. This is because you cannot eliminate all risk of injury when taking part in exercise. However, you can minimize risk to an acceptable level, which may be judged as “low” or “medium”.

Consider a contact sport, such as rugby or American football. The nature of contact between players in these sports exposes participants to a risk of injury, as each tackle brings the likelihood of experiencing high forces. This may or may

not result in an injury. Steps to reduce the likelihood and severity of the injury can be taken. If either the likelihood or severity is reduced, this may reduce the overall risk—imagine moving diagonally down to the left in Table 3.

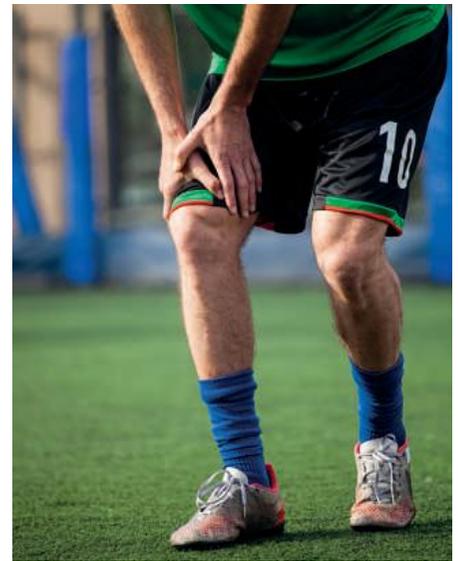
Exercise or participating in sport may expose participants to very high risk of injury. However, it is the duty of care of officials, players and coaches to have strategies in place that aim to reduce that risk towards medium or low if possible.

Activity 1

Consider an everyday action that you do regularly. Identify a risk of harm with that activity.

Classify the likelihood and severity of the risk occurring, then use Table 3 to assign an overall risk level.

Identify two to three strategies that have been put into place by others or by yourself that reduce either the likelihood or severity of that risk.



▲ Figure 1

ATL Research skills

Research the medical emergency that happened at the Euro 2020 Football Championships involving Denmark midfielder Christian Eriksen.

Considering the eventual positive outcome for Eriksen following his cardiac arrest, we can conclude that the player received effective medical treatment, which began within seconds and minutes of his cardiac event.

1. Identify the severity and the likelihood of a 29-year-old professional footballer suffering a sudden cardiac arrest on the pitch.
2. Outline the strategies that the tournament organizers, staff in the Denmark squad and the players on the pitch used.
3. Comment on whether these strategies reduced:
 - a. the likelihood of the risk
 - b. the severity of the risk.
4. If you were the organizer of a similar tournament, what strategies would you put in place to reduce the risk of cardiac arrest?



▲ Figure 2 Christian Eriksen

Measurement

When discussing risks in sport, the magnitude of risk must be considered to avoid exercise and physical activity being viewed in a negative manner. The benefits of both exercise and physical activity often outweigh the risks. One method of quantifying this is by calculating injury rates per 1,000 hours of play.

For example, if an injury such as concussion in youth rugby has an injury risk of $\frac{6}{1,000}$ hours, then there may be approximately six occurrences of concussion for every 1,000 hours of youth rugby.

It is important to put that into context considering that a youth rugby match may be 90 minutes in length. If a player

competed in one rugby match every week along with two training sessions of 90 minutes each week for a whole year, this would still only consist of 234 hours. It would take the player four years to reach close to 1,000 hours.

Additionally, the injury risk of $\frac{6}{1,000}$ hours is not an indication that six incidences of concussion will happen in that time, but rather a risk that it could happen. This is before risk-reducing strategies are implemented, which may further reduce the injury risk number.

Key terms

Resistance training A general term used to describe exercises that cause the muscles to contract against an external resistance (for example, body mass, elastic bands or dumbbells).

Weightlifting A competitive sport in which the athletes use barbells in competition to perform two competitive lifts: the “snatch” and the “clean and jerk”. In training, weightlifters may use both dumbbells and barbells as well as a variety of benches and racks. Weightlifting is governed internationally by the International Weightlifting Federation.

ATL Thinking skills

Resistance training for younger individuals

The benefits of a resistance training programme include positive outcomes of improved motor skill performance, gains in speed and power, developing physical literacy, reducing the risk of injury, and injury rehabilitation. Many individuals enter competitive sports at a young age, and possessing adequate strength to keep up with increased demands on the body is valuable to help reduce the risk of injury and optimize gains in performance (Stricker, Faigenbaum, 2020). Muscular strength is also an important component of health-related fitness programmes, such as exercises that improve muscular strength, muscular endurance and power components. The external load (resistance) can be in the form of equipment such as a barbell, dumbbell, resistance bands or simply the body mass of an individual against the force of gravity, as in body weight exercises (Fullerton, Gaudreault, 2023). Research supports a wide acceptance that children and adolescents can gain strength from resistance training with low injury rates if the activities are performed with an emphasis on proper technique and are well supervised. Therefore, it is important to incorporate resistance training into physical education classes and youth sport and exercise programmes to increase muscular strength and reduce the risk of overuse injuries (Stricker, Faigenbaum, 2020). In conclusion, under qualified supervision, age-appropriate resistance training programmes that take into account the biological maturity of athletes are associated with improved performance and enhanced physiological and psychosocial health. Additionally, under proper supervision that includes sound technique and fatigue management strategies, resistance training activities for young athletes are no more injurious than other sports activities (Pierce et al., 2021).

Internal and external risk factors

Risk factors of injury can be varied across sports and exercise types. They are often a complex interaction of both internal and external risk factors that may increase the likelihood and/or the severity of injury.

- **Internal risk factors** are those relating to the person exercising or participating in physical activity. These are athlete or participant dependent.
- **External risk factors** relate to outside the exercising person, for example, the environmental conditions or the playing surface.

The risk factors may differ for different types of injury.

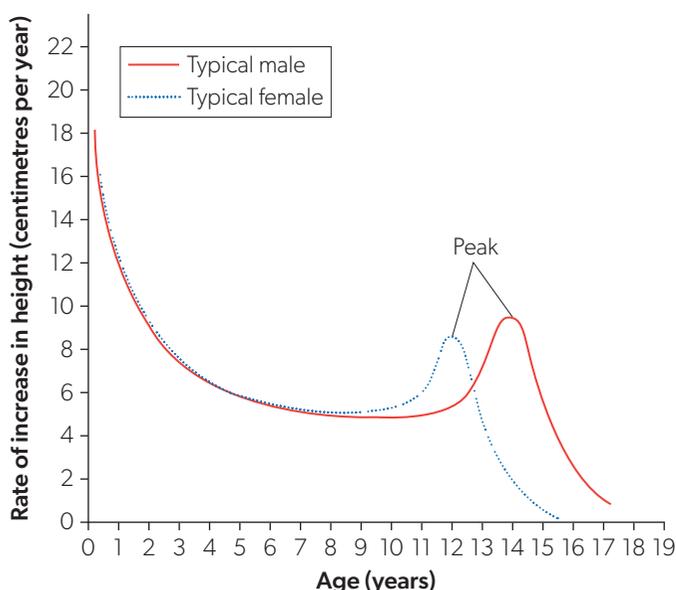
Internal risk factors: Age

One of the most common risk factors, especially in youth sports, is age. Across youth sports, there is evidence of higher injury risk factors with increasing age.

One factor is adolescent growth of bone tissue and other musculoskeletal components, especially in the lower limbs. This skeletal growth can rapidly create a size difference between the bone and soft tissue. Often this is temporary until the soft tissue matches the increase in skeletal growth. However, during this period an individual may experience reduced balance. This can increase the injury risk of, for example, ankle sprains.

The injury risk in adolescence is not always higher for all injuries. In fact, children tend to have more flexible bones, and these exhibit a degree of elasticity which results in a lower risk of fracture injuries. In younger children, the speed of exercise or activity is also lower. Therefore, the forces applied to their bodies tend to be lower, reducing the risk of soft tissue injury. However, due to the growth in bone during adolescence, younger athletes are at a higher fracture risk in specific areas of the long bone (chapter B.1.2). These areas include the growth plate, involving the junction between the epiphyseal plates and the formed bone (diaphysis), as well as near the articular cartilage.

Other injury risks in youth sport include the increase in height and weight of players, which is often not linear. For example, looking at a class of children in the same year at school, it would be uncommon for all of the students to be the same height and weight. This can cause large variations in physical characteristics in players facing each other in sport, exercise or competition. Differences in strength, speed and force-generating capacity can lead to an imbalance when two opponents meet in a contact sport, for example. An example of youth rugby union suggests that injury risk increases from the 12–14 age group to the 15–18 age group, which often links to the period of highest growth in adolescence (Figure 3).



◀ Figure 3 Rate of increase in height by age and sex difference

ATL Thinking skills

Consider why mountain biking has a greater risk of injury than road cycling.



▲ Figure 4

Observations

Internal risk factors: Effects of training

A study (Sinisgalli et al., 2021) of 99 amateur triathletes (19 females and 80 males) investigated the association between training volume and race times in the Ironman distance triathlon. They found total race time did not differ significantly among those who trained up to 14 hours per week compared with those who trained more than 20 hours per week. They concluded that high volumes of training (more than 20 hours per week) did not have a positive impact on performance compared with lower volumes of training (up to 14 hours per week). Why do you think amateur triathletes can perform equally well with a lower volume of training? Refer also to chapter A.3.1 on qualities of training.

Internal risk factors: Effects of training

In many sports, such as rugby union, weight training may be introduced during the adolescence transition period, up to 18 years of age. While the benefits of this format of training are well known, it also increases the injury risk compared with younger children who do not take part in heavier load training. The actual magnitude of risk may be low—and may be reduced even further by sensible precautions common in school settings.

In the case of rugby union, the volume of tackles often increases due to the shift from training to more competition matches during adolescence. Evidence suggests this shift from training to matches corresponds to a change in injury rates from $\frac{2}{1,000 \text{ hours}}$ to $\frac{4}{1,000 \text{ hours}}$. In younger children, the format of rugby union is more often touch rugby—a non-contact variation of the sport—which limits injury risk.

The volume of exercise also relates to the volume of training and the risk of injury. Across sports, including overhead sports, climbing and cycling, large increases in training can increase the risk of injury. The volume of climbing and the difficulty appear to influence the injury risk, with longer sessions increasing injury risk. The ratio between training and competition also affects the injury risk in cycling, as does the type of cycling.

Internal risk factors: Previous injury

A significant injury risk factor for all age groups is previous injury. Across sports, a history of a previous injury increases the risk of a recurrent injury. This is likely due to reduced strength and proprioception (the sense of movement and body position provided by proprioceptors, refer to chapter A.1.1) following the original injury. If these are not fully restored before returning to performance, the risk of injury is increased.

It is common to have reduced range of movement in an injured joint. Rehabilitation aims to restore the original range of movement. However, there is an increase in injury risk with a decrease in range of movement in the shoulder for sports such as basketball.

There are varied reasons why an athlete might return to competing before their rehabilitation is complete. In climbing, for example, a survey found the most common reasons to return to sport early were the thought that the injury was minor, fear of losing skill or technique, or that a competition was near. Losing a spot on a team and pressure from peers or coaches were other less common reasons for returning to sport early.

Internal risk factors: Sex differences

In recent decades there has been a significant increase in female sports participation globally, leading to an increased need for and interest in understanding sex differences as a risk factor for injury.

One study (Edouard et al., 2015) reported that during 14 top-level international athletics championships (Olympic Games, World Championships, European Championships), male competitors had higher risk of injuries than female competitors: the rate of injuries per 1,000 registered athletes was 110 for male competitors compared with 88 for female competitors. The male competitors incurred more injuries in the thigh, but fewer stress fractures than female competitors. However, Edouard et al. found no sex difference for cause and severity of injury.

Across sports, some of the most common sports injuries include bone stress injuries, anterior cruciate ligament injuries and concussions and these injuries can be suffered irrespective of sex (Lin et al., 2018). Rather than a one-size-fits-all treatment approach, managing these injuries with an understanding of sex-specific differences (such as hormones) may help to optimize their individualized recovery.

Some empirical data have suggested that biologically female athletes are at a greater risk of incurring a sport-related concussion compared with biologically male athletes. Biologically female athletes also have greater neurocognitive impairments, more total self-reported symptoms and longer recovery times (Covassin et al., 2018) following concussion. In contrast, Zech et al. (2022) found no significant sex differences for concussion rates.

In their meta-analysis, Zech et al. (2022) provided evidence for sex differences in the injury rates in team sports (basketball, field hockey, soccer, handball, rugby union and volleyball) for high-level players aged ≥ 16 years. Biologically male players showed higher injury rates for overall, upper extremity, hip/groin, thigh and foot injuries compared with biologically female players, whereas female players had more anterior cruciate ligament injuries.

It is important to highlight that research examining sex differences in the causes of sport-related injury is in its infancy, and further study is needed, because understanding sex differences has important implications for the assessment, management and treatment of sport-related injury.

Internal risk factors: Pregnancy

During pregnancy

In a report in 2015, the American College of Obstetricians and Gynecologists concluded that there is no evidence to support a claim that regular physical activity during pregnancy may cause musculoskeletal injury. In the absence of any medical issues, everyone should start or continue exercising, in line with guidance from the World Health Organization (WHO) (chapter A.3.2).

However, during pregnancy, contact sports with an increased risk of experiencing high forces to the abdomen (such as soccer, basketball and ice hockey) and activities that involve risk of a fall (such as horseback riding, skiing and snowboarding) should be avoided.

The increase in body weight as pregnancy progresses is associated with increased loading at the joints. Therefore, weight-supported activities, such as exercising in water, may be more comfortable compared with weight-bearing exercises (such as walking) in the later stages of pregnancy (Santos-Rocha et al., 2022).

It has been suggested that changes in the ligaments associated with pregnancy may have implications for an increased risk of injury. Additionally, there is an impact on balance with the centre of gravity changing location due to the change in weight distribution during pregnancy. Thus, activities that require jumping movements and quick changes in direction (such as aerobic dancing), which can stress joints, should be done with caution to minimize the risk of joint injury (Santos-Rocha et al., 2022).

Postpartum

Postpartum refers to the period of time immediately following childbirth. With elite athletes, pregnancy does not seem to impair performance postpartum. Many elite athletes report *improved* performance after pregnancy. However, some research suggests that postpartum elite athletes may have increased rates

This work must not be reproduced, stored, transmitted or circulated in any other form.



▲ Figure 5 Aerobic physical activity is recommended during pregnancy

of injury, which may be made worse by a rapid return to and progression of activity postpartum (Kimber et al., 2021).

Thea et al. (2022) stated that elite athletes must adapt training and competition activities during and after pregnancy to reduce their risk of injury. However, best-practice guidance and management of pregnant and postpartum elite athletes are limited by the lack of high-quality evidence available within these populations. Additional studies are needed to provide evidence-based recommendations so athletes may return to sport safely. For example, there is some good evidence that relative energy deficiency in sport (RED-S) can affect performance of elite endurance athletes in a variety of ways, including increased injury risk in the short term (chapter A.2.2). However, little is known about the long-term impact of RED-S on athletes during pregnancy and postpartum (Mottola et al., 2023).

Here is some general advice regarding endurance and strength training (Bo et al., 2018).

Those who have been regularly exercising at least at a moderate level during pregnancy can expect their maximal oxygen uptake (VO_2max) to return to their pre-pregnancy level or even higher after delivery. In the postpartum period, start endurance training gradually. Low-impact activities such as cross-country skiing (Figure 6), fast walking, low-impact aerobics and step training put little pressure on the pelvic floor and can start soon after birth.

Strength training in the postpartum period should start gradually with a “pelvic floor muscle first” focus. This can be done with a pre-contraction of the pelvic floor muscle and holding the contraction during exercises that are accompanied by increased intra-abdominal pressure—such as bench press, heavy abdominal exercise, leg press and squat (Figure 7). There should also be a focus on abdominal and back muscles.



▲ Figure 6



▲ Figure 7



▲ Figure 8 Joint hypermobility has been associated with an increased risk of injury

Internal risk factors: Congenital factors

Congenital means present at the time of birth. Congenital factors may increase the risk of sports injury. These factors can vary widely and include:

- structural abnormalities that affect bones, joints, ligaments or muscles and increase the risk of injury during sport and exercise (such as joint hypermobility)
- factors such as bone density, muscle strength, collagen production and tissue healing capacity
- neurological conditions, such as cerebral palsy, which can affect motor control, coordination and balance.

It is important to note that, although congenital factors can influence injury risk, they do not necessarily determine an individual's fate. With proper guidance, conditioning, medical management and sports science support, individuals with

congenital factors can still participate in sports safely and minimize their risk of injuries. Again, more research is needed on this topic but a challenge for sports injury researchers is that congenital factors are not easily controlled.

Internal risk factors: Psychological factors

Psychological factors include death of close family members, end of relationships, sleep quality and quantity, as well as overall stress. All of these factors can increase the risk of injury, likely due to fatigue relating to reduced or lack of sleep affecting performance, biomechanics, and recovery from training or previous injury.

External risk factors: Personal protective equipment

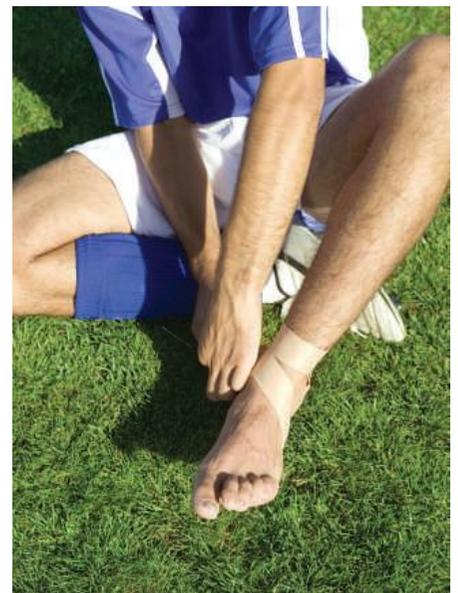
Many sports use protective equipment. For example, taekwondo is a popular combat Olympic sport, and for safety, each of the competitors has to wear a trunk protector, head protector, forearm guards, hand protectors (gloves), shin guards, foot protectors (socks), a mouthpiece and a groin cup. In other sports, such as skiing/snowboarding, helmets are worn to reduce the risk of brain injury, including concussion.

Using protective equipment (such as ankle bracing/taping and wrist guards) may help prevent musculoskeletal injury. For example, a study about ankle bracing and taping among previously injured adult and youth athletes found they reduced the risk of ankle sprain re-injury by 69% and 71%, respectively (Janssen et al., 2014). However, the research evidence does not support the preventative effect of ankle or knee bracing/taping as a primary strategy to prevent ankle and knee injuries in youth sport, except in the case of recurrent injury (Yang et al., 2005). Other factors around the use of ankle bracing and taping include comfort and the availability of qualified personnel.

Russell et al. (2011) examined the use of a wrist guard in snowboarding. Wrist guards provide a significant protective effect in reducing the risk of wrist injury, wrist fracture and wrist sprains. Russell et al. estimated that, for every 50 snowboarders who wear wrist guards, one wrist injury will be prevented. This has potential implications for other sports, such as skateboarding and rollerblading.



▲ Figure 9 Taekwondo competitors have lots of protective equipment



▲ Figure 10 Taping an ankle injury

ATL Thinking skills

Contact sports have high rates of injury. A study (Marshall et al., 2002) investigated the injury prevention effect of regulations governing protective equipment in two full-body contact sports: American college football and New Zealand club rugby union.

Both sports involve significant body contact and have a high incidence of injury. Extensive body padding and hard-shell helmets must be used in college football but they are not allowed in rugby union. Marshall et al. found that the injury rate in college football was approximately one-third the rugby union rate. Rugby union players suffered numerous lacerations, abrasions and contusions to the head region, but the incidence of these injuries in college football was almost zero. Injury rates were more similar for the knee and ankle, two joints largely unprotected in both sports.

To reduce the risk of head injury in rugby union, some players opt to use protective headgear. Initially designed to reduce “cauliflower ear” injuries, modern designs include various types of padding that aim to reduce the risk of injury due to excessive application of force. However, in opposition to other close contact sports, such as college football, where the protective headgear is mandatory and involves a rather bulky helmet with a rigid polycarbonate shell with flexible foam padding, rugby union headgear is lighter and is usually made of a padded compliant material, such as leather or synthetic fibre textiles. The presence of rigid plastics is prohibited (Sarandan et al., 2023).

Discuss whether regulations insisting on wearing of protective equipment by players in contact sports reduce the incidence of injury.

Other innovative approaches are being used in different sports. For example, breakaway bases have been examined in baseball and softball and have consistently demonstrated a protective effect on sliding injuries in adult and youth populations (Emery, Pasanen, 2019).



▲ Figure 11 Wrist guards worn during rollerskating

ATL Research skills

Research the importance of helmet fit and/or helmets with face protection in collision sports.



▲ Figure 12 Protective equipment worn during mountain biking

Mountain biking and personal protective equipment

Mountain biking is a sport with high incidence of injury. Riding downhill is where most serious injuries occur. Downhill mountain biking is a popular extreme sport drawing increasing numbers of participants at both competitive and non-competitive levels. The sport takes place during summer in many countries, especially in mountainous areas where ski resorts are used as venues. Downhill mountain biking usually involves high-velocity runs, including jumps, turns and various manoeuvres, which, in combination with the hard and rocky underground of the downhill trails, can lead to the risk of serious injury. The use of protective equipment (such as neck braces to reduce cervical spine injuries) is encouraged (Figure 12). In 2011 Becker et al. surveyed 249 riders (from Germany, Luxembourg, Switzerland and Austria) across one summer season, and the most commonly reported injuries they found are shown in Table 4. A more recent study assessed the prevalence of mountain biking injuries in both elite and amateur riders. Elites train more and wear the same amount of protective gear items compared to amateurs. They found an equal number of injuries in elites and amateurs. Therefore, the use of protective equipment (such as neck braces) in mountain biking is encouraged for *all* participants.

▼ Table 4 Downhill mountain biking injuries in one summer season among European riders

Mountain biking injuries		
Injury type	<i>n</i>	%
abrasion	316	64
contusion	279	57
torsion	72	15
laceration	62	13
strained muscle	45	9
fracture	32	7
concussion	23	5
ligament strain	23	5
joint dislocation	15	3
joint inflammation	7	1
ligament rupture	4	1
others	23	5

Protective equipment in ice hockey

Ice hockey involves a combination of high speed with the use of sticks, a fast-moving puck and physical contact among players. It is a popular youth sport in several countries (such as Canada and South Korea). The physicality and fast-paced gameplay in ice hockey are associated with a high rate of injury, including concussion. This is why players must wear impact protective clothing and equipment. The protective equipment includes helmets, mouth guards, shoulder pads, elbow pads, padded gloves, padded pants and shin guards. Even with such impact protective equipment over the whole body, the risk of injury is still considerably high. An interesting five-year longitudinal study by Kolstad et al. (2023) of ice hockey players

(ages 11–18; $n = 3,330$ players) in Alberta (Canada) analysed the relationship of equipment and concussion. They found that wearing a mouthguard was associated with a lower concussion rate, supporting a mandate of mouthguard use in youth ice hockey associations to promote concussion prevention and player safety.

External risk factors: Position

Evidence suggests external injury risk factors in contact sports such as rugby union include position, with those who play as “forwards” at a higher risk of shoulder injury when compared with those who play as “backs”. This is likely due to the amount and type of tackles and collisions and, therefore, forces these players are exposed to. Match duration also has an impact, with an increase in injury risk during the last quarter of the match versus the first. This is likely due to increasing fatigue leading to changes in biomechanics and performance levels—for example, increased pressure to achieve a win towards the end of a close game involving “riskier” movements.

In other sports, such as baseball, there is some evidence that position can affect injury risk. Pitchers and catchers appear to have a higher risk of shoulder injury versus infield players. This is likely due to the number of throws that a pitcher and catcher complete. These are similar and higher than that of an infield position. A higher volume of throws can relate to a greater risk of injury in the main joint of the throw (the shoulder).

Longer race distance is a risk factor for injuries in trail runners. However, this is unlikely to be due to the longer distances of the race event alone. Runners entering these races are usually more experienced and have a higher weekly running distance, which could be associated with a higher risk of injury.

External risk factors: Playing surface

There is a higher injury risk when playing on artificial playing surfaces (such as AstroTurf or 3G pitches). The increased injury risk is to the upper and lower extremities as well as torso injuries. This is often related to abrasion injury (refer to injury types later in this chapter).

External risk factors: Equipment

An example of sporting equipment is the set-up of bike geometry in cycling. Many bikes can be adjusted for saddle height and some for handlebar height. In elite cycling, many more adjustments can be made (Figure 13).

There is some evidence that correctly setting up road bikes can reduce the risk of injuries in cycling. The recommendation is that bikes are set up by a professional who will adjust each setting for the individual rider. This aims to reduce the repetitive forces through joints, reduce the risk of extreme joint angles and minimize some muscles being shortened or lengthened for prolonged periods of time.



◀ Figure 13 Bike geometry

Activity 2

Consider the different settings of bike geometry in Figure 13 and the cyclist in Figure 14.

Describe the effect of adjusting bike settings (1, 2 and 3) on the athlete's joints.

For example:

- what would happen to the joint angles of the athlete's knee during pedalling if the saddle height (distance 1) was increased?
- what joint angles would be affected if distance 2 was increased?



▲ Figure 14

Musculoskeletal injuries

Musculoskeletal injury can be defined as a reduction or loss of function or structure of a muscle, bone, ligament or tendon. It can also relate to disorders of blood vessels, nerves or related soft tissue. The normal structure of muscles, bones and tendons, as well as muscle fibre structure, is discussed in subtopic B.1.

Musculoskeletal injury types

There are several types of injury that can relate to muscle. These can be grouped into:

- lacerations or shearing injuries
- contusions or compression injuries
- muscle strains.

These types of injury can affect the muscle, bone or connective tissue, for example, the tendons or ligaments around a joint.

Laceration injuries occur when the skin or even muscle is cut by an external object, for example, the studs of a rugby boot cutting a player's finger. Laceration injuries may also be caused by friction between two surfaces rubbing together. A common example is friction caused between the skin and ground or playing surface. Consider a tennis player sliding their knee across a clay court—this may cause an abrasion injury.



▲ Figure 15 A laceration injury caused by sliding across a tennis court

Contusion or compression injuries occur when a compressive force is applied to the muscle, bone or joint. These types of injuries usually occur in contact sports and involve colliding with another player or equipment. If sufficient compressive forces are applied to the muscle, this may cause bleeding (clinically known as haematoma), which can result in bruising of superficial or deep muscle regions. If the force is applied to a skeletal structure, it may cause a broken bone (clinically known as fracture). Or if the force is applied to the head (the skull), it may cause **concussion**. Concussion can be classified separately as a brain injury and may result in impairment of neurological function due to direct or indirect biomechanical forces (such as a blow to the head or body).

Strain type injuries occur when muscle fibres are stretched beyond their normal limit. There may be excessive force applied and the structure or function of the muscle fibre is reduced or lost. Consider the sliding filament theory mentioned in chapter B.1.3, and how the myofibril might be affected should the muscle fibre be stretched beyond its functional limits.

Activity 3



▲ Figure 16

A study by Timpka et al. in 2014 outlined an injury case study of a footballer during a Women's Champions League football game. During a cross ball, this player collides with a defender and both fall to the ground. During the fall, the footballer's ankle is caught between the ground and the defender. Immediately the player feels pain in her right ankle. She receives treatment on the pitch by the team's physiotherapist and the player reports a severe pain score of 8/10 (where 10 is the worst pain). The physiotherapist decides to send the player to hospital where she receives clinical scans and tests. These reveal a partial rupture of the anterior tibiofibular ligament but no fracture. The doctor diagnoses tibiofibular ligament injury of the right ankle.

1. What type of sports injury did the player suffer?
2. What details can be included to describe the sports trauma?
3. Can you think of an injury type from another area of the body?

Linking question

Can overtraining lead to altered gait, in turn leading to injury?
(A.3.1)

Consider:

- when injury occurs
- if change in posture is associated with fatigue in endurance events
- athletes training with underlying risk factors subconsciously adapt their gait to compensate
- repetitive sport, insufficient recovery, and adaptations to gait
- Wolff's law
- perceived discomfort and recruiting an alternative musculoskeletal structure to compensate.



Linking question

How does training or participation in sport and exercise affect rates of injury? (A.3.1)

Consider:

- recovery of tendons and bones post-training
- production of collagen
- volume of exercise and training error
- risk of injury from overloading
- risk of injury from underloading (for example, going into competition unprepared)
- training errors (for example, distance, duration and intensity of a run)
- pain-monitoring (for example, a numerical pain rating scale)
- acute and cumulative trauma.

Acute and chronic injuries

Most injuries can be classified as either acute or chronic depending on the onset of the injury mechanism.

Acute injuries occur immediately or suddenly due to an excessive application of force (acute trauma). Lacerations and shearing injuries, contusion and compression injuries most commonly have an acute injury mechanism. That is, they are caused by the immediate actions of an object or player. Examples of acute injuries include a fractured ankle (Figure 17), anterior cruciate ligament rupture or tear, and concussion.



▲ Figure 17 An ankle fracture is an example of an acute injury

Chronic or overuse injuries occur due to repeated application of force over time (cumulative trauma). A single bout of exercise with associated forces is unlikely to cause an injury as the forces are not sufficient to result in the loss of function or structure. However, even lower magnitudes of force repeated again and again on the same region of the body (such as a muscle, tendon or joint) may result in injury. Chronic injuries are often gradual in onset. Typically, chronic injuries can be caused by repetitive activity or exercise over the course of several weeks. This cumulative trauma can be related to an overuse mechanism of injury. Examples of chronic injuries include tennis elbow (clinical term: lateral epicondylitis), shin splints and tendon inflammation (clinical term: tendonitis).

Types of injury common to sports

A study by Ritzer et al. in 2021 reviewed data from a US high school sports-related injury surveillance system called Reporting Information Online (RIO™). The RIO™ system uses a nationally representative sample of high schools during 13 consecutive school years for nine different sports. In total 52,285 injuries were reported; 93% were classified as acute and 7% were classified as chronic or overuse injuries.

The data suggest that most acute (49%) and overuse injuries (66%) in high school students were in the lower limbs. The head, face and neck represented 26% of acute injuries but only 1% of chronic injuries. The upper limbs represented 20% of acute injuries and 19% of chronic injuries. Whereas the trunk represented one of the smallest proportions among body sites for acute (5%) and chronic injuries (13%).

The four most common types of acute injury were ligament sprains (32%), followed by concussion (21%), then muscle strains (12%) and contusions (12%). The most common types of chronic injury were muscle strain (23%) and tendon inflammation (23%).

Concussion does not always have to involve loss of consciousness but may include headaches, changes in vision, unsteady balance, changes in behaviour, cognitive impairment (such as slower reaction times or memory loss), vomiting and drowsiness.

Activity 4

Table 5 presents an extract of the data collected from the RIO™ system.

▼ Table 5

Sport and sex characteristic	Acute injuries	Acute injuries (%)	Overuse injuries	Overuse injuries (%)	Total injuries
soccer, male	3,663	90.62	379		4,042
basketball, male	3,912	93.61	267		4,179
soccer, female	4,456	90.79	452		4,908
basketball, female	3,687	90.70	378		4,065

Source: adapted from Ritzer et al. (2021).



1. Copy and complete Table 5.
2. Were more acute or chronic injuries reported in total?
3. Which sport category has the highest percentage of acute injuries?
4. Is there a similar pattern for acute injuries for male and female sex characteristics?

Biomechanical maladaptation and injury risk

Biomechanical maladaptation can lead to certain body parts being subjected to excessive stress or load during sports activities. By identifying and correcting maladaptation, we can redistribute the stress more evenly throughout our bodies and help prevent overloading joints or muscles, which can lead to injury. When our bodies have biomechanical maladaptation, it means we may not be moving as efficiently as we could be. These inefficient movement patterns can place unnecessary strain on our bodies and increase the risk of injury. If we can learn to improve our movement mechanics to become more efficient this can reduce the risk of injury.

For example, a golfer with a maladaptation in their swing mechanics might receive coaching to correct their posture, grip or swing technique. This can help them generate power more efficiently and reduce the risk of strain or injury.

Biomechanical maladaptation can compromise the stability of our joints, making them more susceptible to injury. For instance, if someone has weak or imbalanced muscles around their knee joint, it can lead to poor alignment and increased stress on the knee ligaments and cartilage, increasing the risk of injuries like ligament tears or cartilage damage. By correcting this maladaptation through exercises and strengthening programmes, we can enhance the stability of our joints and reduce the risk of injuries associated with joint instability.

Therefore, when we move, it is important to keep our joints, muscles and bones appropriately aligned. This distributes forces and stresses evenly throughout our bodies, reduces the strain on any particular area and lowers the risk of overloading or damaging a specific body part.

By learning and practising correct techniques, we can avoid putting excessive stress on vulnerable areas of our bodies. For example, if a runner has a biomechanical maladaptation that causes their foot to roll inward excessively when they land (over-pronation), it can lead to injuries such as shin splints or stress fractures. By correcting this adaptation through exercises, footwear or orthotics, the runner can maintain a more stable foot position, reducing the risk of such injuries.

Biomechanical maladaptation can lead to muscle imbalances. Certain muscles become overactive or underactive. These imbalances can affect joint stability and increase injury risk. By identifying and addressing these imbalances, we can restore correct muscle function and promote stability around the joints. This helps prevent excessive joint movement, reduces the risk of joint instability and decreases the likelihood of injury. Importantly, when our bodies move in a more efficient and coordinated manner, we waste less energy on unnecessary movements or compensations. This increased efficiency allows us to generate

more power, speed and agility while reducing the strain on our muscles and joints. It helps us perform at our best and decreases the risk of fatigue-related injuries caused by inefficient movements.

For example, when playing soccer you may notice that, when you kick the ball, your knee collapses inward. This is not the best way for your knee to move, and it can put a lot of stress on the knee joint. A coach can show you exercises and techniques to help you kick the ball with your knee in the right position. By practising and making these changes, you can lower the risk of injuring your knee while playing soccer. As another example, when playing basketball, you may notice that you always land with your knees turning inward when you jump. This is called knee valgus, and it can put a lot of strain on your knees. To correct this, your coach can demonstrate exercises and techniques to help you land with your knees straight and aligned properly. By practising and making these changes, you will reduce the risk of injuring your knees while playing basketball.

Overall, by correcting biomechanical maladaptation, we can enhance our movement mechanics, increase joint stability, improve movement efficiency and reduce stress on vulnerable areas of our body. These adjustments help decrease the risk of sports-related injuries.



Linking question

How can the constraint-led approach to skills acquisition be applied to identify and correct biomechanical maladaptation? (C.2.1)

Consider:

- factors that influence how we move and perform skills—key constraints affecting movement patterns, such as internal (strength) or external (rules of a game)
- observing and analysing the skill/movement
- modifying constraints
- encouraging learners to explore different movement solutions and problem-solve (promote active learning to help students develop effective biomechanical adaptations)
- feedback that encourages students to reflect on their movement patterns and make adjustments
- progressively increasing more complex challenges and constraints
- individual differences.

Practice question

Outline the risk factors that contribute to the development of chronic and overuse injuries in sports. (4 marks)

Summary

- Injury can be defined as a reduction or loss of bodily function or structure.
- Injury can reduce a person's ability to exercise, which might demotivate them to improve their health through physical activity.
- Injury risk assessment aims to identify the likelihood of an injury happening as well as the severity of the consequences should it happen.
- To assess the risk, first you must quantify the likelihood and severity.
- Risk factors of injury can be varied and are often a complex interaction of both internal and external risk factors, which may increase the likelihood and/or the severity of injury.
- Internal risk factors relate to the person exercising or participating in physical activity, for example, age, history of previous injury, differences in sex, pregnancy or congenital factors.
- External risk factors relate to outside the exercising person, for example, personal protective equipment, the volume of competing and training, playing surface and biomechanical geometric set-up of sporting equipment (such as road cycling).
- Musculoskeletal injury can be defined as a reduction or loss of function or structure of a muscle, bone, ligament or tendon.
- Musculoskeletal injury types can relate to muscle and can be grouped into lacerations or shearing injuries, contusions or compression injuries and muscle strains.
- Concussion can be classified separately as a traumatic brain injury and may result in impairment of neurological function due to direct or indirect biomechanical forces.
- Acute injuries occur immediately or suddenly by a specific injury mechanism.
- Chronic injuries can develop over a period of time that is often gradual in onset.
- Correcting biomechanical maladaptation can enhance movement mechanics, increase joint stability, improve movement efficiency and reduce stress on vulnerable areas of the body, adjustments that can help decrease the risk of sports-related injuries.

AHL

Check your understanding

After reading this chapter, you should be able to:

- define injury
- understand the concept of risk
- calculate the risk of injury in sport
- describe what risk factors of injury are
- identify and discuss the internal risk factors of injury for age, previous injury, sex differences, pregnancy and congenital factors
- identify and discuss the external risk factors of injury for personal protective equipment, performance, training, playing surface and biomechanical set-up of sporting equipment
- outline different types of musculoskeletal injury common to sports
- distinguish between acute and chronic injuries
- understand the relationship between technique and the risk of chronic or overuse injuries
- discuss how correcting biomechanical maladaptations can reduce injury risk.

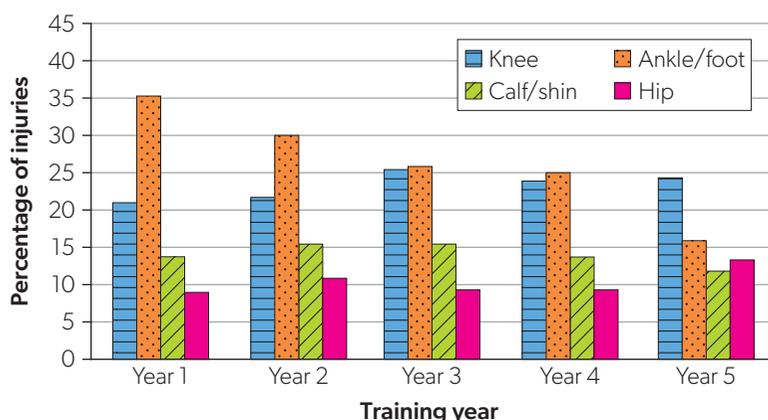
AHL

Self-study questions

1. Explain risk of (sport) injury.
2. List **three** external risk factors of injury.
3. Outline the three main groups of musculoskeletal injuries and provide a sporting example for each.
4. Distinguish between an acute and a chronic type of injury in the same sport.
5. For **two** types of acute injury to a muscle, compare the likely signs and symptoms that an athlete may experience.

Data-based question

A study investigated the injury rates of recruits in a national army ($n = 12,501$) over five consecutive years. The data (4,777 musculoskeletal injuries) for the most common areas of injury were grouped by the location of injury. Overuse (non-stress fracture) lower limb injuries were the most common. The figure below shows the percentage of injuries for the ankle/foot, calf/shin, knee and hip across the five years.



▲ Figure 18 Adapted from Heagerty et al. (2017)

1. Identify the most common area of injury in the first three training years. (1 mark)
2. Calculate the percentage difference for ankle/foot injuries between Year 2 and Year 3. (2 marks)
3. Describe the pattern of knee injury percentages across the five training years. (3 marks)
4. Explain overuse injuries in **two** different sports of your choice. (4 marks)

B.3.2

Interventions related to injury

Syllabus understandings

B.3.2.1 Methods of lowering the risk of injury attempt to minimize the abnormal application of forces and maximize the ability of the body to absorb any such application of force.

B.3.2.2 The initial stages of injury treatment often involve mitigation of inflammation. Serious injuries that involve complete tears or major fractures will sometimes require surgical repair. In the healing process, therapeutic modalities (some managed by para-professionals) are provided to promote healing and a safe return to activity.

B.3.2.3 Treatment of concussion varies based on the specifics of the injury. The pace of recovery is not always linear.

Introduction

Interventions in sport aim to reduce the risk of injury by either lowering the likelihood of the injury happening in the first place or reducing the severity of the injury should it happen. This can be achieved by minimizing the application of excessive forces or maximizing the ability of protective equipment to absorb these forces. Consider the forces applied to the body and the risk of injury to an ice hockey player colliding with an opponent if there were no protective equipment used.



▲ Figure 1 Protective equipment is essential in ice hockey

Other interventions aim to reduce the likelihood of a muscle strain occurring via flexibility training, warm-up programmes or exercises completed to lower the risk of injury, known as **prehabilitation**. These programmes or exercises aim to better prepare the athlete's body for the forces and range of movements involved in exercise, during either training or competition. Coaching safe and correct technique in sport also aims to reduce injury risk, as participants are more likely to be exposed to excessive forces and ranges of movement in muscles and joints when performing an incorrect technique.

Other interventions occur after the injury has happened and have less of a preventative aim, but more of a treatment and recovery role to play. Often this is performed by a qualified professional clinician such as an orthopaedic surgeon, doctor or physiotherapist. Their aim is to promote healing and enable and promote a safe return to exercise.



▲ Figure 2 Prehabilitation exercises aim to prepare the athlete's body for the forces and ranges of movements involved in future exercise

Interventions to lower injury risk

Protective equipment

Protective equipment is now commonplace in many, but not all, contact sports. Often protective equipment has been added and incorporated into rule changes of the sport (such as mandatory protective eyewear for field hockey players), or promoted early on in a sport's history (such as helmets in competitive snowboarding).

In field hockey, protective eyewear has been shown to significantly reduce the incidence of severe eye injuries and severe head or face injuries. However, the risk of other injuries (such as concussion) remains unchanged, which highlights the specific nature of protective equipment in reducing certain injuries, but not all.

In soccer, after the introduction of a new law that made shin guards compulsory, a study of players in the Netherlands found the incidence of lower leg injury reduced by 20% over a five-year period. However, compliance with compulsory equipment measures is often not recorded. Surprisingly, it has been reported only 63% of college ice hockey players wear mouthguards, despite it being a mandatory rule. Whereas, after a change in policy of rugby union in New Zealand, mouthguard use went from 67% to 93%. This was also accompanied by a reduction in dental injuries during the same period.

Rule changes

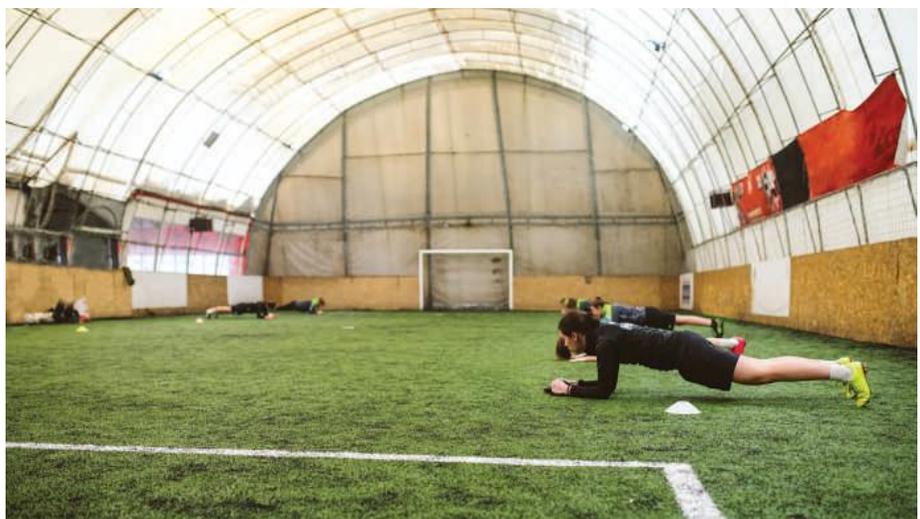
Changes in the rules of sports have also seen a reduction in injury risk or rates.

- One of the clearest examples is the ban of body checking in junior ice hockey, where a player deliberately makes full contact with an opponent to slow or stop their movement with the puck. Following the ban, there was a 50% reduction in injury rate and a 64% reduction in concussion rates.
- In pole vaulting, an increase in the minimum area of crash mat from 17.7 m² to 30 m² led to a reduction in annual fatalities from 1.0 to 0.22 per 100,000 participants.
- In cheerleading, a ban on the basket toss movement on hard surfaces led to injury rates decreasing from 1.55 to 0.40 per 1 million cheerleaders.
- Following a ban of a certain type of tackle in American football, cervical spinal injury rates reduced from 30.66 to 10.66 per 100,000 players and quadriplegia rates reduced by 85%.

Less clear are discussions to limit or ban heading (hitting the ball with the head) in soccer for youth players to reduce the risk of concussion injuries. The evidence to support this is lacking and further research is warranted. Even with this, the Scottish Football Association (SFA) has recommended a ban on heading for players under 12 years old and limited the amount of repetitive heading practice to once a week for adults.

Prehabilitation

Interventions that aim to best prepare athletes for exercise, training and competition can also aim to prevent injury. Prehabilitation is commonly used in medical settings to physically prepare an individual for an intervention, such as surgery, to achieve a better outcome by identifying and addressing known risk factors. Similarly, in sport, prehabilitation refers to proactive rather than reactive interventions used to reduce risk of injury and maximize performance. It typically includes neuromuscular facilitation, endurance and strength training, plyometrics and balance along with functional movements (Linton, Valentin, 2020). In 2003, FIFA developed an injury prevention programme called “The 11”. This aimed to increase coordination, ankle and knee stability, as well as trunk and lower limb flexibility. The exercises were based on evidence or best practice for core stability,



► **Figure 3** The plank is one of the FIFA 11+ programme stretch exercises; there is good evidence that FIFA 11+ is effective at reducing injuries

balance, dynamic exercises and eccentric hamstring strength. The programme lasted 10–15 minutes and needed no equipment apart from a football. Two countries adopted this programme; in Switzerland there were 11.5% fewer match injuries and 25.3% fewer training injuries after four years.

In 2006 the programme was developed into the popular FIFA 11+ with the addition of running at the start and end of the warm-up programme. This is to prepare the cardiovascular system better for the training or competition effort (chapter A.1.3). The programme includes preventative exercises involving core and lower limb strength, balance and agility. The programme has now been lengthened to 20–25 minutes and requires a football and cones.

There is good evidence that the FIFA 11+ is effective at reducing injuries. Bollars et al. (2014) found a 21% reduction in total injury rates following a programme that included FIFA 11+. Larger reductions in injury rates of up to 50% have been found in young female players following the FIFA 11+ programme being performed at least twice a week. Compliance with any warm-up or injury prevention programme is key and can be challenging. In Switzerland—one of the first countries to adopt the FIFA 11+ programme—uptake of injury prevention programmes has remained around 21%–22% between 2008 and 2015.

There are many other injury prevention programmes available for other sports, which often include multifaceted programmes. For example, in Sweden, the *Knee Control Program* has been found to reduce anterior cruciate ligament (ACL) injuries. In South Africa, the *BokSmart* programme has dramatically reduced the number of severe spinal injuries in youth rugby union players. Similar programmes called *Tackling Rugby Injuries* and *RugbySmart* in New Zealand have shown a 50% decrease in incidence of injury. Both of these programmes also contain fair play messages and coach education, and have been incorporated into their respective countries' coaching qualifications to enhance compliance.

The mechanisms behind the positive effects of the FIFA 11+ are multifactorial. The increase in neuromuscular control can involve quicker stabilization time during dynamic movements. Increased static and dynamic balance have been found following the FIFA 11+ programme, as well as enhanced agility. Improved knee strength ratios between the quadriceps and hamstring muscle groups have also been found. Differences between muscle group strength ratios have been suggested to increase injury risk.



Activity 1

Research the FIFA 11+ programme. Describe how Part 1 is similar to soccer movements. Are there any exercises included in this part that surprise you?

Review Part 2 and note the progression levels (1–3) of the exercises. Pick one exercise and describe how it is made harder through the levels.

Discuss which element each of the six exercises is targeting (strength, balance or agility). Are there some exercises that target more than one?

Comment on why these exercises have been selected for the sport of soccer.

◀ Figure 4 The two-legged knee squat is recommended as part of the *Knee Control Program*, which can reduce ACL injuries

Scaling sporting equipment

The benefits of scaling sports equipment are well documented and patent, as highlighted by Buszard et al. (2016):

Consider a 7-year-old playing basketball with a full size ball and a basket at the same height as used for an adult, or a 6-year-old playing tennis on a full size court with a ball that bounces above the head. In both circumstances, children are likely to experience difficulty in completing the task successfully.

Buszard et al. reviewed literature on:

- the relationship between modified sport for children and psychological factors such as self-efficacy and engagement with the task
- the empirical evidence that links scaling (such as modified equipment and/or reduced play area) in children's sport with enhanced skill performance and skill acquisition
- whether scaling the equipment and play area for children leads to the development of more biomechanically efficient movements and, logically, a reduced risk of injury
- the interaction between equipment modification and cognitive processes.

They concluded that scaling constraints in the environment (equipment and play area) allows children to play sport in a manner that more closely represents the adult game, and that scaling is an effective strategy to enhance skill performance and this seems to aid learning. From a sports injury perspective, they reported on research evidence that scaling equipment can reduce the risk of injury by constraining children's technique to more efficient movement patterns.

Referring to an example from cricket, they stated that shortening pitch length (a task constraint) in cricket not only simplifies the skill for junior fast bowlers but also generates more efficient movement kinematics, decreasing the likelihood of lower back injuries—a common injury in junior fast bowlers. Similarly, studies have shown in tennis that smaller rackets and lower-compression balls (scaling/modifying sport equipment) led to a greater proportion of balls struck out in front of the body and with a low-to-high swing—both of which are considered desirable when playing a forehand stroke, and less likely to result in injury as there will be no need to correct biomechanical maladaptation.

However, there is a paradox about the notion of repetition, skill and injury. For example, if modifying the ball and court in tennis results in less variable movement patterns due to the increase in similar repetitions from applying correct technique earlier in the learning process (greater improvements in skill), a question arises: if taken to an extreme, could more repetitions also load musculoskeletal tissue in such a way that the likelihood of overuse injuries in children is increased?

Injury treatment

It is important to note that treatment of injury should be managed by a professional, such as a doctor or physiotherapist. Initial treatment following an injury may also be administered by a first aider. As described previously, there are many different types of injuries that can be sustained across multiple sports. The more serious of these may need medical or even surgical input. For example, complete muscle tears (the most severe level of muscle strain) may need to be

surgically repaired. Fractures of the bone may heal with a period of rest and immobilization (often in a cast), but more severe fractures may be unstable and may not heal properly without surgical repair. Often this can involve aligning the fractured bones in an operating theatre under general anaesthetic and then using internal fixation (metal pins and plates) to stabilize the fracture.

After initial treatment—whether first aid or by a surgical or medical professional—rehabilitation begins. This aims to promote healing and a safe return to exercise or competition. This can be a short (a matter of days) or long (more than six months) period. It is often managed by clinical professionals such as physiotherapists. Often, a rehabilitation programme will focus on improving the range of movement of the affected muscle or joint, progressing onto strengthening the injured area via static, functional and dynamic exercises. If rehabilitation involves an athlete returning to competition, then sport-specific exercises are used in a progressive method.

Physiotherapists use a number of treatment modalities to promote and enhance healing and recovery. These include exercises given to the patient, manual therapy involving manipulations of the joint affected, massage of the affected muscle and electrotherapy (such as ultrasound), as well as advice, reassurance and encouragement to the patient.

In the early stages of rehabilitation, often the main symptom is pain of the joint or muscle affected. This may be accompanied by swelling (inflammation or oedema). This pain often reduces in a matter of days, although it can be debilitating, resulting in reduced movement of the area affected or reduced mobility overall of the athlete. This decreased movement, along with inflammation, can cause secondary issues of reduced range of movement or stiffness of the injured area. If the reduced mobility continues, muscle weakness can also occur.



▲ Figure 5 Internal fixation of fractured bones



▲ Figure 6 Ice used to reduce inflammation

Ice, compression and elevation

One of the most common acute treatment modalities is the use of ice (or cryotherapy), with the aim of reducing inflammation.

Several acronyms have been published for the use of cryotherapy for acute injury management (Table 1).

▼ Table 1

Acronym	Explanation
ICE	Ice, Compression and Elevation
RICE	Rest, Ice, Compression and Elevation
PRICE	Protection, Rest, Ice, Compression and Elevation
POLICE	Protection, Optimal Loading, Ice, Compression and Elevation

The mechanisms for applying ice, compression (for example, via bandages) and elevation relate to both cold-induced analgesia (pain relief) and reduction in inflammation. There is much debate in rehabilitative research whether applying ice does in fact reduce inflammation and promote healing. A typical ice pack treatment would be applied for 20 minutes and not repeated until one hour later.

Compression bandages reduce the oedema by increasing the pressure of external tissue, which promotes lymphatic drainage of the injured area. Venous return is also enhanced, which is the amount of blood and fluid returning via the veins.

Elevation aims to use similar mechanisms to aid the return of fluid from the injured area.

ATL Research skills

The RICE (Rest, Ice, Compression, Elevation) protocol was the preferred method of treatment for acute musculoskeletal injuries since its origin in a 1978 publication entitled *The Sports Medicine Book* by Dr. Gabe Mirkin. According to the protocol, whenever there is a strained muscle, ligament or tendon involving sudden pain and swelling, the four components of RICE—rest, ice, compression and elevation—should be applied. Since then, alternative acronyms have entered into use, such as METH: Movement, Elevation, Traction and Heat (Catanzaro, 2012).

1. Is the RICE protocol a credible method for enhancing the recovery process of acute musculoskeletal injuries?
2. Does applying ice to injured tissue reduce swelling but delay recovery?
3. Why is it important to review research evidence before deciding to follow RICE, or any similar protocol?

Non-steroidal anti-inflammatory drugs

Non-steroidal anti-inflammatory drugs (NSAIDs) can also be used both to alleviate pain and to reduce inflammation. However, these are not suitable for everyone, and best practice holds these should be recommended by a medical professional such as a doctor or a pharmacist.

In sports injuries, a balance is often struck between the healing benefits of inflammation and the reduction of pain because both inflammation and pain play important roles in the body's natural healing process. When an injury occurs, inflammation helps to protect the injured area, remove damaged tissue, fight off potential infections and initiate the healing process. It also helps to stimulate blood flow to the injured area, bringing essential nutrients and immune cells that aid in tissue repair. Pain alerts us to the presence of an injury and encourages us to take protective measures to prevent further harm. Pain can be a natural response to inflammation, as the chemicals released during the inflammatory process can stimulate pain receptors in the affected area. The balance between inflammation and pain management is necessary to facilitate healing. For example, suppressing inflammation could hinder the healing process and delay recovery. Also, by managing pain, athletes can maintain or restore some level of function, allowing them to participate actively in rehabilitation exercises and promote a faster recovery.

The previously mentioned debate surrounding the application of ice to reduce the inflammation stems from discussions on whether inflammation should be reduced to promote healing. There is evidence that inflammation is an important healing stage following injury, which should perhaps be encouraged, or, at least, not discouraged or stunted. More research is required to investigate the most effective management of acute injuries in relation to inflammation and pain.

Treatment of concussion

Concussion injuries can vary case by case, from person to person within the same sport. This is due to different injury mechanisms, differences in the person injured with regards to physical characteristics (such as weight and skeletal proportions) and brain physiology and function. What may also be different are the pace of recovery and the final destination of rehabilitation (such as a return to the classroom, or competitive sport environment). The speed of recovery is not always linear and may involve an apparent increase in rate of recovery, followed by a plateau where symptoms do not improve.

Treatment of concussion can be classified by the stage at which the management is given. Immediate management involves the time after the injury, often the remainder of the day. Such slogans as "If in doubt, sit them out" have gained popularity in recent years. This emphasizes the recommendation that players who suffer a concussion injury should not return to exercise or play that same day. It is important that players with a suspected concussion injury are assessed by a medical professional.



Activity 2

Recently the acronym of PEACE & LOVE has appeared in the literature. Research the explanation of this and comment on the aspect of acute injury management that is missing.

After immediate management, athletes should be restricted from significant physical activity until the symptoms resolve. Return to education should be aimed for initially, although this may not be as straightforward as a simple return to the classroom. The student may find that certain classes are more challenging, concentration levels may be affected and again the recovery may not be linear.

After a return to education has been completed and is stable, then a gradual return to exercise can be implemented—refer to Table 2.

▼ Table 2 Graduated return to sport strategy following a concussion injury

Stage	Aim	Activity	Goal of each step
1	symptom-limited activity	<ul style="list-style-type: none"> daily activities that do not provoke symptoms 	gradual reintroduction of work/school activities
2	light aerobic exercise	<ul style="list-style-type: none"> walking or stationary cycling at slow to medium pace no resistance training 	increase heart rate
3	sport-specific exercise	<ul style="list-style-type: none"> running or skating drills no head impact activities 	add movement
4	non-contact training drills	<ul style="list-style-type: none"> harder training drills, such as passing drills may start progressive resistance training 	exercise, coordination and increased thinking
5	full contact practice	<ul style="list-style-type: none"> following medical clearance, participate in normal training activities 	restore confidence and assess functional skills by coaching staff
6	return to sport	<ul style="list-style-type: none"> normal game play 	

Source: adapted from McCrory et al. (2017).



Linking question

To what extent may mental toughness affect recovery from injury?
(C.1.2)

Consider:

- positive mindset and adherence to rehabilitation
- resilience and setbacks/challenges/managing emotional ups and downs during recovery
- pain, “athletic identity” and mental toughness
- mental toughness, rehabilitation affecting participation, and depression
- coping with pain and pain-monitoring tools (such as Silbernagel et al., 2020).



Linking question

How does the type of motivational climate (for example, mastery oriented, performance oriented) impact the recovery process? (C.3.2)

Consider:

- types of motivational climate
- mastery orientation and resilience
- working at your own recovery pace versus pressure to recover quickly
- how a combination of both motivational climates could impact the recovery process.

Practice questions

1. Explain the role of protective equipment in preventing concussion injuries. (3 marks)
2. a. Describe a return to sport strategy following concussion. (4 marks)
b. Explain why teachers need to facilitate academic support for students with sport-related concussion. (4 marks)

Summary

- Interventions in sport aim to reduce the risk of injury via either lowering the likelihood of the injury happening in the first place or reducing the severity of the injury should it happen.
- Protective equipment, changes in sporting rules, flexibility training, scaling of sporting equipment and injury prevention programmes all aim to reduce the risk of injury.
- Injury treatment aims to promote healing and a safe return to exercise or competition, and is often managed by clinical professionals such as physiotherapists.
- Protection, rest, ice, compression and elevation aim to reduce pain and inflammation but strike a balance between the healing benefits of inflammation and the amelioration of pain.
- Treatment of concussion can vary case by case, from person to person within the same sport.
- Players who suffer a concussion injury should not return to exercise or play that same day. After a return to education has been completed and is stable, then a gradual return to exercise can be implemented.

Check your understanding

After reading this chapter, you should be able to:

- describe the interventions to lower injury risk relating to protective equipment, sporting rule change, injury prevention programmes and scaling sporting equipment
- outline injury treatment.

Self-study questions

1. Discuss the different interventions available to reduce the risk of injury when participating in sport or exercise.
2. Define the acronym POLICE, in relation to cryotherapy for acute injury management.
3. List **five** examples of protective equipment from different sports.
4. Describe how a change in a rule of sport aims to reduce the risk of injury.
5. Identify **three** strengthening exercises that aim to prevent injury in a sport other than football.

Data-based question

Sport and recreation is the leading cause of injury in youth in Canada. A study evaluated the effectiveness of a school-based sports injury prevention programme to reduce injuries through 15-minute warm-up training sessions (aerobic, agility, strength and balance exercises) over 12 weeks during physical education lessons in Canada across two years. The intervention group ($n = 655$, age range 11–16 years) were compared with a control group ($n = 501$, age range 11–16 years). The injury incidence by injury type for both groups is shown in Table 3.

▼ Table 3

	All injuries		Lower limb injuries		Medically treated injuries	
	control	intervention	control	intervention	control	intervention
Number of injuries	69	54	51	35	49	24
Injury rate (number of injuries per 1,000 hours)	2.064	1.477	1.526	0.957	1.466	0.656

Source: adapted from Emery et al. (2020).

1. Identify which group had the lower limb injury rate. (1 mark)
2. Calculate (to one decimal place) what percentage had medically treated injuries for the control group. (1 mark)
3. Explain the effect of the 12-week warm-up intervention programme on:
 - a. all injuries (3 marks)
 - b. lower limb injuries (3 marks)
 - c. medically treated injuries. (3 marks)

C.1

Individual differences

What characteristics explain how and why some individuals succeed and experience well-being in sport and health contexts more than others?

This topic will help you to understand why personality is important in sport and exercise. The topic discusses social learning theory, which helps explain behaviour. The concept of mental toughness, an important predictor of athletic performance, is introduced as an important psychological resource to overcome challenging and difficult circumstances. The link between expectations and behaviour has received careful scrutiny, such as the connection between what we expect and what we do. The topic concludes with some discussion of the phenomenon called self-fulfilling prophecy and examines how such expectations can influence behaviour.

C.1.1 Personality

Syllabus understandings

C.1.1.1 Personality refers to individual differences in characteristic patterns of thinking, feeling and behaving. Personality is typically understood to be an interaction between genetic traits and the environment.

C.1.1.2 Social learning theory is a situational approach to understanding behaviour.

C.1.1.3 Personality can change over a long period of time.

AHL

Introduction

Each year, the British broadcaster BBC hosts an awards ceremony called *BBC Sports Personality of the Year*. The programme is a review of domestic and international sport. It is watched by millions of sports fans around the world. At the end of the programme, one sports person is awarded the trophy for the “BBC Sports Personality of the Year Award”, voted for by the public. In this context, the word *personality* describes someone who is well-known and popular. But this is not what we usually mean when we use this term.

To understand what the term “personality” means, we need to consider how the concept of personality has developed. Humans have been interested in how the mind works for millennia, but experimental psychology is a relatively new science. Since the birth of experimental psychology, the only constant seems to be continual scientific advances as psychologists seek to understand, predict and modify human behaviour. In so doing, psychologists are continually refining scientific techniques to investigate who we are as individuals and why we think and behave in the ways that we do.

If psychologists are to realize their goal of helping people to help themselves, it is important that the views of the individuals are taken into consideration. Therefore, theories of human personality are necessarily accompanied by techniques of collecting information about human personality (such as questionnaires, interviews and observations).

As we advance our understanding of how we think and behave, new knowledge adds to or conflicts with previous understanding. To get to the forefront of current thinking, psychology students must consider the contribution and limitations of work carried out since the beginning of the field. Therefore, it is important to appreciate what each theory concerning personality adds to our understanding of the way that human beings think and behave. However, keep in mind that just because a theory of personality is widely accepted and endorsed, it does not mean that it can be applied uncritically. There is an important rule that is observed by applied psychologists that is relevant here: “test before you try”. It means that a psychologist needs to understand what factors influence a performer’s personality before they intervene.



▲ Figure 1 Lewis Hamilton is one of only a few sportspeople to have been awarded the BBC Sports Personality of the Year Award multiple times

Theories of personality have the potential to deepen our understanding of human performance in sport and exercise, and to enable us to prepare athletes to perform beyond what they consider to be their potential. However, the uncritical application of mainstream psychology theories related to the study of personality has led some sport and exercise psychologists to take a negative view of their potential impact.

The aim of this chapter is not to classify aspects of people's personalities into being high in one factor and low in another. Rather, it is to understand how psychologists can maximize an individual's performance in a specific activity. After studying this chapter, make up your own mind as to what is important and what is not for sports scientists to understand as they seek to assist performers and exercisers alike.

Defining personality

Personality has been defined as, "those relatively stable and enduring aspects of individuals which distinguish them from other people, making them unique but at the same time permit a comparison between individuals" (Gross, 1992).

Key point

Personality is the sum of the characteristics that make a person unique.

The *relatively stable* part of this definition is important: if aspects of personality were not stable or enduring, they would be very difficult to study. Also, the effect of this apparent instability on our personal relationships would be very serious. After all, we need to be able to predict others' behaviour, and they need to be able to predict ours. For example, we often share exciting news with someone because we have made a prediction that they will be interested, give us praise or affirm our efforts. Imagine someone has just achieved a personal best or an award. Consider how they would feel if the person who they thought would be pleased for them was actually indifferent or reacted negatively. They would likely be confused, upset, deflated and even concerned. If this pattern of inconsistent or indifferent behaviour were to continue, they might no longer seek that person out and may withdraw from them. Making accurate assessments of personality is something we routinely carry out as we go about navigating our social lives. We make judgements about how people will likely respond to us, and we will respond to them. However, deviations from established, normative patterns can hamper communication and cause confusion and concern.

Our personalities define who we are—in our own eyes and in other people's opinions—and what we are likely to think and feel. Having relatively stable and enduring patterns of behaviour allows us to develop, forge and maintain relationships. Children from a very young age learn to predict what their parents or guardians will care or be concerned about. Imagine a child growing up in an environment where they cannot predict what their parent or guardian will deem important because that adult has an unstable personality. This situation can lead to negative social, psychological and biological consequences for the child. Our personality can have a marked and sustained effect on the people around us—both positive and negative.

We use social skills to form, maintain and repair relationships in all areas of our lives. Learning how to assess others' personalities is an essential social skill. This is also true in sport and exercise contexts. Therefore, it is important to ask: what role does personality play in the context of sport and health?



▲ Figure 2 Children from a very young age learn to predict the behaviour patterns of those around them

Trait-based approaches to personality

Researchers in mainstream psychology and personality theory have developed psychometric tools to measure personality in a reliable and consistent fashion. These measurement tools can be used to measure:

- state (for example, characteristic ways of thinking, feeling and behaving in a given situation at one point in time)
- trait personality factors (for example, ways of thinking, feeling and behaving that are consistent across social situations and differ systematically between individuals).

Trait-based approaches to personality assume that the constituent components of personality are relatively stable over time.

From this perspective, behaviour is primarily determined by the individual, and situational and/or environmental factors play a comparatively minor role. For example, if a performer is conscientious and always prepares carefully for competition, then we could expect this also to be true in other areas of that person's life, for example, when filling in job applications. However, Weinberg and Gould (2011) make an interesting point that personality traits *predispose* us to ways of thinking, acting and feeling, but it is not a given that our behaviour will always follow the predicted pattern. Therefore, a trait is considered to be the default pattern that we follow. It is likely that we will follow the pattern, but it is not a certainty that we will do so.

Key point

Personality traits are enduring patterns of thoughts, feelings and behaviours that are relatively stable over time.

ATL Thinking skills

Traits are considered to predispose an individual to act in a certain way regardless of the situation or circumstances. For example, a highly competitive athlete will be predisposed to giving 100% regardless of the situation or score. Does this mean that the athlete will always be competitive in sport situations, or does it mean that the athlete is likely to act in this way?

The big five personality traits

The most widely accepted model of personality is the “**big five**” **personality traits** (Gill, Williams, 2008). In this model, there are five major dimensions of personality.

1. Openness to experience Someone with a high level of openness to experience likes trying new things, such as new foods. Someone with a low level of openness to experience prefers doing the same things over and over again.

2. Conscientiousness Someone with a high level of conscientiousness is responsible and organized; for example, they always complete their homework on time. Someone with a low level of conscientiousness may frequently forget to do their homework.

3. Extraversion Describes how outgoing and social a person is. Someone with a high level of extraversion loves being around other people, enjoys talking and making new friends, and often feels energized and happy when with others. The opposite of extraversion is **introversion**—an introvert enjoys spending time alone and doing activities on their own.

4. Agreeableness Describes how friendly and cooperative a person is. Someone with a high level of agreeableness is generally kind, considerate and likes to help others.

5. Neuroticism Describes how someone experiences and handles their emotions. Someone with a high level of neuroticism tends to worry a lot, gets easily upset or anxious, and feels stressed in different situations. The opposite of neuroticism is **emotional stability**.

These five dimensions span individual differences and have been found to be the most important personality characteristics (Weinberg, Gould, 2023).

When you begin to mature, you become more aware of what your personality reveals. For example, situations that you feel comfortable or uncomfortable in: situations that you enjoy and thrive in versus situations that you do not look forward to. It is likely that we all possess aspects of our personality that enable us to perform in certain situations but either hold us back or inhibit our effectiveness in others.

Sport psychologists are divided on how important aspects of personality are at determining how successful a performer we will become. For example, there are advantages to being either an introvert or an extravert. A conscientious introvert is likely to get a good deal of quality work done. Whereas an extravert might regard new learning/training environments as an opportunity to meet new people and learn new things.

ATL Thinking skills

Does simply knowing an individual's personality traits always help us predict how that person will behave in a particular situation? Think of players you may know who anger easily during a game, whereas other players in the same team seldom get angry. Is the angry player more likely to become angry in other situations, for example, when being disciplined by a teacher in the classroom?

Activity 1

The "big five" model of personality contends that there are five major dimensions of personality:

- neuroticism
- extraversion
- openness to experience
- agreeableness
- conscientiousness.

Identify the dimension of personality from the descriptors in Table 1.

▼ **Table 1** The five major dimensions of personality

Dimension	Descriptors
	amiability, altruism, modesty
	enthusiasm, sociability, assertiveness
	nervousness, anxiety, anger
	constraint, achievement striving, self-discipline
	originality, need for variety, curiosity



▲ Figure 3 There is no one personality profile associated with elite performance

Measuring aspects of personality

There are four main ways to gather scientific data regarding personality. Psychologists working in the field of personality have developed an acronym, LOTS (Block, 1993), to make it easy to remember what these four categories of data are.

LOTS stands for:

- L-data—*lifetime* history
- O-data—*observations* from knowledgeable others including parents and friends
- T-data—experimental procedures and standardized *tests*
- S-data—information provided by the individual (*self-reported*).

To develop an understanding of how to measure personality it is important to consider how a psychologist might use the information gathered from these different sources. The goal of a psychologist working with personality data is to consider how these factors are influenced by the environment in which that individual lives, and therefore how personalities alter over time and according to experiences.

To be confident in the assertions they make, psychologists need to know the information they are collecting about someone's personality is reliable. To do so they need to understand the confidence limits of the data they are working with and consider what might be reliable and unreliable information.



Experiments

If you were planning to use an online questionnaire (survey) to investigate the influence of university students' personality on their leisure behaviour choices:

- why is the representativeness of the sample (for example, subject studied, gender) important?
- could there be selection bias if participation in the survey was voluntary?

The big five and sports performance

Psychologists have yet to determine what types of personality characteristics are associated with elite performance.

Extraversion and conscientiousness have been linked to adherence in exercise programmes, whereas neuroticism has been negatively related to physical activity (Rhodes, Smith, 2006). If we want to achieve something, we often have to accept that it is going to be uncomfortable for a period until we think we are reaching success. A person with a more neurotic personality is likely to be

averse to trying new activities in unfamiliar surroundings with people they do not know. This person could conclude that most forms of exercise are simply not for them. Or, they might find a way to adapt to the unknowns with all the positive implications that exercise brings for their health and happiness. Similarly, if you are an introvert, do you accept that speaking in a group meeting is best left to the extraverts in the room? Or, do you find a way to approach the situation that enables you to get your points across?

Consider the paradox of perfectionism (Weinberg, Gould, 2023). In sports psychology this has been researched intensively. Perfectionism is characterized by setting high standards of performance, striving to be flawless and a tendency to be overcritical of your performance. Interestingly, these aspects of our performance are often commended—in relation to both our academic work and more generally (such as sport, music, art). However, being overly critical can have negative consequences on your self-concept and reduce the likelihood that you will persevere at an activity, which is why perfectionism can be seen as a paradox.

Given the pros and the cons of perfectionism, it has been divided into two constructs:

- **adaptive perfectionism**, which emphasizes a focus on high standards, and not being overly concerned about making mistakes or about how others think of you
- **maladaptive perfectionism**, which embodies a focus on high standards, concern over making mistakes, and concern about what others think of you.

The implications of a person's perfectionist orientation are very different: adaptive perfectionism is positive, and maladaptive perfectionism is negative (Weinberg, Gould, 2023).

Given that attainment and its pursuit are rewarded, how we approach high performance holds considerable consequences. We have seen how our respective personalities enable us and inhibit us in certain situations. Moreover, the costs of being inhibited from acting can be considerable. Approaching high performance from a maladaptive perfectionism perspective risks poor performance (Grugan et al., 2020), burnout (Hill, Curran, 2015) and excessive exercise/doing too much (Flett, Hewitt, 2005). However, approaching sport and exercise with an adaptive perfectionism orientation implies that you are going to set high standards and work hard to achieve them—while paying less attention to external and internal critical voices.

Therefore, it may be necessary to change an aspect of our personality to adapt to changing circumstances or improve our physical and/or mental health. Is it possible to realize this aim?

The question that Hudson et al. (2019) were interested in asking is: how does this change come about? Is it enough to desire a change in your personality, or do you have to actively pursue it?

Hudson et al.'s study investigated this question. Participants provided self-report ratings of their own ("big five") personality traits. Then, over a 15-week period, participants were free to accept and complete weekly challenges that related to aspects of their personality that they wanted to change. Results demonstrated that accepting a challenge did not predict trait personality changes. Only actually completing challenges (performing trait-typical behaviour) predicted change over time.

This demonstrates that, if we want to become less neurotic or more emotionally stable, it is possible to do so. The same applies to the other “big five” dimensions. Therefore, accepting and completing challenges that push you to speak in a public meeting if you are an introvert, or adhering to an exercise programme if you are not a self-regulated conscientious exerciser, can challenge and change aspects of your personality. It takes a significant period of time and work at focused challenges, rather than merely desiring change, but it is possible.

ATL Thinking skills

Pick one of the “big five” personality dimensions that relates to an aspect of your personality that you would like to change. Why do you want to change this dimension, and what might be an example of you doing so?

At the conclusion of the Florida Conference on Personality and Sport in 1975, Robert Singer, an eminent sport psychologist, observed, “we have tried to fish for minnows with a net designed for whales; we cannot really complain about the size of the catch” (Singer, 1975).

Singer was suggesting that general personality factors, and the instruments we use to measure them, are not sensitive to the more subtle differences in cognition, emotion and behaviour that determine sport performance.

For many, his comment seemed an effective epilogue to a long debate on the role of personality theories in sport—an area of study that was a dominant topic in the early days of sport psychology. An earlier comment by Rushall (1970), another eminent sport psychologist, was even more explicit: “personality is not a significant factor in sport performance”.

Consider that, under certain circumstances, being an extravert can also have its disadvantages—and neuroticism its advantages. Similarly, maladaptive perfectionism carries a number of negative associated outcomes, despite people who exhibit it really wanting to perform well. Therefore, personality factors do influence our performance—but not always directly. This might be what Rushall and Singer were driving at—instead of focusing on the “big five”, it may be more helpful to focus on more specific aspects of a performer’s behaviour, thoughts or emotions.



Linking question

What are the confounding variables when investigating the impact of personality type on performance outcomes for players of team sports?

(NOS, Inquiry 1)

Consider:

- skill level of the players
- player experience in team sports
- team dynamics, such as communication, cooperation and leadership
- coaching style of the coach
- physical attributes such as strength, power, speed, agility and endurance
- goal orientation
- external factors, life events, environmental conditions (such as the weather).

Interactionist view of personality

In the 1930s, a group of psychologists developed the principle of **interactionism** in human personality. One of the main supporters of this principle was Kurt Lewin. He became one of the most influential social psychologists of the 20th century. Lewin suggested that neither nature (inborn tendencies) nor nurture (life experiences) can account for an individual's behaviour and personality. Instead, he proposed that our personalities are developed through a constant interaction between the person and their environment.

To neatly summarize this, Lewin formulated the following equation:

$$B = f(P, E)$$

The equation states that behaviour (B) is a function (f) of the person (P) and their environment (E).

This has important ramifications for the way we think about improving human performance, and how to treat illness associated with poor lifestyle choices. Therefore, exercise psychologists need to be aware of the effect the environment has on the individual.

An interactionist view of personality holds that the individual's experiences cannot be understood if personal and situational factors are separated (Mischel et al., 2003). While the interactionist view of personality is still a matter of some debate among certain psychologists, the principle of interactionism (that organisms and environment interact to determine behaviour) is widely recognized, particularly in the fields of biology and genetics. Lewontin (2000) states that genetic and environmental influences are intertwined, making development "contingent on the sequence of environments in which it occurs".

Yet, a fundamental part of who we are is dependent on our genes. If Lewin's equation is correct, then our genetic profile will interact with the environment in which we work and live.

A more contemporary model of interactionist theory than that provided by Lewin can be found in the work of the psychologist Walter Mischel, who takes what is known as a social-cognitive approach. He is interested in four personality variables (Beneckson, 2011):

- competencies—our skills and knowledge
- encoding strategies—our particular style and the schemas we use in processing information
- expectancies—what we expect from our own behaviour and our anticipations of our performance levels
- plans—what we intend to do.

The interaction of these cognitive factors with environmental situations results in the expression of personality (Mischel et al., 2003).

Essential to understanding personality from an interactionist standpoint is that you consider how an individual's personality unfolds, or develops, across a number of social situations. Behavioural instances, if repeated, have the potential to demonstrate the inner workings of a meaningful characteristic, or what may be considered a behavioural signature, of an individual's personality (Mischel et al., 2003). Mischel's work, as it is epigenetic in nature, has much in common with the research conducted by Albert Bandura (to be discussed later in this chapter).

In summary, it is important to get an insight into an interactionist approach to personality because as psychologists, and sports scientists, we need to understand the role that genetic, epigenetic and environmental factors can play in athletes' behaviour, particularly, for example, when we consider the central role that talent development plays in human performance.



Linking question

How do personality factors affect an individual's motivation? (C.3)

Consider:

- extraversion, collaboration, teamwork and seeking recognition from others
- extraversion, socializing, leading and interaction
- introversion, individual activities and working independently
- conscientiousness, diligence, goal-orientation, a sense of competence
- agreeableness, helping others, contributing to a team, positive work environment
- neuroticism, fluctuations in anxiety, and self-doubt
- openness to experience, personal growth, learning and creativity
- what motivates curious, imaginative and open-minded individuals
- whether individuals can exhibit a combination of traits
- if other factors influence an individual's motivation.

Social learning theory and personality

One of the most influential theories in psychology is **social learning theory (SLT)** (Bandura, 1977; 1997; 2001). Social learning refers to the process through which individuals acquire new behaviours, attitudes and skills by observing and imitating others. A remarkable feature of SLT is our capacity to learn without reinforcement (rewards or punishments). According to the principles derived from extensive research, SLT states that we have a capacity to learn by observation, even in the absence of rewards (Pervin et al., 2005). SLT emphasizes our individual capacity to influence our destiny and to try to help us achieve our potential.

ATL Thinking skills

When athletes hold their coach in high regard, they are more likely to be inspired and motivated by their actions and achievements. They see their coach as a role model and aspire to replicate the coach's behaviours, such as their work ethic, discipline and commitment.

- If athletes hold their coach in high esteem, are they more likely to trust the coach's judgement?
- Do athletes see their coach as a role model, not just in terms of skills and strategies but also in terms of personal qualities, such as resilience, sportsmanship and leadership?
- When athletes hold their coach in high regard, are they more likely to value their feedback?

Key points

- The interaction between personality traits and social learning is dynamic, and athletes can learn to modify and adapt their natural tendencies in response to the social environment.
- Social learning and personality adaptation over time is an ongoing process that contributes to an athlete's growth and development in their sport.
- Personality traits do not determine or restrict an athlete's potential, and social learning plays a key role in this.

According to the view of SLT, personality structures are mainly cognitive: that is, they are related to the processes of knowing, being aware, thinking, learning and judging. According to Pervin et al. (2005), to get a full understanding of SLT and how it relates to personality there are four constructs that must be taken into account:

- competencies and skills
- beliefs and expectancies
- behavioural (evaluative) standards
- personal goals.

Competencies and skills

How someone speaks, or appears, is often used to make judgements about their personality. For example, whether they appear to be sad or outgoing. Bandura (1982) argues that how we are perceived by others is influenced by our own feelings of competence. Therefore, an individual can appear shy and introverted because they are not confident at carrying out a particular task or role, not because that is how they behave all the time. In summary, how you behave depends on the actual skills you have and whether you expect to be good at something.

Beliefs and expectancies

A crucial component of psychological change and self-improvement is **beliefs** and **expectancies**.

- Beliefs relate to how the world is. For example, how well someone is performing a role in a team.
- Expectancies relate to what an individual *thinks* will happen in the future. For example, what an individual thinks might happen with regard to the role they play in that team.

Behavioural standards

A mental “standard” is a criterion for judging the goodness or worth of a person, thing or event.

- Behavioural (evaluative) standards are standards concerning one’s self or personal standards.
- Personal standards are fundamental to human motivation and performance.

Thus, you use behavioural (evaluative) standards to judge the goodness or worth of your own behaviour.

According to Bandura (1986), we evaluate our own actions and then respond in an emotionally satisfied way (for example, we meet our standards for performance) or dissatisfied way (for example, we fail to meet our standards for performance). It is a kind of “internal guidance/psychological system” through which people consider their own actions, and contrasts with behaviourist theory which argues that ongoing behaviour is determined by forces in the environment.

TOK

Behavioural standards provide a tool through which the link between moral standards and moral behaviour can be studied.

Can you think of times when you have been emotionally satisfied or dissatisfied with your own actions?

Activity 2

Taking part in sport provides individuals with a range of experiences that can shape their personality. Discuss the following questions in small groups.

1. Can athletes learn to adapt their behaviours, communicate more effectively, and manage conflicts through interactions with teammates, coaches and opponents?
2. How are positive traits such as resilience, discipline, determination and self-confidence developed in athletes?
3. Do coaches help develop traits in athletes such as self-discipline, goal setting and a growth mindset?
4. Does engaging in reflection help athletes identify their strengths, weaknesses and areas for growth?
5. Does reflection allow athletes to set personal goals, evaluate their progress and adapt accordingly through enhanced self-awareness, greater emotional intelligence and sound decision-making?

Activity 3

While certain personality traits may be associated with performance in particular sports, the relationship between personality and athletic performance is complex and multifaceted. Each athlete is a unique individual. A combination of factors can influence their performance, such as genetic, physiological, psychological and environmental factors.

Answer the following questions using examples from your favourite sport.

- Does the impact of situational factors on performance often outweigh the impact of personality traits?
- Is there one single personality profile that can account for the complexity and diversity of factors that influence performance across different sports and levels of competition?
- Does relying only on an initial personality profile for an athlete overlook the potential for an athlete's personal development (for example, in their motivation, mental toughness and/or emotional control through exposure to competitive environments)?

Personal goals

A key concept that relates to influencing change in our personalities is the identification and realization of goals (refer also to chapter C.5.1). Sometimes, to improve athletic performance, athletes need to be made aware of what they are good at and helped to identify ways that they can maximize their performance potential. This facilitating role is often performed by sport and exercise psychologists who identify competencies (performance profiling) in an athlete, and then challenge a performer to improve themselves through appropriate goal setting.

Social cognitive theory: self-efficacy

Before we examine athlete case studies of performance profiling and goal setting, it is necessary to understand how performance can be improved on an individual basis. **Self-efficacy** refers to the expectation that people hold regarding their own capabilities for performance.

Research conducted by Baumeister et al. (2003) and Bandura and Locke (2003) demonstrated that the relationship between self-efficacy and physical performance was robust. If you can increase feelings of self-efficacy then a consequent increase in physical performance can be observed. Self-efficacy is “confidence towards learning”.

Henry Ford once famously said, “Whether you believe you can or you can’t, you’re right.” Although his viewpoint is extreme, its essence is correct. However, the important difference between Ford’s viewpoint and SLT is that SLT is valuable to everyone: it demonstrates how meaningful change that is personal to an individual can be achieved.

It is important to understand that self-efficacy is distinct from self-esteem. Self-esteem refers to a person’s global evaluation of their personal worth. Self-efficacy refers to what someone feels that they are able to achieve in a given setting.

ATL Thinking skills

Consider the example below. It illustrates the difference between self-efficacy and self-esteem.

Ian Woosnam is a former world number one golfer. He has won 48 professional tournaments. Read carefully what he states about his performance.

I had a bit of the twitches in the last couple of rounds here last year but I've got the long putter this week and hopefully I'll be able to knock the short ones in.

I've been working with Bob Torrance recently and getting my swing near where it used to be. I've put on a bit of distance as well and feel I've actually got a chance of winning this week. It's been a long time since I thought that.

I feel I haven't had a good putting week for as long as I can remember. I can have two good putting days and then two poor ones and shoot 74 or 75. I still feel I can win and I want to win again before I'm 50.

Fifteen years ago I would come in and say I was going to win the tournament. If my putting was good I knew I was going to win certain tournaments. These days my putting isn't strong enough to say that but I am working on it.

This example outlines why it is vital to understand the important difference between self-efficacy and self-esteem. Consider how Woosnam evaluates himself as a putter, but not a golfer. He knows what he needs to do to win. He also knows that most of his golf game is in great shape, but not his putting. If you were to measure his self-esteem as opposed to examining his self-efficacy, the result you would get would be imprecise and would not enable a sport and exercise psychologist to design a tailored performance solution.

Importantly, self-efficacy can be manipulated because it refers to specific competencies and expectations; self-esteem is far more cumbersome because it includes many facets of a person's life. With regard to Woosnam's putting, using techniques discussed below it may in fact be possible to increase his self-efficacy by influencing his view of what can be achieved and thereby increasing his confidence towards learning (self-efficacy).



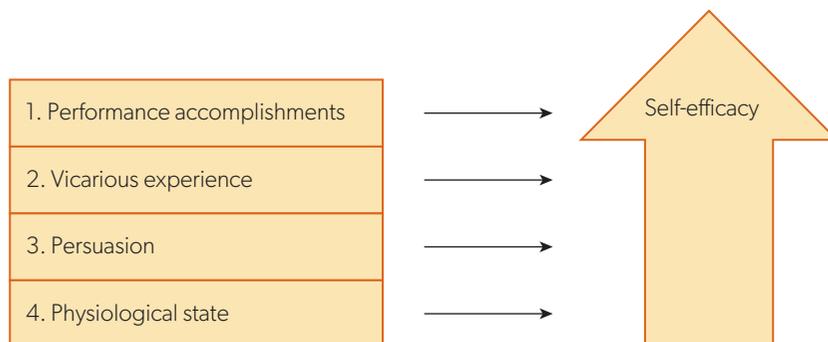
▲ Figure 4 Ian Woosnam

To measure perceived self-efficacy, Bandura states that a micro-analytic research strategy should be used. What he means by this is that an individual should be measured immediately before the performance of specific behaviours in specific situations (such as putting, not golfing).

Now, recall Singer's 1975 quote from earlier in this chapter: "we have tried to fish for minnows with a net designed for whales". Think about the relative imprecision with which personality has been investigated in relation to sports performance. If we extrapolate from SLT, taking into account individuals' beliefs and expectations regarding their future performance, human personality should be studied in relation to specific areas of a person's life, and not examined as a whole.

How can self-efficacy be manipulated?

An antecedent is defined as previous or pre-existing factors that are known to increase self-efficacy. To improve performance, the four factors shown in Figure 5 can be used in isolation, or in combination, to increase self-efficacy.



▲ Figure 5 Antecedents of self-efficacy

1. Performance accomplishments

Performance accomplishments are described by Morris and Summers (1995) as the most potent antecedent of self-efficacy. Before we discuss this particular type of antecedent it is important to recognize what is perceived by a particular athlete to be a performance accomplishment.

A technique commonly used by psychologists to ascertain how athletes see themselves is termed “performance profiling” (Butler, Hardy, 1992). It stems from psychologist George Kelly’s work on personal construct psychology, which emphasizes that psychologists need to try to understand the ways in which athletes perceive the world in which they train, live and perform (Gucciardi, Gordon, 2009). The performance profile encourages practitioners and researchers to regard an individual’s perception or meaning of their performance as a vital source of information to optimize performance (Gucciardi, Gordon, 2009).

The information being elicited from an athlete concerns *their view of their* performance. It is their opinion about what makes them effective, and also how they could improve aspects of their performance in relation to the best performer they can think of. You may think this does not sound very different from a questionnaire that you may have had experience of filling in. However, questionnaires impose constructs on performers (for example, they tell you whether you are an extravert or an introvert), whereas a performance profile allows an athlete to create a personalized profile.

Once the categories are generated by an athlete, and in some cases compared with a profile completed by a coach, the performer is encouraged to take ownership of their profile. This gives the performer a central role in how to close the gap between their current performance self and their ideal performance self.

Case study

Accurate performance profiling helps win Olympic medals

Butler et al. (1993) used the performance profile to assess the beliefs of boxers and their coaches about the technical, tactical and physical qualities they possessed before boxing at the Olympic Games in Barcelona in 1992 (Figure 6). In total, 16 boxers and 3 coaches took part.

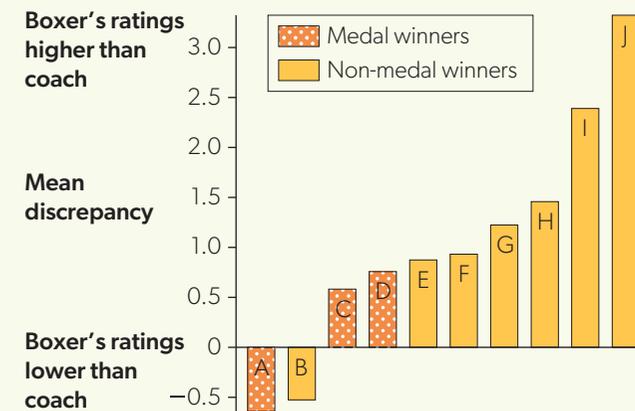
The boxers were divided into three groups and asked to brainstorm what they believed the characteristics of a champion or elite boxer to be. After this, each group shared their vision of the common characteristics. The boxers assessed themselves against each common characteristic. If there was a difference in the assessment between the ideal champion and the boxer, then they set goals to try to reduce any discrepancy.

Immediately before the Games, the coaches reviewed each boxer’s profile. Where the athletes and the coaches were in overall agreement regarding the respective strengths and weaknesses of a performer’s profile, the boxer’s performance was closely associated with the attainment of a medal.

Where the beliefs and the expectations of the coach and the performer were closely matched, performance profiles could be used to gauge performance accomplishments accurately. In three out of four cases where the mean discrepancy in the performance profile was low



between the coach and the boxer, a medal was attained. According to the work of Butler et al. (1993), using the performance profile to gauge accurately the perception of strengths and weaknesses is associated with achievement at the highest level.



▲ Figure 6 Mean discrepancy of ratings on physical qualities for 10 of the boxers

Goal setting is another powerful tool to improve self-efficacy with regard to performance in sport. In 1990, Locke and Latham published their book entitled *A Theory of Goal Setting and Task Performance*, in which they outlined the characteristics of purposeful and accurate goal-setting practices. Most of us are familiar with the acronym SMARTER goals (Specific, Measurable, Attainable, Realistic, Time-based, Exciting, Review). However, Locke and Latham (1990) stated that it is also important to consider goal difficulty and types of goals. Refer to chapter C.5.1 for more on effective goal setting.

2. Vicarious experience

Vicarious experience (VE) is sometimes described as modelling. Seeing an example of how to complete a task by a peer can act as a stimulus to attempt an activity you might not have considered otherwise. But there are positive and negative aspects to modelling. Consider how you would feel if you observed one of your peer group successfully completing a task you were expected to perform.

From a positive standpoint, training with a group of people who are striving to be better at a task—whether academic or sporting—has the potential to spur you on to achieve feats that you did not think possible, provided you are not in awe of the people completing the task in the first place. For VE to influence self-efficacy, you have to believe it is possible that you can complete the target activity.

From a negative standpoint, Bandura demonstrated that acts of aggression, if viewed by impressionable people, can be unthinkingly repeated in similar social situations. The negative aspect of modelling has obvious implications for the repetition of socially undesirable behaviours, such as bullying. It is important that we understand how and when to use VE positively—but we should also be aware of the benefits of VE for skill acquisition.

In summary, VE has been shown to have a powerful change-provoking effect on the subsequent behaviour of the individual observing the target behaviour (Bandura, 1982).



▲ Figure 7 Seeing an example of a peer succeeding can spur you on to achieve feats that you did not think possible

Case study

The inspiring power of persuasion

Consider the effect of Nelson Mandela's presence in the changing room before the Rugby World Cup Final in 1995. Joost van der Westhuizen, the Springbok scrum-half, said the following.

There was a lot of stress in the changing room... It was dead quiet and suddenly the door opened and there was Nelson Mandela walking in... I think the best thing was to see him in a Springbok jersey, that was the best thing for us—it was a total surprise. Then we realized that the whole country was behind us, and for this man to wear a Springbok jersey was a sign, not just for us, but for the whole of South Africa, that we have to unite, and we have to unite today.

Not only did Mandela wear a sporting shirt that was previously considered to be an emblem that upheld apartheid, but the shirt he wore had a number 6 on the back—the number that François Pienaar, the captain, would wear that day. The persuasion that took place was in word and in deed. It came from one of the most inspirational figures of our time and he did not just say, 'You can win this', his actions went beyond sport. It was about demonstrating the potential of healing cultural rifts and saying to the players 'we have a future together—we all wish you well'.



▲ Figure 8 Nelson Mandela presents the Webb Ellis Cup to the South African captain François Pienaar after the team's victory in the Rugby World Cup Final in 1995

Activity 4

Think how you would like to be persuaded, and who you would like to be persuaded by.

Discuss this with your classmates.

Would you all have chosen the same source, repeating the same message?

3. Persuasion

Bandura uses the term persuasion, but he is specifically referring to verbal persuasion (Morris, Summers, 1995). However, persuasion can also come in the form of an act. Persuasion often comes from a high-status individual and is designed to encourage you to act in a particular way. For example, it can be inspirational to be persuaded by someone you hold in high regard.

We have seen the potential impact of persuasion when used by a high-status individual, at the right time, in the right place. But can you persuade yourself to enact a difficult task?

A specialism among psychologists concerns the use of imagery (chapter C.5.2). Evidence has shown that emotionally charged images, personal to the performer, can be used to motivate in training, or form part of a pre-performance routine designed to adjust the level of arousal (Morris, Summers, 1995).

Like VE and modelling, persuasion must come from a credible source. As with all the antecedents of self-efficacy, the factors in the model presented need to be used in a positive fashion, not in a way that is perceived as critical.

4. Physiological state

The final antecedent of increased self-efficacy concerns the interpretation a performer makes of their physiological state prior to performance. Preparing to perform in front of an audience, or trying a new but challenging activity, often results in heightened levels of arousal.

In terms of cognitive processes, arousal often results in attentional narrowing and selecting the most relevant cues upon which to focus. The construct of attention has three dimensions:

- Concentration (or effortful awareness). For example, listening intently to your sports coach during a timeout in basketball.
- Selective attention—the ability to focus (“zoom in”) on relevant information and ignore distractors that compete for our attention. For example, ignoring the hostile crowd of spectators and listening intently to your sports coach during a timeout in basketball.
- The ability to coordinate two or more actions at the same time. For example, checking the score on the scoreboard while at the same time listening intently to your sports coach during a timeout in basketball.

We will study arousal and attentional control further in chapter C.2.2.

Potential for change in personality

Almost 2,000 years ago, a philosopher (and Roman Emperor)—Marcus Aurelius—wrote that, “Everything is but what your opinion makes it; and that opinion lies within yourself.”

Therefore, the capacity to change established traits in our personalities lies within us. Reflecting upon what was discussed earlier in this chapter, by taking an interactionist approach advocated by Lewin, we have come to understand that the environment influences our genetic make-up throughout our lifespan. Examining factors in mental health has illustrated the importance of understanding human behaviour from an epigenetic viewpoint.

Through his work on SLT, Bandura (1982) has demonstrated the effect of four powerful antecedents (performance accomplishments; vicarious experience; persuasion; physiological state) that can influence our confidence in approaching learning (self-efficacy). Therefore, the role of psychologists working in the realm of human performance is to show individuals that the power to determine their future really does lie in their own hands—people can, with the right tools and focusing on specific factors, alter and influence their own personality. However, before change occurs, psychologists need to collect reliable information.



Linking question

How can observer bias be controlled when undertaking interviews and observations? (Inquiry 1)

Consider:

- learning how to conduct interviews or observations
- standardizing data collection, consistency, individual bias
- clarity of research purpose/aim, objectives
- multiple observers, individual bias, intra- and inter-observer/interviewer reliability
- where possible, blind/double-blind procedures
- pilot study
- triangulation.

Personality and health

Some studies (for example, Rhodes, Smith, 2006) have previously shown that extraversion and conscientiousness are positively related to physical activity involvement, but neuroticism is negatively related. This makes sense because individuals who are more sociable or outgoing and more self-disciplined and achievement-oriented are more likely to exercise, but people who are depressed and anxious are less likely to exercise. However, as highlighted by Weinberg and Gould (2019), “similar to the relationship between personality measures and athletic involvement, these associations are relatively small and mostly correlational”. That is, few cause–effect relationships have been established.

Type A and type B personalities are two main categories of personality that are known to influence whether an individual acquires health-related problems like heart disease. Type A people tend to be highly competitive, self-critical and ambitious, and are often characterized as being impatient and aggressive. They are more prone to stress, exhibit a sense of urgency and are perceived as less patient than type B individuals. Type B individuals tend to be more tolerant, relaxed and reflective than type A, and they are often characterized as being laid back and living a stress-less life. They are generally perceived as being more patient and less stressed. They appear to be more content, more tolerant, more adaptable to change and less driven by time pressure than type A personalities (Hisam et al., 2014).

Type A individuals were found to be prone to developing coronary heart disease. However, more recent studies have shown that negative characteristics (including anger and hostility) were also associated with adverse cardiovascular health. A new personality type has been named as the type D distressed personality; however, research findings are equivocal on this. Some personality traits (for example, optimism, conscientiousness, openness to experience and curiosity) have been found to be protective factors against the development of coronary heart disease and therefore are called “cardioprotective” personality traits (Sahoo et al., 2018).

One of the primary reasons for studying personality and health is to understand ways to improve health and reduce mortality risk. Friedman and Kern (2014) reviewed the research literature on personality, well-being and health. They highlighted that the study of personality (an individual’s relatively stable predispositions and patterns of thinking, feeling and acting) and its relationships to well-being and health continues to be plagued by an over-reliance on self-report measures. Friedman and Kern concluded:

1. It is unproven that happiness is a direct cause of good health.
2. It is unproven that negative emotion, worry and depression are significant direct causes of disease.
3. It is unproven that challenging work in a demanding environment usually brings long-term health risks.
4. Individual strivings for accomplishment and persistent dedication to one’s career or community are often associated with sizeable health benefits.
5. Individuals who are conscientious (that is, prudent, dependable, well-organized and persistent) stay healthier, thrive and live longer.

General health is usually well reflected by longevity (lifespan) because the people who live the longest usually are not those who have been struggling with diabetes, cancer, heart disease and other chronic disorders. But measures that also directly consider the health-related quality of life (HRQOL), such as the number of years that one lives without significant impairment, are of increasing interest to researchers. Huang et al. (2018) examined relationships between personality characteristics and HRQOL. From the 76 studies included in their systematic review, they found greater extraversion, agreeableness, openness, conscientiousness, optimism, self-esteem, self-efficacy and sense of coherence were all related to better HRQOL, whereas greater neuroticism and type D personality were related to poorer HRQOL.

Nikčević et al. (2021) examined personality and health anxiety during the COVID-19 pandemic. They found that three personality traits (extraversion, agreeableness and conscientiousness) were negatively associated with health anxiety, suggesting that these personality traits have a protective effect against health anxiety. However, it is important to highlight that more caution is warranted before policymakers offer health recommendations based on short-term or correlational findings from personality, well-being and health studies, and to recognize the need for more longitudinal studies investigating how, when and why personality can affect health (and well-being).

ATL Research skills

Are exercise and increased levels of physical fitness associated with increases in self-esteem?

ATL Thinking skills

What does “prudent” mean in the context of personality, well-being and health?

ATL Thinking skills

Wilson (2019) reported that there is a growing consensus that personality plays an important role in a person’s typical physical activity level and their desire to engage in exercise. Do you think physical activity practices shape personality?

Conclusions about personality

The uncritical export of mainstream personality theory into sport and exercise psychology has been met with mixed success. As yet psychologists have not been able to identify personality characteristics, such as the “big five”, that directly influence sporting success. However, there is evidence that certain personality traits will aid us in environments that we perceive to be favourable; conversely, they may hinder us in less favourable circumstances.

Therefore, it is important that we are able to reflect on our performance and focus on aspects that can be improved. Targeted improvements can be made at a macro-level (“big five”) and a micro-level (performance profiling). A major reason for this is that the factors that combine to form our personalities are in part biological, psychological and social. These three factors are connected and their influence varies over time, sometimes affecting us subtly. However, during significant life events, their impact can be significant and long-lasting.

It is what we do with the attributes that we have—and those that we can develop—that defines how successful we will become. A major factor in determining how well we adapt and learn is self-efficacy. Importantly, the antecedents of self-efficacy have been determined and outlined. Psychologists need to be able to gather meaningful, reliable data to work from before they decide what antecedents of self-efficacy may increase an individual’s confidence towards learning.

So how should we view personality? Briefly, on the basis of the evidence discussed in the present chapter, we can conclude that personality is dynamic; it can be influenced by environmental factors and our own willingness to complete programmes that facilitate change. It is also relatively stable—but crucially, psychologists have developed techniques that enable us to approach difficult tasks with increased confidence, so individuals can shape their own destiny.

Practice questions

1. a. Outline ethical issues associated with the measurement of an athlete’s personality. (2 marks)
- b. Using an example, predict the effect of positive and negative emotions on performance. (3 marks)
2. Discuss how attitudes and behaviours in sport or exercise settings are linked to social learning theory. (4 marks)

Summary

- Personality is a relatively stable construct, which is important because other people need to predict how we will react to social circumstances.
 - However, our personalities are not completely fixed, which allows us to adapt to changes in our social circumstances.
 - Our personalities are influenced by our genetic traits and interactions with the environment in which we live.
 - The uncritical export of mainstream personality theory into sport and exercise psychology has met with mixed success.
 - The “big five” personality traits are openness, conscientiousness, extraversion, agreeableness and neuroticism.
 - The acronym LOTS makes it easy to remember the four categories of personality data collected: lifetime history, observations, tests and self-reported data.
- AHL**
- Social learning theory assumes that humans learn behaviour through observational learning, that is, learn by watching models and imitating their behaviour.
 - An important development of social learning theory is to include how people are motivated not only by role models but also by their own beliefs and previous experiences.
 - A major factor in determining how well we adapt and learn is self-efficacy. At certain times in our lives we need to learn new skills and adapt to different environments. In this regard, self-efficacy is a key attribute.
 - Personality can change over a long period of time. Sports psychologists need to be aware of the environment in which athletes are training and performing, and the effect that this may have.
 - As yet psychologists have not been able to identify particular personality traits that predict sporting success.

Check your understanding

After reading this chapter, you should be able to:

- give an overview of personality in sport and exercise settings, and why it is important
- define the term “personality”
- consider how personality is stable but not “fixed” and the importance of this for relationships
- discuss approaches to understanding personality and behaviour
- outline social learning theory
- understand the relationship between personality and behaviour in sport and exercise
- explain how personality can change over time.

AHL

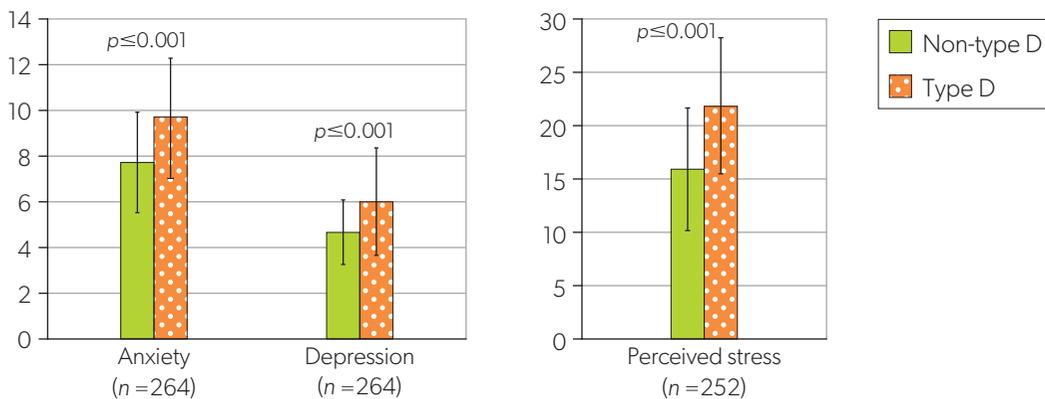
Self-study questions

1. Outline what the term *personality* means.
2. State the component parts of Lewin’s interactionist equation.
3. Distinguish between introversion and extraversion.
4. Using examples from sport, discuss how athletes possessing different levels of the “big five” dimensions will behave differently.
5. Explain how social learning theory can help our understanding of personality.



Data-based question

The type D personality (individuals who frequently experience negative emotions) was developed to identify cardiac patients at risk of developing emotional and interpersonal difficulties. A 2012 study of Icelandic cardiac patients used a questionnaire to investigate the relationship of type D personality with anxiety, depression, stress and health-related behaviour. Following analysis the cardiac patients were divided into two groups: type D and non-type D personality (do not frequently experience negative emotions). The differences in mean (\pm SD) anxiety, depression and perceived stress are shown in Figure 9 (lower scores = “less”). Additionally, the average prevalence of some health-related behaviour practices is shown in Table 2.



▲ Figure 9 Anxiety, depression and perceived stress scores according to personality type

▼ Table 2 Prevalence of health-related behaviour practices in relation to personality type

	Eat fruit and vegetables every day (%)	Smoke cigarettes (%)	Use anxiety-reducing medication regularly (%)
Type-D personality	70	17	15
Non type-D personality	81	8	11

Source: adapted from Svansdottir et al. (2012).

1. State which group had:
 - a. less depression (1 mark)
 - b. more perceived stress. (1 mark)
2. Distinguish between groups for health-related behaviour practices. (3 marks)
3. Discuss social learning theory and personality. (5 marks)



C.1.2 Mental toughness

Syllabus understandings

C.1.2.1 Mental toughness is an aspect of personality that partly explains how individuals manage challenging and pressurized situations.

AHL

C.1.2.2 The theory of the “self-fulfilling prophecy” in sporting success suggests that a sportsperson’s perceived self-confidence results in greater persistence and effort, leading to an increased probability of eventual success.

C.1.2.3 Mental toughness is positively associated with better health outcomes, including fewer depressive symptoms, fewer burnout symptoms and improved sleep quality.

C.1.2.4 Attribution theory illustrates how the locus of control and stability can impact subsequent confidence.

Introduction

In recent years, there has been an increased awareness of the psychological factors involved in high performance. Mental toughness has been frequently associated with success in a wide variety of activities: academic achievements, career success, military rank and sports, to name a few.



▲ Figure 1 To complete the Vendée Arctique solo race, you need mental toughness

What is mental toughness?

An athlete’s success or failure depends on many factors including physical, tactical, technical and psychological factors. The psychological factor is often the factor that differentiates winners in sports.

Mental toughness is a disposition that is influential in sporting success. Both athletes and coaches refer to mental toughness as one of the most important psychological characteristics related to outcomes and success in elite sport.

Research has concluded mental toughness to be an important factor for high-performance success in sports including: mixed martial arts, soccer, tennis, hockey, Australian football, cricket, rugby league and endurance athletes.

Mental toughness components are higher in individuals who are able to endure physical exertion for longer periods. For example, ultra-endurance events have been described as prolonged periods of physical activity covering a greater distance than the standard marathon (42.195 km) or lasting more than 6 hours. Ultra-endurance events that are solely completed on foot are generally termed ultra-marathon events. These range from about 50 to 100 km (or more) and often involve challenging terrain. Examples include the Hawaiian Ultra Running Trail (161 km), Badwater 135 (217 km) and the 6693 Arctic Ultra (566 km).



▲ Figure 2 Runners in the Badwater 135 ultra-marathon

A recent study (Brace et al., 2020) of 56 elite ultra-marathon runners suggested there was a threshold of mental toughness that performers require to be of the standard needed to be able to prepare for and compete in elite ultra-marathon events. Once this mental toughness threshold is met, other factors are likely to be more influential in determining elite-level ultra-marathon performance.

The concept of mental toughness was promoted by Loehr in 1982, building on work by Cattell et al. three decades earlier. Loehr suggested that “tough-mindedness” was an aspect of personality.

A recent study (McAuley et al., 2022) examined genetic associations with personality and the mental toughness profiles of English academy football (soccer) players (mean age 14 years). Findings suggested that the mental toughness and personality profiles of academy footballers may be partly determined by genetic factors.

The term mental toughness attempts to explain how individuals manage challenging and pressurized situations. It is considered to be partly determined by inherited characteristics, and partly by learning, experience and the environment.

Despite the popularity of the term mental toughness, there remains a lack of consensus on the definition or conceptualization of the term. This may be because mental toughness is multidimensional and can be considered an umbrella term (a term used to unite related concepts). There is a strong overlap with other related terms, such as “hardiness”, “coping skills”, “optimism” and “resilience”.

Jones et al. (2002) identified key attributes of mental toughness, including:

- self-belief
- determination

- resilience
- handling pressure
- coping skills
- remaining focused
- persistence.

ATL Thinking skills

- Does hardiness capture the unique nature of the physical and mental demands of competitive sport?
- Are mental toughness, coping skills and performance outcome related?
- Do more optimistic individuals exhibit increased effort to achieve their sporting goals?
- Are being able to “bounce back” from setbacks, handle failure and overcome adversity with determination all attributes associated with resilience **and** mental toughness?
- Resilience or mental toughness—which one is “thriving on the experience and excelling despite adversity” and which one is “returning to normal functioning”?

Mental toughness appears to be multidimensional. It is often associated with:

- unshakeable self-belief
- the ability to rebound after failures (resilience)
- persistence or refusal to quit
- coping effectively with adversity and pressure
- retaining concentration in the face of potential distractions.

The term mental toughness is attractive because it is a “catch-all” concept that can be used to develop elite performers. However, the individual factors that determine success are likely to be much more nuanced. Still, a recent systematic review concluded that research into mental toughness and performance has consistently shown that better performances are associated with higher levels of mental toughness.

TOK

It is important to consider the validity of experimental results when reading scientific findings. Validity refers to how accurately a construct has been measured during a scientific experiment. It is often dependent on how well a measurement scale reflects the construct it is designed to evaluate.

A lack of a clear consensus on the construct mental toughness has resulted in a variety of definitions and measurement scales. Some are unilateral, some contain multiple facets.

- What does it mean for scientific experiments measuring constructs when there are multiple understandings of the construct?





- How can you test theories about the relationship between two constructs (such as mental toughness and mindfulness) if there is a lack of clarity on the construct itself?

As with many social science constructs, there is an element of imprecision and ambiguity. So, it is important to consider questions of construct validity.



Activity 1

Do the following help to define mental toughness?

- Control—ability to handle many things at once.
- Commitment—being deeply involved with pursuing goals despite difficulties.
- Challenge—thriving in constantly changing environments.
- Confidence—maintaining self-belief despite setbacks.

Mental toughness and perceived control

Mental toughness is widely used to describe athletes who perform in pressurized circumstances. Although it may seem clear what mental toughness means, no consensus has been reached regarding its conceptualization (Thom et al., 2021). It is believed that mentally tough performers are disciplined thinkers who respond to pressure in ways that enable them to remain relaxed, calm and energized simply because of the ability to sustain positive energy flow despite adversity. Athletes strive to understand, interpret, anticipate and control their world in order to deal effectively with it. **Perceived control** reflects a tendency to feel and act as if one is influential. Mental toughness is multidimensional and includes having the natural or developed psychological edge that enables athletes to:

- cope better than their opponents with the many demands of sports (competition, training, lifestyle)
- be more consistent and better than their opponents in staying determined, focused, confident and in control under pressure.

Mental toughness and commitment

Commitment can be thought of as “stickability”, reflecting the ability to carry out tasks successfully, despite problems or obstacles. Committed individuals are less likely to give up in pressurized situations, such as a cup final. Clough et al. (2002) proposed that commitment, control, challenge and confidence represent the 4Cs model of mental toughness.

Commitment concerns deep goal involvement. For example, the commitment component has been shown to be positively associated with academic achievement (Crust et al., 2014). Mentally tough individuals are highly committed to whatever they are doing, so it is therefore likely that mentally tough students would have high levels of attendance and put a lot of effort into coursework and preparation for examinations.

Dagnall et al. (2021) investigated the use of mental toughness in elite athletes to counter negative psychological effects arising from COVID-19. They reported that athletes scoring low on commitment will be prone to distractions and accordingly find it difficult to complete tasks including exercise and training routines. In

agreement with others (for example, Leyton-Romain et al., 2021) they stated that coaches could increase levels of commitment by encouraging athletes to focus on their enjoyment and love of the sport, as well as achievable goal setting.

Mental toughness and challenge

In the context of mental toughness, **challenge** relates to the extent to which challenges are seen as opportunities. For example, based on the conceptualization of mental toughness, athletes high in mental toughness would perceive a stressful event, such as competing against a badminton player they have never previously beaten before, as a challenge. That is, they see it as something that can be influenced and acted upon, and they see themselves as capable of doing so. A mentally tough athlete will view this stressor as a challenge they actively want to deal with and be determined and focused to achieve optimal performance.

Research seems to support the importance of exposure to adversity. For example, Sarkar et al. (2015) explored the beneficial effect of adversity with 10 Olympic gold medallists. In their study, the Olympic champions suggested that adverse experiences were used to fuel the athletes' future effort and application.

Powell and Myers (2017) examined mental toughness in relation to Paralympic athletes. The athletes reported that challenge was readily accepted and was interpreted as a positive opportunity rather than a threat. This is reflected in the following quotes from two of the Paralympic athletes:

... mental toughness is the challenge of everyday life, so for me it is freedom and independence and it is something I do not need help doing ... mental toughness is in everyday life, if you compare me pushing my chair, if I stood up and walked through that door it would take 300 times more energy than an abled bodied person so actually for me it is trying to balance the fact that I am constantly tired from what I have to do.

... trying to overcome the challenges in the sport, I think it prepares you better for everyday life ...

Mental toughness and confidence

There is a positive and significant relationship between mental toughness and sports confidence, which suggests that mental toughness contributes to the development of **confidence** in athletes. Mentally tough athletes view adversity as a challenge, have lower anxiety and respond positively to pressure in ways that can contribute to their confidence.

In summary, mental toughness can develop athletes' confidence because mentally tough athletes are more likely to have effective responses to stress and pressure, which can, in turn, build their confidence.

Mental toughness and resilience

Mental toughness and **resilience** share similarities in that both concepts promote positive adaptation in the face of adversity. Mentally tough athletes are more likely to have effective responses to stress, which can contribute to their resilience. Resilience is positively associated with sport achievement and psychological well-being, which suggests that resilient athletes are more likely to perform well and have better mental health. Mentally tough athletes can excel under pressure, which is a key component of resilience. To conclude, mental toughness increases your resilience.

Developing mental toughness

The development of mental toughness in sports is often understood through traditional **psychological skills training (PST)**. However, this section will also consider how the development of mental toughness could be understood through more contemporary **mindfulness** and **self-compassion training**.

Mindfulness training has been shown to increase mental toughness and well-being in athletes—through enhanced confidence in their ability to overcome challenges and achieve emotional control (Ajilchi et al., 2022). Mindfulness training has also been shown to improve attention (Mardon et al., 2016) and cognitive flexibility (Cooper et al., 2020) in performance settings—both of which contribute to mental toughness.

Similarly, self-compassion has been shown to be critical to the development of mental toughness (Wilson et al., 2019). Although these constructs have previously been thought to be “incompatible” (for example, self-criticism versus self-kindness), recent research has established that they share similarities. For example, both assist in coping with sport-related difficulties, and both are used by athletes to manage stress, focus attention, regulate thoughts and emotions, and persevere despite setbacks (Wilson et al., 2019). Additionally, both can be considered as sets of psychological skills that are somewhat learned, and somewhat innate.

Self-compassion is conceptualized as containing three core components (Neff, 2003):

- kindness (versus self-judgement)
- common humanity (versus isolation)
- mindfulness (versus over-identification).

The kindness aspect includes optimism and self-belief, whereas the mindfulness aspect is closely related to attention and concentration, which are essential components of mental toughness (Wilson et al., 2019).

Importantly, mindfulness has been promoted as a way of developing and maintaining both mental toughness and self-compassion, and when used together in a complementary balance could create the optimal mindset for sporting success (Wilson et al., 2019; Stamatis et al., 2020; Ajilchi et al., 2022). Commonly used methods of mindfulness training for enhancing performance are the Mindfulness-Acceptance-Commitment (MAC) approach, and the Mindful Sport Performance Enhancement (MSPE) approach. There are also specific ways of training self-compassion—such as the Mindful Self-Compassion approach (Neff, Germer, 2018).

What is PST?

PST is a change-based approach to improving performance. The intention is to provide the athlete with strategies to reduce, avoid or control their state of mind. Traditional PST interventions have sought to attain an optimum internal state, through evoking certain thoughts and emotions and avoiding others. This is in contrast with mindfulness-based approaches (covered later in this chapter), which offer a rather different perspective. A commonly used technique in PST is imagery, which can be used to support self-confidence, emotional control, or coping with pain and injury. Other commonly used methods include goal setting, self-talk and arousal regulation.

How does PST support mental toughness?

As we have seen, the concept of mental toughness includes many aspects of psychological skill (self-belief, determination, handling pressure, coping skills, remaining focused and persistence). Thus, the development of PST is likely to contribute to an individual's overall level of mental toughness. The required set of psychological skills that need to be developed will be individual-specific, depending on the characteristics of the athlete and the task demands of the sport. Recent developments have included self-regulation training, which provides a framework for developing coping skills beyond traditional PST to include self-monitoring and self-evaluation (Richards, 2011).

ATL Thinking skills

Why are we obsessed with mental toughness? There is no consensus definition of mental toughness, but there is something there—that is, we are mentally tough about mental toughness and keep at it, believing in it. In attempting to understand the achievements of elite performers, we look for explanations. One obvious feature is the mental qualities they possess. However, for everyday conversations, complex explanations are no good—we need a single concept, like mental toughness, that encapsulates everything about the performers' characteristics. Mental toughness is attractive because it offers the idea of a potential panacea. In other words, if we know what this thing is we can cultivate it to develop elite performers. Are elite champions mentally tougher than the others?

What is mindfulness?

We experience the world through our mind. The mind is capable of amazing things—but it can also make things difficult for us. Evolution has prioritized our survival over our contentment. This means that we have become very good at noticing what is wrong (judgement) or what might go wrong (fear). We often have what is called a “negativity bias”, which means we hold onto our negative experiences more than we do our positive experiences. As a species, we have become very good at worrying, regretting and catastrophizing—in fact, we are genetically predisposed to these negative tendencies!

In sport, this means we can be very aware of external threats (such as the opposition, spectators, judges or the environment). This sense of threat can also be triggered by our internal worries (such as fear of failure, or inability to cope under pressure).

Another aspect of our survival legacy is that we have become very good at thinking about the past (learning from experience) and thinking about the future (for example, anticipating or planning). This means we're not so good at being “in the present”. For example, a golfer may be thinking about a past mistake (such as a missed putt on the previous hole) or a potential future mistake (such as a missed putt on the next hole).

Mindfulness is “paying attention in a particular way: on purpose, in the present moment, and non-judgmentally” (Kabat-Zinn, 1994). It is the “awareness” that comes from paying attention. An abbreviated definition of mindfulness would be: “present moment awareness”.

Mindfulness has its roots in ancient philosophical traditions, such as Buddhism, which originated in India and developed across Asia. Meditation is often used as

a technique to develop the state and skill of mindfulness. We can use mindfulness “practices” to train ourselves to become more aware of the present moment. This approach to performance enhancement brings together contemporary psychological science with ancient psychology and wisdom.

Mindfulness training uses certain key practical features—these are the specific “practices” that help to cultivate mindfulness. There are both “formal” meditation practices (such as the body scan, mindful movement, sitting meditation and breathing space meditation) and “informal” practices, which include mindfulness in everyday life (routine activities, such as brushing your teeth or washing the dishes) and offer small opportunities to practise staying in the present moment.



Activity 2

The difference between thinking and feeling/experiencing

As you read this, bring your attention down to your feet. Often at this point we conjure up an image of our feet in our mind or we look down at our feet. Is this the case for you? In which case, you are simply *thinking* about your feet.

Now, let’s try something a little different. Imagine if you were to dive into a pool of water, you are immersed by the water and can feel the physicality of the water on your body. Now, read the following guidance. Then put down the book and give it a go:

It’s like you are placing your feet in a bath of awareness. Surrounded by this awareness, observe the physicality, or “felt” sensations on and in the feet from the inside out. Perhaps noticing the temperature, any stillness or movement in progress, any tingling, lack of sensation, any contact points with socks and the floor, or maybe you are noticing any impulses to wiggle the toes or urges to move things. Whatever you notice, there is no need to change anything.

This is *feeling/experiencing* our feet, rather than simply thinking about our feet. We are paying attention in a particular way, on purpose in the present moment, and non-judgementally.

Mindfulness and performance

To be mindfully absorbed in a task (focused on the present moment and non-judging) is essential for performance. It resonates with other ideas about peak performance such as flow (Csikszentmihalyi, 1975) and ideal performance states (Gould, Udry, 1994). Mindfulness is a state that promotes automatic, task-focused, intentional behaviour. Well-learned skills are allowed to occur in a seemingly effortless manner.

The Integrative Model of Human Performance (Gardner, Moore, 2007) explains the role of mindfulness in performance. Functional performance involves non-judging, mindful absorption in the task. In contrast, dysfunctional performance involves inflexible rules, self-doubt, efforts to control the mind and attention on the potential ramifications of failure.

Mindfulness is an acceptance-based approach to performance enhancement—rather than trying to “avoid” our experience by changing, controlling or fixing, it teaches us to be with and “accept” our experience no matter what it may be. Note: acceptance is not the same as resignation. Experiential acceptance allows for skilful responding to the present moment, whereas experiential avoidance can lead to habitual reactivity.

Mindfulness and acceptance-based approaches have shown efficacy within and outside of sport—not only do they enhance and maintain performance, but they also increase well-being and general life functioning (Gardner, Moore, 2017). There are now several systematic reviews and meta-analyses (such as Verhaeghen, 2020) on the efficacy of mindfulness-based interventions for enhanced athletic performance. There is still a need for more methodologically rigorous trials—but there is preliminary support for the efficacy of mindfulness-based performance enhancement strategies.

How can mindfulness support mental toughness?

The introduction of mindfulness and acceptance-based approaches has triggered a new wave of training approaches. These approaches seek to stimulate a “modified relationship” with thoughts, feelings and emotions, rather than attempting to “alter” these experiences—which is in contrast with traditional control-based PST (Gardner, Moore, 2017). Trying to control our state of mind may briefly succeed, but it can increase self-focus, preoccupation with reducing unpleasant experiences and scanning for discomfort.

Rather than having to reach a particular “state” to perform well, mindfulness approaches promote psychological “flexibility”. So, it is not the presence or absence of negative cognitions/emotions that is important, but the degree to which the performer can accept these and remain engaged. Indeed, Gardner and Moore (2007) define mental toughness as “the ability to act in a purposeful manner, systematically and consistently, in the pursuit of the values that underlie performance activities, even (and especially) when faced with strong emotions that we as humans naturally want to control, eliminate, or reduce”. Mindfulness-based approaches promote the reduction of efforts to control internal experiences, positively influence the experience of emotion, teach metacognitive awareness and promote attentional focus onto performance-related stimuli—all of which can be considered as fundamental to mental toughness. In particular, mindfulness has been shown to enhance attention and emotion regulation and to reduce stress. It has also been suggested that a tendency towards mindfulness may be associated with higher mental toughness (Ajilchi et al., 2022).

Mental toughness and self-compassion

Mental toughness has been associated with successful performance in stressful and competitive environments. Findings suggest athletes can benefit from mental toughness (Stamatis et al., 2020). However, mental toughness has also been associated with less-adaptive characteristics, such as self-criticism, harshness and self-judgement (Wilson et al., 2019). The relationship between mental toughness and mental health is still unclear. Whereas some (such as Bauman, 2016) have suggested the terms are contradictory in elite sport, others (such as Gucciardi et al., 2017) suggest mental toughness can be associated with positive mental health outcomes. Stamatis et al. (2020) report that mental toughness has been associated positively with motivation, self-efficacy, thriving, sleep quality and psychological well-being, and negatively with stress and depression.

Overall, findings suggest that mental toughness may be beneficial. But there may be some negative aspects. Mental toughness has been associated with harsh self-criticalness, self-judgement and stubbornness. For example, stubborn persistence through injury is not always conducive to adaptive outcomes

ATL Thinking skills

Roger Federer, the tennis legend, has highlighted the importance of mental toughness in reaching his top performance. But is there a dark side to mental toughness?

Is there a culture in certain sports (such as ultra-endurance) to push through pain and compete with injuries? What might be the consequences of this?

Does mental toughness in athletes cause them to avoid being seen as weak?

Do mentally tough athletes in certain sports avoid seeking mental health counselling?



▲ Figure 3 Roger Federer

(Johnson et al., 2023). While mental toughness has the potential to help athletes through injury, high levels have been associated with negative behaviours (such as non-adherence to recovery protocols) during rehabilitation (Levy et al., 2006).

Self-compassion has been proposed to help circumvent these potential pitfalls and complement the injury recovery process (Johnson et al., 2023). Self-compassion is a balanced, non-judgemental approach to relating to oneself when experiencing pain, inadequacy, suffering and failure. It is believed that self-compassion can enable an athlete to approach, embrace and move forward positively after setbacks.

Although mental toughness and self-compassion might seem at odds with one another, it seems that both can coexist to help athletes overcome setback experiences. A 2019 study (Wilson et al.) explored how elite athletes perceived and experienced mental toughness and self-compassion in their pursuit of athletic success. The athletes were two snowboarders, a swimmer, an ice skater, a downhill mountain biker, a trampolinist and a rock climber. All had competed at the Olympic Games or the World Championships.

Wilson et al. found that mental toughness and self-compassion are compatible. Both can create an optimal mindset for coping with setbacks in sport and achieving success. Mental toughness was used to persevere through difficult training/competitions, while self-compassion helped the athletes to cope after setbacks.

This perspective represents a wider understanding in recent literature and research—that the constructs of mental toughness and self-compassion are compatible and can be used in a complementary way to create and balance optimal mindsets for success. Indeed, some have suggested that best practice in working towards optimal mental health in athletes should include training in both mental toughness and self-compassion skills (Stamatis et al., 2020).



Linking question

Is there a relationship between mental toughness and self-compassion in athletes experiencing sports injury? (B.3.2)

Sport injury is an issue for competitive athletes. Around 9 out of 10 athletes experience an injury in their athletic career. Athletes experiencing injury may struggle to find methods to cope with this setback effectively. Finding ways to help athletes cope with injury is important. Mental toughness and self-compassion have the potential to help athletes through their injury experience.

Consider:

- whether athletes with high levels of mental toughness have difficulty withdrawing from training and competition when injured
- the consequences of some injured athletes believing that being mentally tough equates with self-sacrifice
- whether injured athletes use self-compassion as a resource to help them work through an injury with patience (and kindness) rather than being overwhelmed with frustration and anger
- if it is an advantage for an athlete to be able to access mental toughness and self-compassion when experiencing injury.



▲ Figure 4 Around 9 out of 10 athletes experience an injury in their career

ATL Thinking skills

Think about a setback or disappointment you experienced recently. Maybe in the sport you practise, such as an injury, losing a game or not being selected for a team.

On a scale of 1–5 (where 1 = not at all, 5 = extremely), how compassionate were you towards yourself?

If you scored low, was this a helpful response to your setback? Did it help you bounce back quickly? How was it helpful?

If you scored high, was this a helpful response to your setback? How?

Self-compassion and mental toughness appear to be two contradictory concepts. However, recent literature (such as Wilson et al., 2019) suggests they are compatible. Can athletes be tough yet compassionate towards themselves? Are there some situations where self-compassion might be more helpful than being mentally tough?

Measuring mental toughness

Lack of consensus on the definition of mental toughness makes it difficult to measure. It is made up of lots of different constructs, such as self-belief, resilience and coping skills. An attempt was made by Clough et al. (2002) to develop a Mental Toughness Questionnaire (MTQ48) based on the hardiness subcomponents (control, challenge and commitment) plus confidence. As Richards (2011) suggested, this is a little confusing since the questionnaire is mainly based on the hardiness construct.

Other questionnaires include the Sports Mental Toughness Questionnaire (SMTQ; Sheard et al., 2009) and the Mental Toughness Index (MTI; Gucciardi et al., 2015). Each of these questionnaires is used to determine athletes' mental toughness levels using Likert scales. As mental toughness is difficult to observe, it requires self-report assessment. A recent review (Farnsworth et al., 2022) of mental toughness measures recommended that more studies are needed to investigate the reliability of mental toughness measures to determine their stability over time.

Limitations of self-report assessment for mental toughness

There are limitations with self-reporting, such as the possibility of self-presentation (wanting to give a good impression). There are also biases, such as expectancy effects (giving the answers you think are wanted). However, psychometric tools are commonly used in studies of psychological constructs, and authors are required to publish reliability scores.

It is important to note the difference between “traits” and “states”. In other words, the extent to which a characteristic is stable and trait-like versus the extent to which it is **malleable** and can be influenced by training. Another take on this is that “states can become traits”—thus the development of certain states over time (for example, level of anxiety, ability to be in the present moment) means that these states can become more trait-like. This reminds us that mental toughness can be difficult to observe when based on self-report assessment. The same is true for questionnaires that measure psychological skills, mindfulness and self-compassion, all of which have been shown to be relevant in understanding mental toughness.

Key term

Malleable Able to be changed.

Activity 3

The MTI

Find out and compare your mental toughness using the MTI. The MTI is an eight-item measure that instructs participants to indicate how they typically think, feel and behave as an athlete using a seven-point Likert scale ranging from one (false, 100% of the time) to seven (true, 100% of the time). The sum of the eight items yields a mental toughness score, with higher scores indicating higher mental toughness.

Instructions: Using the scale below, indicate how true each of the following statements is as a description of how you typically think, feel and behave as an athlete—*remember, there are no right or wrong answers so be as honest as possible.*

▼ Table 1 Likert scale

1	2	3	4	5	6	7
False, 100% of the time						True, 100% of the time

▼ Table 2 The MTI

1	I believe in my ability to achieve my goals	1	2	3	4	5	6	7
2	I am able to regulate my focus when performing tasks	1	2	3	4	5	6	7
3	I am able to use my emotions to perform the way I want to	1	2	3	4	5	6	7
4	I strive for continued success	1	2	3	4	5	6	7
5	I execute my knowledge of what is required to achieve my goals	1	2	3	4	5	6	7
6	I consistently overcome adversity	1	2	3	4	5	6	7
7	I am able to execute appropriate skills or knowledge when challenged	1	2	3	4	5	6	7
8	I can find a positive in most situations	1	2	3	4	5	6	7

Source: Gucciardi et al. (2015).

Linking question

How do mentally tough individuals cope with stress? (C.4.2)

Consider:

- mental toughness is partly determined by inherited characteristics, and partly by learning, experience and the environment
- individual characteristics and the task demands of the sport
- explicit use of real-life challenges to teach and embed coping skills
- developing mental resilience in athletes through the experiences coaches set up in their development environments



- positive association of mental toughness with motivation, self-efficacy, thriving, sleep quality and psychological well-being
- negative association of mental toughness with stress and depression.



Linking question

How can utilizing single- and double-blind experiments support causal claims of how mental toughness affects coping with stress? (Inquiry 1)

Consider:

- if blinding participants and researchers will help eliminate bias that could influence the results
- the distinction between single-blinded experiments and double-blinded experiments
- use of a control group
- random assignment of participants to the tested group or the control group
- controlling variables and causality
- replicability, reliability of the findings and confidence in causal claims.

ATL Thinking skills

Research design, mental toughness and coping with stress

In a single-blinded experiment, the participants do not know whether they are in the group being tested or the control group. The group being tested would receive some training or treatment to enhance their mental toughness, while the control group would not receive any special training. Both groups would then face a stressful situation, and their reactions would be observed and compared.

The reason we keep the participants unaware of which group they are in is to avoid bias. If they *knew* they were being tested, they might try to act differently or give answers that they thought the researchers wanted to hear. By keeping it “blinded” (a secret), we get more accurate results.

In a double-blinded experiment, neither the participants nor the researchers know which group is which. This is done by randomly assigning participants to either the tested group or the control group. There are various ways this can be done, such as using a random number generator.

Random assignment helps ensure the validity and reliability of the experiment by minimizing the impact of confounding variables and potential biases. Therefore, the researchers conducting the experiment are “blinded” because they do not know who received the training and who did not. This helps eliminate any bias or influence from the researchers’ expectations.

Self-confidence as a self-fulfilling prophecy

The term “self-fulfilling prophecy” was coined in 1948 by Robert Merton, although others had previously explored the concept. Self-fulfilling prophecy is a concept that suggests our beliefs and expectations about ourselves or others can

actually influence the outcomes we experience. When you have a strong belief in your abilities and feel confident about your skills, you are more likely to take on challenges and persist in your efforts. This belief creates a positive mindset that fuels your motivation to succeed.

When you perceive yourself as confident, you are more likely to persist in the face of obstacles or setbacks. Instead of giving up easily, you will put in more effort and try different strategies to overcome the challenges you encounter. This persistence stems from your belief that you have what it takes to achieve your goals. Perceived confidence leads to a willingness to put in extra effort because you believe that your actions will make a difference. You are more likely to work harder and practise longer. This increased effort is driven by the belief that your hard work will pay off. By persisting and putting in greater effort, you improve your chances of eventually achieving success. Your confidence pushes you to keep going, learn from your mistakes and adapt your approach as needed. This continuous effort and determination increase the likelihood that you will reach your desired outcome. Therefore, the self-fulfilling prophecy suggests that perceiving yourself as confident leads to greater persistence and effort. This, in turn, increases the probability of eventual success because you are more motivated to overcome challenges and work towards your goals.



▲ Figure 5 A positive self-fulfilling prophecy

Overcoming a negative self-fulfilling prophecy: confidence and belief

When you expect something to go wrong, you are creating a negative self-fulfilling prophecy: expecting something to happen actually helps cause it to happen. This phenomenon is common in both competitive sport and exercise programmes. There can be a vicious cycle of negative fulfilling prophecies in which expectation of failure leads to actual failure. This lowers self-image, which in turn increases expectations of future failure. Refer also to the section on learned helplessness later in this chapter.

The good news is that athletes can overcome a negative self-fulfilling prophecy. Self-confidence is key to this. There are several types of self-confidence, including:

- confidence about one's ability to execute physical skills (such as run a sub 4-minute mile)
- confidence about one's ability to use psychological skills (such as imagery)



▲ Figure 6 A negative self-fulfilling prophecy

- confidence about one's ability to use perceptual skills (such as decision-making)
- confidence in one's level of mental and physical fitness, and training status
- confidence in one's learning/improvement potential
- belief in one's ability to achieve (both winning and improved performance)
- belief in one's superiority over the opposition.

Elite athletes have strong belief in their abilities. This is consistent with the importance of self-belief in the context of mental toughness.

Self-confidence can help athletes:

- arouse positive emotions (for example, remain calm and relaxed when under pressure)
- facilitate concentration (for example, effective attentional focus on the task at hand)

- set challenging goals that push them to their limits
- increase effort, particularly in sports that require persistence (for example, experiencing mental fatigue while playing a three-hour tennis match in the heat)
- focus on their strategy (playing to win rather than playing to not lose)
- maintain momentum (view situations in which things are going against you as challenges and react with even more determination).

The outlined benefits of self-confidence are important because confidence affects performance. In other words, there is a positive relationship between confidence and performance.

Learned helplessness

Learned helplessness is an acquired condition in which an individual perceives that their actions have no effect on the desired outcome of the task or skill. The individual feels doomed to failure and believes that nothing can be done about it.

Imagine you have a friend named Felix. Felix likes playing basketball but has had some bad experiences on the basketball court. Every time Felix plays, they seem to lose or make mistakes. After a while, Felix starts to believe that they can never win or improve, no matter how hard they try. This is called learned helplessness.

For Felix, it is like feeling stuck in a situation where they think there is no way to make things better. In Felix's case, they feel like no matter how much they practise or try their best, they will never win a basketball game.

This lack of perceived control affects their future because it makes them stop trying or putting in effort. Felix might think, "What's the point of practising basketball? I'll never win anyway." So they give up easily, do not try their best, and might even avoid playing basketball altogether.

But learned helplessness is just a feeling. It is not the actual truth. In reality, Felix might have the potential to get better at basketball and win games. It is their belief that they have no control that holds them back.

ATL Thinking skills

Most coaches consider sport to be at least 50% mental when competing against an opponent of similar ability. Do you agree or disagree? Why?



▲ **Figure 7** Learned helplessness: “What’s the point of practising basketball? I’ll never win anyway.”

The good news is that people can change their mindset and overcome learned helplessness. By realizing that they have the power to improve and that their efforts can make a difference, they can regain control over their future. It is all about believing in yourself and understanding that even if things are tough now, they can get better with time, practice and perseverance.

There are several ways that coaches, teachers and others (such as parents and exercise leaders) can help to prevent (or rectify) learned helplessness states. For example, setting task goals (individual-specific mastery goals) and downplaying ego goals. It is also important to be conscious of the attributions made while giving feedback because this can influence a performer’s interpretations of performance success—and future motivation. Compare the following two contrasting types of feedback from a physical education (PE) teacher to a student in a volleyball lesson:

1. “You did not set the ball correctly. Make sure you contact the ball above and in front of your forehead. Focus and you will get it with practice.”

The PE teacher not only conveys instructional information to the student but also informs them that they can accomplish the task—highlighting that persistence and effort will pay off.

2. “You did not set the ball correctly! You did not contact the ball above and in front of your forehead. Don’t worry though—I know soccer is your game, not volleyball.”

A well-meaning message—but one that informs the student that they will not be good at volleyball, so do not bother trying.

For optimal outcomes in learning and performance situations, the key is to emphasize task goals, focus on individual improvement and link attributions to individual goals.

Mental toughness, depressive symptoms, burnout and sleep

Mental toughness means having a strong and resilient mind. This is associated with better health and well-being in many ways. For example, when someone has mental toughness, they are better at dealing with feelings of being sad and depressed. They can bounce back quicker and find ways to feel happier again. So, athletes with mental toughness are less likely to feel sad for a long time and have fewer symptoms of depression.

Key point

Burnout is a plateau in performance as a result of overtraining accompanied by a decrease in motivation to train. Burnout is not just a physical state, it involves a psychological or emotional element as well. It can lead to a very talented and enthusiastic athlete giving up a sport altogether.

Burnout happens when we feel very tired, stressed and exhausted from doing too much. But athletes with mental toughness can control their situation better. For instance, they know when to take breaks to avoid burnout.

Sleep is important. It is a time for our bodies and minds to rest and recharge. Athletes with mental toughness have the ability to relax their mind and switch off before going to bed—they do not worry or think too much, which helps them fall asleep faster and have a good night's sleep. This is important because when we sleep well, we wake up feeling refreshed and ready for the day.

So, mental toughness can help individuals handle sad feelings, avoid getting overwhelmed and sleep well at night. It is all about having a strong and resilient mind that can bounce back from tough situations and knowing how to take care of themselves.

A study (Gerber et al., 2018) involving 197 young athletes in Switzerland investigated the effects of stress and mental toughness on burnout and depressive symptoms. The athletes were from a variety of sports: soccer, handball, volleyball, swimming, judo, track and field, tennis, hockey, karate, mountain biking and golf.

The percentage of athletes with clinically relevant levels of burnout and depressive symptoms was 12% and 9%, respectively. The researchers reported that, compared with participants with low mental toughness, those with higher mental toughness scores reported significantly fewer mental health issues when exposed to high stress. In other words, mental toughness offset some of the negative consequences resulting from high stress exposure.

Another study (Graham et al., 2021) of ultra-endurance athletes competing in a 120-mile, 3-day Arctic ultra-marathon examined the relationship between mental toughness and mood. A significant relationship was found between mental toughness and mood state. Higher mental toughness was associated with lower depression.

Another study (Haghighi, Gerber, 2019) examined the relationship between mental toughness and depression, burnout, anxiety and sleep in 2,007 university medical students (with no mental health issues). The key findings were that high levels of mental toughness were associated with lower stress perceptions, lower depressive symptoms, lower anxiety and burnout levels, and less frequent sleep complaints. Other studies (such as Li et al., 2020) have also found that mental toughness plays a significant role in decreasing sleep problems.



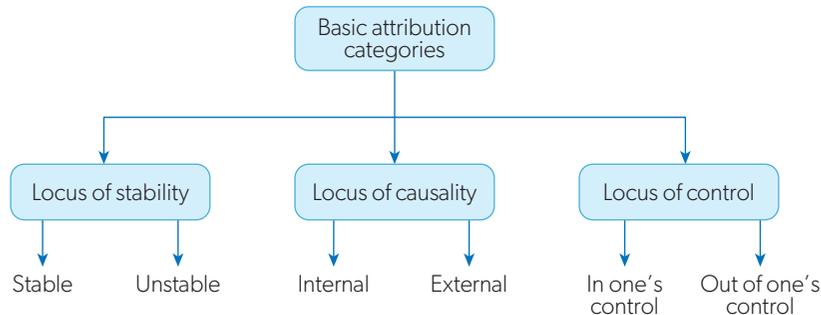
▲ Figure 8 Competitor on the Dempster Highway during the 6633 Arctic Ultra, 2018

Attribution theory

Attribution theory focuses on the reasons people use to explain their successes and failures. Information about the reasons for the outcome of an event affects the expectancy of future success and failure and also the feelings people experience, which, in turn, affects achievement behaviour.

Originally, Heider (1958) classified the attributions for success and failure into four categories: ability, effort, task difficulty and luck. However, Weiner (1985) identified that these attributions did not cover all possible reasons for success and failure. Consequently, Weiner provided a classification system that can be used for all possible attributions, not just the four that Heider originally proposed. These categories (Figure 9) are:

- locus of stability (stable or unstable)
- locus of causality (internal or external)
- locus of control (under control or not under our control).



▲ Figure 9 Weiner's attribution categories

Consider the following example.

A middle-distance runner could attribute winning or losing a race to:

- a stable factor such as ability, or an unstable factor such as luck
- an internal cause such as effort, or an external cause such as the quality of the opposition
- a factor they could control such as the race plan, or a factor out of their control such as the weather conditions.

Following a defeat, most people use external attributions and blame other factors (such as luck). But after a success, most people use internal reasons (such as effort or ability) to explain the outcome. This is known as the "self-serving bias".

If, however, an individual perceives that their failure is due to a lack of ability (which is both stable and internal) and that their actions have no effect on the outcome of the task (are out of their control), then a state of "learned helplessness" can exist. In this situation, the individual feels doomed to failure and feels that nothing can be done about it.

Attributions have an important effect on expectations of future success or failure and affect emotional reactions. Attributing performance to stable, internal factors has been linked to pride and expectations of future success.

Using the example of the middle-distance runner again: if the athlete attributes their performance success to an internal cause (such as the training programme),

they are more likely to feel pride and expect the outcome to occur again in the future. This in turn is likely to influence their future achievement motivation and to motivate them to continue to train hard.

How attribution theory can impact an athlete's confidence

When competing there are two important things that affect how confident you feel about winning: locus of control and stability.

If an athlete believes they have won because of things they did, such as practising or trying hard, then they have an internal locus of control. This means the athlete thinks they have control over what happens to them.

But if an athlete thinks they have won because of things outside of their control (such as luck or the competition being easy), then they have an external locus of control. This means the athlete believes that things happen to them without much control on their part.

Stability is about how an athlete thinks about the future. If they believe that winning the competition was something that will always happen because they are really good at it, then they think it is a stable factor. This means the athlete expects to keep winning in the future.

But if the athlete thinks that winning was just a lucky one-time thing and that it might not happen again, then they think it is an unstable factor. This means they do not expect to win all the time.

Therefore, if an athlete believes that they won the competition because of their own effort and skill (internal locus of control) and that winning will happen again in the future (stable), they will feel more confident. However, if an athlete thinks that winning was just luck (external locus of control) and that it might not happen again (unstable), they might not feel as confident. So, attribution theory shows that how you explain why things happen can affect how confident you feel about yourself. When you think that you have control and that good things will keep happening, you will feel more confident.

Key point

Attribution theory looks at whether an athlete puts their successes or failures down to luck, skill, the circumstances on the day or other factors.

Weiner (1985) established an interesting link between attribution theory and need achievement theory. It seems that individuals with a high need to achieve attribute their success to internal causes of ability and effort and their failure to lack of effort, whereas low need achievers attribute their failure to external factors and in some cases to a lack of ability.

Despite the logic and appeal of attribution theory, its popularity has decreased. It has been criticized on the basis that, although it may be useful in telling us why things go wrong, it does not tell us how to put them right, as well as for its lack of application to sport. It has also been criticized for focusing on why people expect to succeed, but not on why they want to succeed (Dweck, Elliott, 1983).



Linking question

Do mentally tough performers last longer on a maximal test after they reach their theoretical maximum? (A.2.3, A.3.1)

Consider:

- if mental toughness can explain how individuals manage challenging and pressurized situations
- self-belief, determination, resilience, handling pressure, coping skills, remaining focused and persistence
- if better performances are associated with higher levels of mental toughness
- if stubborn persistence (for example, through injury or pain) is conducive to lasting longer on a maximal test
- if there is a dual role for mental toughness and self-compassion to create the optimal mindset for lasting longer on a maximal test.



Linking question

How can the strength of relationships between mental toughness and performance in maximal physiological tests be determined?

(A.2.3, A.3.1)

Consider:

- whether the lack of consensus on the conceptualization of the umbrella term mental toughness makes it difficult to measure
- mental toughness is difficult to observe (it requires self-report assessment)
- limitations with self-report (such as self-presentation, and biases such as expectancy effects)
- the dichotomy between traits versus states
- if relationships measured by correlation show cause.

Practice questions

1. Discuss why mental toughness and mental health might be seen as contradictory in elite sport. (4 marks)
2. Outline two reasons why it is important for sports coaches to understand that expectation of failure can bring about a self-fulfilling prophecy in athletes. (2 marks)

Summary

- Mental toughness has frequently been associated with success in a wide variety of activities.
- Athletes' success or failure depends on the combination of many factors including physical, tactical, technical and psychological factors.
- The psychological factor is usually the determinant for the winners in sports.
- The term mental toughness attempts to explain how individuals manage challenging and pressurized situations.
- Mental toughness is considered to be partly determined by inherited characteristics, and partly by learning, experience and the environment.
- Mental toughness is often associated with unshakeable self-belief, the ability to rebound after failures (resilience), persistence or refusal to quit, coping effectively with adversity and pressure, and retaining concentration in the face of potential distractions.
- Better performances are associated with higher levels of mental toughness.
- Mental toughness can be developed through techniques including psychological skills training (PST) and mindfulness.
- Mental toughness and self-compassion can coexist to help athletes overcome setback experiences.
- Perceived confidence leads to increased probability of eventual success.
- There are ways that the learned helplessness state can be overcome.
- Mental toughness is positively associated with better health outcomes.
- Attribution theory shows that how you explain why things happen can affect how confident you feel about yourself.

AHL

Check your understanding

After reading this chapter, you should be able to:

- discuss characteristics of mental toughness
- outline how psychological skills training can help develop mental toughness
- understand the relationship between mental toughness and self-compassion
- be aware of ways of measuring mental toughness
- outline how self-confidence can function as a "self-fulfilling prophecy" to influence success
- outline how to overcome learned helplessness
- discuss links between mental toughness, depression, burnout and sleep
- describe how attribution theory factors can impact confidence.

AHL

Self-study questions

1. List **four** key attributes of mental toughness.
2. Discuss the relationship between mental toughness and health.
3. Explain why mental toughness is important in high-stress sporting situations.
4. Identify **three** possible characteristics of an athlete described as “mentally tough”.
5. Outline what self-fulfilling prophecy means using an example from a sport of your choice.

AHL



Data-based question

A recent study assessed the effect of mindfulness training on increasing mental toughness and psychological well-being. Forty-two female university students participated.

Group 1 completed a 7-week mindfulness programme.

Group 2 was the control group (no intervention).

Pre- (time 1) and post- (time 2) measurements of mindfulness and mental toughness were done by both groups. Mean \pm SD scores are shown in Table 3, where higher scores = more/greater.

▼ Table 3 Measurements of mindfulness and mental toughness in university students completing a mindfulness programme and controls

	Group 1 (experimental)			Group 2 (control)		
	T1	T2	T3	T1	T2	T3
mindfulness	49.0 \pm 4.7	59.0 \pm 5.2	59.2 \pm 5.1	49.6 \pm 6.3	50.6 \pm 6.0	51.2 \pm 5.6
mental toughness	45.0 \pm 5.8	52.1 \pm 5.4	53.3 \pm 5.1	44.6 \pm 5.1	45.9 \pm 5.4	46.2 \pm 5.8

Source: Ajilchi et al. (2022).

1. Identify which group has the higher mean mental toughness score post-intervention. (1 mark)
2. Distinguish between the experimental and control groups at the two-month follow-up point (time 3). (2 marks)
3. Discuss the use of mindfulness-based programmes to develop mental toughness in sports. (3 marks)

C.2

Motor learning

How are skills acquired, practised and perfected?

This topic explores how a performer learns to produce the movements required for a skilled action in sport. Two models of motor learning (the information processing model and the ecological model) are introduced, with linear and non-linear pedagogy approaches discussed. Knowledge about the psychological refractory period will help you understand how we respond to stimuli when we are participating in activities. You will also see how the learning and performance of one skill can “transfer” onto the learning and performance of another skill. The topic concludes by considering types of attentional focus, and the importance of athletes focusing on only the relevant cues (and eliminating distractions).

C.2.1

Syllabus understandings

C.2.1.1 Learning, including motor learning, is a relatively permanent change in behaviour brought about by experience, whereas performance is a temporary occurrence, fluctuating over time.

C.2.1.2 The psychological refractory period is the time in which response to a second stimulus is significantly slowed because a first stimulus is still being processed.

C.2.1.3 Transfer of learning refers to the influence of previous experience performing a skill on the learning of a new skill.

Introduction

Skilful performances in sport can bring a great deal of pleasure—whether you are a performer or a spectator. Usually we can appreciate and enjoy the performance of skill in our own sport. But it is often just as pleasurable to observe a skilful performance in sports less familiar to us.

From another perspective—such as the teacher or the coach—seeing one of your athletes execute a skill that you have taught them is an extremely rewarding experience, especially when you know the hard work that has gone into it.

This chapter will further develop your knowledge and understanding of the key factors relating to skill, motor skill learning, and theories of motor skill learning and practice.

The characteristics and classification of skill

The human capacity to perform skills is an important function of day-to-day living. They enable us to type words on a page, ride a bike to work or take part in physical activity. We begin to learn to perform skills from a very young age. We learn to crawl, to walk and then to run.

Some skills are simple and can be mastered with a small amount of experience and maturation, such as walking or lifting an object. Other skills, such as swimming or driving a car, are much more complex. Individuals have to practise to become good at these skills.

This section will take you through a more detailed definition of the term “skill” before explaining the different ways in which skills can be described and categorized.



Activity 1

What are the skills you perform from day to day? Why are they skills?

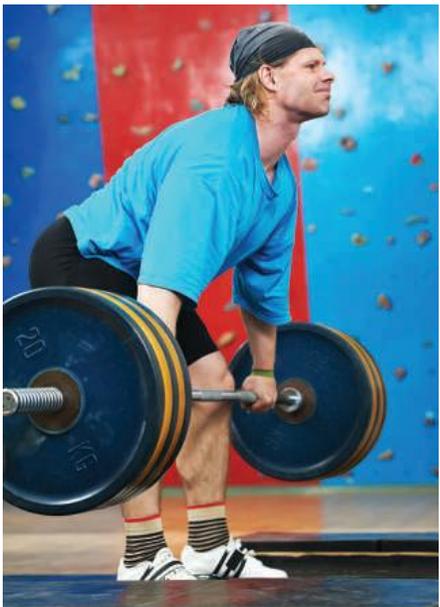
Identify the skills that are involved in a sport or activity you take part in. Why are they skills?

Key term

Skill A specific action (or the level of performance of an action) that has been learned through practice and which has a predetermined outcome or goal.



▲ Figure 1 Typing on a keyboard is a day-to-day skill



▲ Figure 2 Weightlifting is mostly a motor skill



▲ Figure 3 Chess is mostly a cognitive skill

What is “skill”?

The term “skill” can be used to describe either a specific action or the level of performance of an individual. Skill implies that the movement has been learned and has a predetermined outcome or goal. It is not an action that a person can just naturally do; neither is it moving for the sake of moving. For example, idly swinging your legs while you sit on a park bench is not a skill. However, riding your bike to get to the park *is* a skill.

The main characteristics of skills, therefore, are the following.

- They are goal oriented—using the skill will achieve an end result. For example, typing a letter, putting a golf ball in the hole or making a save in soccer.
- They meet the performance goal with maximum certainty. For example, maintaining balance while riding a bike or making 90% of shots in a basketball game.
- They meet the performance goal with minimum outlay of energy. For example, steering a car, staying streamlined in the water during a freestyle race or skiing parallel down the slope.
- They are learned through practice. They require some experience, repetition or feedback from a teacher or coach.

Types of skills

There are many different types of skills. They vary according to the different motor, cognitive, perceptual and perceptual-motor demands placed on the performer.

Motor skill

Weightlifting, for example, is mostly a motor skill because it emphasizes movement and does not require much thinking. Other examples include sprint racing and wrestling.

Cognitive skill

Playing chess involves mostly cognitive skill because it requires lots of thinking. Success in chess is not associated with the execution of the movements. In games such as soccer and field hockey, knowledge of the rules, game objectives and team tactics are cognitive in nature, and are associated with the decision-making element of gameplay.

Perceptual skill

Reading the green in golf is a perceptual skill. The golfer receives information about the type of surface, the run of the green, the distance of the ball from the hole and other environmental conditions through their perceptual senses. This enables the golfer to make a decision about how to make the putt. Perceptual senses include vision, vestibular (senses that help you with balance closely related to your hearing), haptic (touch) and auditory. Another example would be in rock climbing when a rock climber assesses the rock face before a climb.

Perceptual-motor skills

These skills involve the interpretation of environmental stimuli and the motor response to this sensory information. Perceptual-motor skills depend on high perceptual ability and are very important in activities that require the performer to adapt to the environment. Another example would be dribbling with the ball in soccer to beat a defender. It is important to note that most sports involve perceptual-motor skills because they involve thought, interpretation and movement.

Ability in sport

The term “ability” is often confused with the term skill. Although they are related, they are not the same thing. As mentioned previously, skills are largely defined by their purpose, goal or objective, and by the fact that they require practice. Abilities, however, are the traits that we are born with. They are the perceptual and motor attributes, inherited from our parents, that enable us to perform skills. Abilities give us the capacity to perform skills.

Perceptual-motor abilities are abilities that enable the individual to process information about how and when to move. For example, to execute a skill such as a forehand groundstroke in tennis, the tennis player requires perceptual abilities such as multi-limb coordination and response orientation. Motor abilities are those abilities relating to the actual movement. For example, to perform a skill such as the 100m sprint, individuals require motor abilities such as explosive strength and speed of limb movement.

To perform skilfully, the person must have the necessary technique or techniques and choose the correct one to use in any particular situation. In other words:

skill = ability + selection of the correct technique

Key point

A skill is something we learn. An ability is something we are born with.

ATL Thinking skills

Game-playing ability

Kim was good at all of the team games they played in physical education lessons: a natural footballer, basketball player, rugby player and field hockey player. It was obvious that they had strong natural abilities that “fit” those sports.

What natural abilities (motor and perceptual-motor) do you think Kim possessed to excel in these sports?

What are the abilities you have that enable you to be successful in your chosen sport?

Principles of skill learning

In this section we examine a number of factors involved in skill learning. Some are common to everyone but some cover individual differences.

Learning versus performance

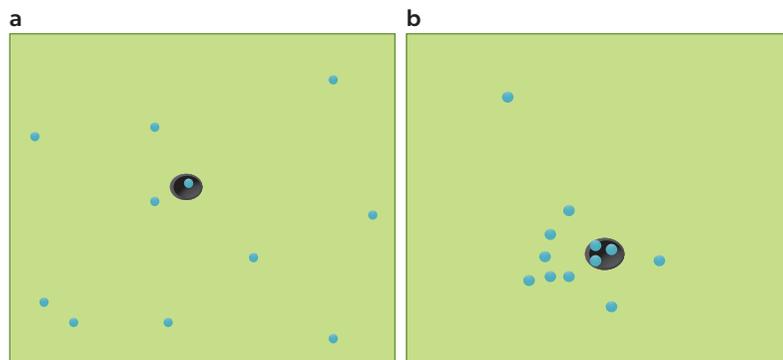
Although we measure learning by observing performance it is important that we know the difference between the two.

Key terms

Performance A temporary occurrence, fluctuating over time.

Learning A relatively permanent change in performance resulting from practice or past experience.

Kerr (1982) defined performance as being “a temporary occurrence fluctuating from time to time: something which is transitory”. Figure 4a shows a learner’s attempts to sink a putt in golf. Notice that one shot actually went in. Figure 4b shows the attempts by an experienced golfer. Notice the way the shots are clustered around one point. Even the beginner can produce one good shot but we are not thought to have fully learned a skill until we can perform it with some consistency. The process of acquiring this consistency is what we mean by learning. Kerr described learning as “a relatively permanent change in performance resulting from practice or past experience”.



▲ Figure 4 Sinking a putt in golf; **a** shows a learner’s attempts, whereas **b** shows the attempts by an experienced golfer

Factors contributing to inter- and intra-individual differences in the rate of learning

We cannot expect an individual to learn a skill that has physical demands that they are not yet capable of meeting. Sometimes, however, the individual has the physical maturation but is simply not fit enough to do the task. In such cases physical training is necessary. The most important factor affecting learning, however, is motivation. The learner needs to want to learn. This is often closely linked to physical maturation. The learner is good at knowing when they are ready to acquire a skill. We will look at motivation in more detail in topic C.3.

ATL Thinking skills

Children provide many examples of the link between physical maturation and motivation in learning. Babies often learn to crawl because they are motivated to get something that is out of their reach. Of course, they cannot do this unless they are sufficiently physically developed.

It is not unusual for children to be motivated to copy older siblings in carrying out skills but wanting to do so before they are physically capable. When the physical catches up with the desire they will successfully attempt the skill.

Sometimes the child is physically capable but is not motivated to carry out the skill. So we have to wait until they do become motivated.

When motivation and physical and indeed mental maturation are coordinated, we say that the child has reached the optimal or critical stage of learning. This is surprisingly young for many skills. If we miss the optimal period, we can have difficulty in catching up with those who did learn at the usual time. In the animal kingdom, failure to learn at the appropriate time can mean that the skill is never learned. Given that most animal skills are involved in survival, this can be fatal.

Transfer of learning

Transfer of learning refers to the effect that practice on one task has on the learning or performance of another task. Transfer of learning can be positive, negative or zero.

- Positive transfer is when the practice of one task has a facilitating effect on the learning or performance of another.
- Negative transfer is when the practice of one task has an inhibiting effect on the learning or performance of another.
- Zero transfer represents no effect.

Table 1 lists types of transfer, with some examples from sport.

▼ **Table 1** Types of transfer

Type of transfer	Example
skill to skill	throwing a ball to throwing a javelin
practice to performance	batting in cricket or baseball against a bowling/pitching machine
abilities to skills	improving dynamic strength in order to start races better
bilateral	a soccer player learning to kick with their weaker foot
stage to stage	from three-on-three basketball to the full game
principles to skills	from learning that long levers aid throwing to throwing a javelin

Approaches to motor learning

In the coming sections of this chapter, we will consider two competing models of motor learning:

- The information processing model, exemplified by schema theory
- The ecological model, exemplified by ecological dynamics theory.

We will consider these models in the context of two different motor learning theories.

Traditional **linear pedagogy** can be summarized by the following key points.

1. Linear pedagogy is based on the information processing theory about learning.
2. Movement experiences of increasing difficulty should lead to a linear learning progression through cognitive stages (cognitive, associative, autonomous).
3. From a linear pedagogy perspective, improving movement proficiency is accompanied by a reduction in cognitive processing while performing.
4. From a linear pedagogy perspective, movement skills should be broken down into basic and simpler movements to facilitate learning.
5. Linear pedagogy can be characterized by a teacher-centred approach.

In contrast, here are some key features of **non-linear pedagogy**.

1. Non-linear pedagogy has been developed and constructed based upon an ecological dynamics approach.
2. Non-linear pedagogy involves exploratory learning and encouragement of individualized movement solutions.

3. From a non-linear perspective, movement skills and learning activities should be practised in performance contexts that capture the dynamics where the skills to be learned can be performed, developed and acquired.
4. In a non-linear pedagogy approach, teachers modify individual, task and environmental constraints to support exploration.
5. Non-linear pedagogy involves a learner-centred approach.

Linear pedagogy approach to motor learning

Information processing model

When we perform skills, we do so in environments of varying complexities. As we saw earlier, open skills in particular are performed in very complex environments.

Think about games such as soccer and field hockey: 22 players, 1 referee and 2 assistants (soccer) or 2 referees (field hockey), the ball, the goals, the line markings, the spectators and the coaches. The players have to take all of this into account when performing.

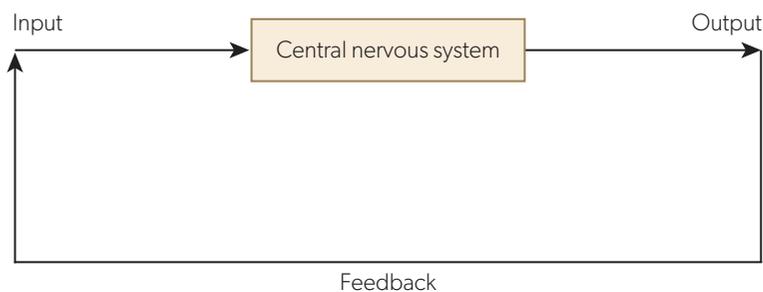
Even receiving a serve in tennis can be quite complex. The receiver has to take into account what kind of serve their opponent is making (this demands looking at all of their limbs and the general body position), the speed and direction of the serve, any spin on the serve, the wind speed and direction, and where they themselves are standing in relation to the service court. At the same time they have to decide what shot to play in order to return the ball and to where they are going to hit the return.

Just how we humans can do this has puzzled psychologists for many years.

Information processing has been explained mainly by developing models, which are depicted in the form of flow diagrams. Figure 5 shows the first of these models, called the Black Box Model.

Activity 2

Choose one or two skills similar to receiving a tennis serve and break them down. This will help you to understand how complex skills can be.



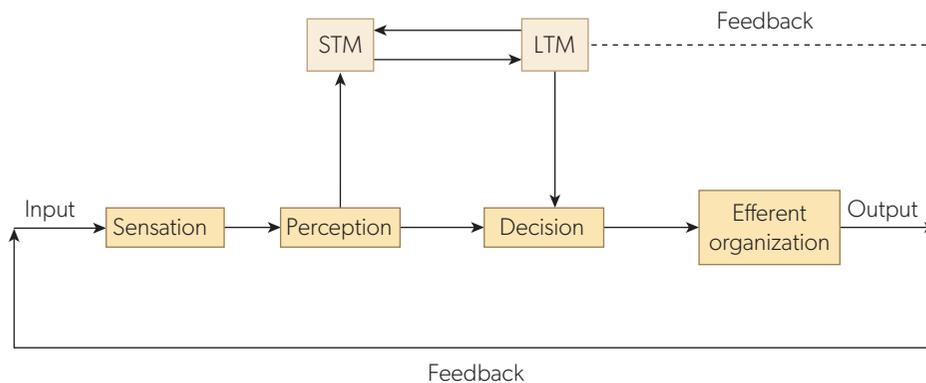
▲ **Figure 5** The Black Box Model of information processing

The input refers to the environment that the performer may see, hear and feel. It is sometimes called the display, or stimulus. In fact, in sport it is very rarely one input but several inputs, as outlined above.

The output is what the performer does. In the example of the tennis player it is what shot they play to return the ball and whether or not this is successful. This is also often referred to as the response.

The box in the middle, labelled central nervous system (CNS), refers to the person's brain and spinal cord. It is called the Black Box because early psychologists did not presume to know what went on in the CNS between experiencing the input and carrying out the response.

One of the first researchers to try to explain what actually happens in the CNS when processing information was AT Welford (1968). Figure 6 is based on Welford's model. We should note that although Welford presented his model linearly, he pointed out that many of the processes are carried out simultaneously.



Note: STM = short-term memory
LTM = long-term memory

▲ Figure 6 The information processing model proposed by Welford

Sensation or sensory input

The senses are responsible for relaying information about the environment to the brain. This information is then interpreted by the brain based on past experience of similar situations, and it is held in the long-term memory (LTM).

The senses can be divided into **exteroceptors**, **interoceptors** and **proprioceptors**.

- Exteroceptors provide information from outside of the body. The main exteroceptors involved in sensation with regard to sport are vision and audition.
- Interoceptors provide information from within the body, for example information about heart rate, lung function and digestive processes
- Proprioceptors provide information about body position and help maintain balance. Refer to chapter A.1.1 for further detail on proprioceptors.

Signal detection

Swets (1964) reckoned that individuals receive more than 100,000 pieces of information per second. This may be information from the environment and/or from within the person themselves. Thus, actually perceiving an important piece of information (what he called a "signal") is problematic. To explain how we do this, Swets developed signal detection theory.

Swets termed the background, non-essential information "noise". This may mean actual noise (such as the sound of spectators) but covers all information that is not part of the signal.

So, noise can be visual or from within yourself, such as worrying about failing. According to signal detection theory, the probability of detecting any given signal depends on the intensity of the signal compared with the intensity of the background noise.

The likelihood of detecting the signal depends on the interaction between two variables, d' and the criterion (C).

- d' represents the individual's sensitivity to that particular signal. This sensitivity may depend on the efficiency of the person's sense organs (for example, eyes or vestibular apparatus). It may also depend on experience (for example, familiar signals are thought to be more readily detected than unfamiliar stimuli).
- C represents the effect of a person's bias on detection. C is thought to be affected by arousal level, which, in turn, affects the probability of the detection of a signal. When arousal is low, the signal is missed (this is an "error of omission"). If, however, arousal is high and detection is considered to be a high priority, the individual may perceive a signal when one does not exist (an "error of commission").

Signal detection proficiency can be improved by ensuring that the performer is optimally aroused, but it can also be aided by good selective attention, which is covered later in this chapter.



Global impact of science

There are numerous examples of the use of signal detection theory in everyday life, and in nature.

For example:

- traffic lights stand out from their background
- signals on railways are easy to see
- road workers wear bright clothing that contrasts with most backgrounds
- cars and trucks have flashing hazard warning lights
- commercial enterprises use billboards and neon lights on shops and theatres
- animals and plants are often brightly coloured to warn predators.

We also see the opposite (signal detection theory in reverse). For example:

- military camouflage clothing is designed to blend in with the background
- animals use camouflage to avoid predators.

Memory

Tulving (1985) described memory as being the "capacity that permits organisms to benefit from their past experiences". The information processing model highlights short-term memory (STM) and LTM. But another stage of memory, the sensory information store (SIS), has also been described. All incoming information is held for a brief time in the SIS. Most of the information is lost within 0.5 seconds. It is only retained and processed if it is attended to. If this information is to pass to STM, it must be rehearsed. Rehearsal means being attended to, or processed mentally and/or physically.

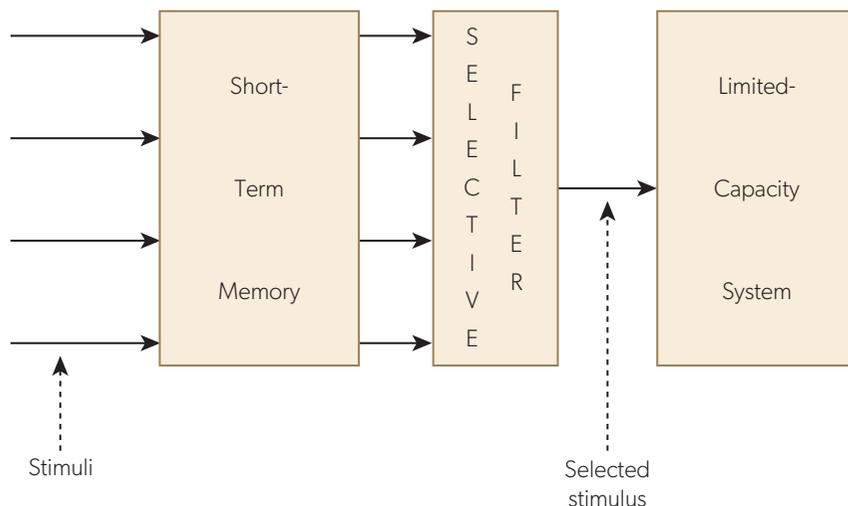
Ninety per cent of all information entering the STM is lost within 10 seconds. Retention and passage to the LTM are dependent on rehearsal—mental, physical or both. Time is not the only limitation on the STM. Miller (1956) found that the STM has a capacity or space limitation. He claimed that individuals could remember 7 ± 2 bits of information. However, this does not mean that if you read out a list of 12 words to a friend they will only be able to remember 9 of them (refer to section on selective attention).

Unlike STM, LTM has no capacity limitations, although sometimes we have difficulty in retrieving memories. We have all experienced that infuriating situation where you cannot recall a person's name.

Selective attention–memory interaction

Given that our STM has a limited capacity, we have a problem when trying to deal with all of the information in our environment. The limitation is so great that some psychologists believe that we can only deal with one thing at a time; this is called single channel theory (Welford, 1968). Others (such as Wickens, 1980) have argued that we can deal with more than one piece of information at a time if the tasks are dissimilar, for example, running down the court bouncing a basketball while at the same time making a decision as to whether to pass or shoot. Running with the ball occupies a different part of the brain to making the decision, so the two tasks will not affect one another.

The way we overcome this limited capacity is by the use of selective attention. Selective attention refers to the individual focusing on relevant information while ignoring irrelevant information. According to Broadbent (1956), all information enters the STM, but we only attend to the selected stimuli. Unselected stimuli are filtered out, but selected stimuli are compared with information stored in the LTM. This allows us to make decisions on what action to take.



▲ **Figure 7** Broadbent's filter model of selective attention

While selective attention takes place as described by Broadbent (stimuli being chosen for processing after entering the STM), we can also make decisions on what to process before the information enters the STM. Past experience of similar situations allows the performer to search the appropriate areas of the environment for relevant information.

Sometimes, attention is involuntary. A sudden loud noise or a flash of bright light will attract our attention, probably as a subconscious safety factor.



Activity 3

Aiding memory

Given that we have a limited STM capacity, we must be careful when asking people to memorize information. What would happen if you gave a list of 12 numbers to a friend and had them repeat them to you in order as soon as you finished? Try it with someone.

According to Miller (1956) we have a capacity of 7 ± 2 bits of information, but it is likely that your friend will remember more than 7, 8 or 9. If they really try, they may remember all 12.

Ask them what they did to remember the numbers. Most will say that they grouped the numbers together, in threes or fours normally. This process is called chunking. Each chunk makes up one bit of information. So, 12 numbers will become 3 or 4 bits of information rather than 12.

ATL Research skills

There are other strategies to help with retention and retrieval for improving learning, skill acquisition practice or teaching/coaching skills.

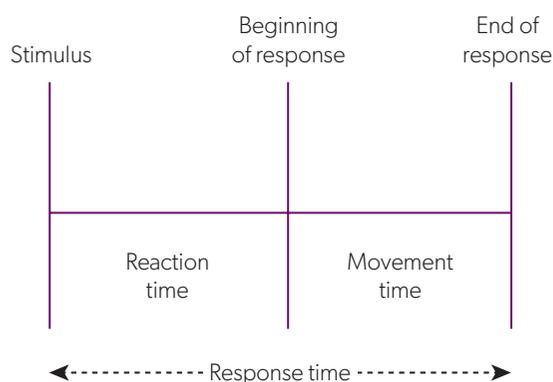
Outline:

- action words
- brevity
- clarity
- organization
- association
- practice.

Response time

Response time is the time from the introduction of a stimulus to the completion of the action required to deal with the problem (McMorris, 2004). It is made up of reaction time and movement time.

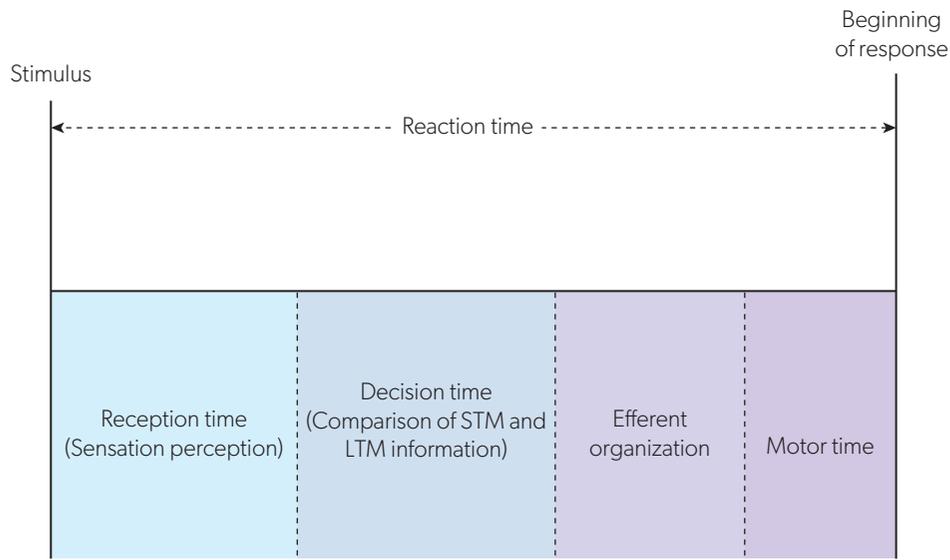
- Reaction time is the time that elapses from the sudden onset of a stimulus to the beginning of an overt response (Oxendine, 1968).
- Movement time is the time it takes to carry out the motor aspects of the performance.



▲ Figure 8 Response time

Response time gets quicker throughout childhood and adolescence; however, as we get older it gets slower. Movement time is affected by fitness, particularly power and speed of limb movement. Training can greatly affect movement time but reaction time is less easy to improve.

Figure 9 shows the stages of reaction time. Notice how it encompasses almost all of the information processing model.

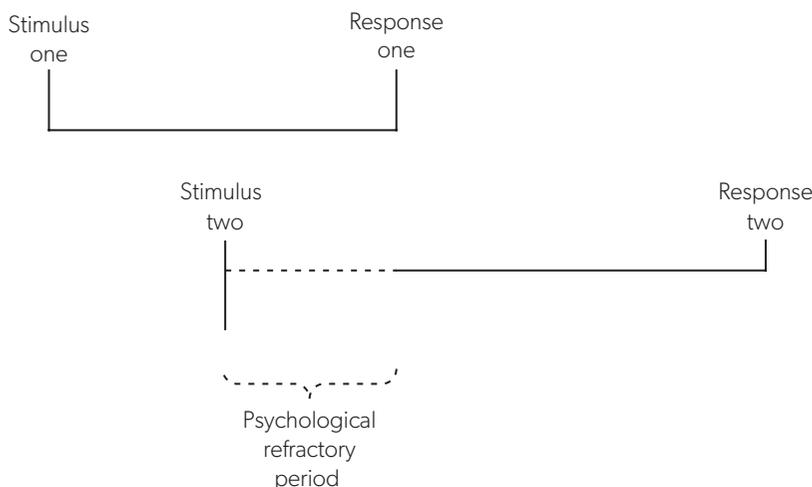


▲ Figure 9 Reaction time

The main factor affecting speed of reaction is the number of choices that the individual has to make. If there are no choices—what we call simple reaction time—the mean times range between 170 and 200 ms. However, as we increase the number of choices—what is termed choice reaction time—the times increase. Hick (1952) found that as you doubled the number of stimulus–response couplings, the reaction time increased. If the reaction time is plotted against the log of the stimulus–response couplings, there is a linear increase. This is known as Hick’s Law. Generally, reaction time increases by about 150ms every time the stimulus–response groupings are doubled.

The psychological refractory period

Earlier we examined single channel theory. To show the single channel at work, Welford (1968) undertook an experiment in which he had participants respond to a stimulus (S1). Reaction time to S1 was as Welford expected. However, when he introduced a second stimulus (S2) shortly after the introduction of S1, the participants demonstrated slower than normal reaction times to S2. Thus, Welford stated that when two stimuli are presented close together the reaction time to the second stimulus is slower than normal reaction time. The time gap was called the **psychological refractory period**. Welford claimed that processing of S2 could not take place until processing of S1 had been completed.



◀ Figure 10 Psychological refractory period

The effect of the psychological refractory period can be seen in many sports. Any example of a feint, dodge or dummy is an example of the use of the psychological refractory period. The feint is S1 and the actual movement is S2. If the timing is correct, the defender will be comparatively slow in reacting to the real movement. This is the skill of rugby players such as Antoine Dupont, basketball players such as Kevin Durant and soccer players such as Alexia Putellas. Similar feints can be seen in the drop shot in badminton or a dummy punch in boxing.

Phases of learning

One of the most widely held theories of learning is that of Fitts and Posner (1967). They claimed that learning takes place in three stages: the cognitive, associative and autonomous phases.

In the **cognitive phase**, the individual tries to make sense of instructions. They use lots of verbal labels. This does not mean instruction has to be verbal, but simply that the individual uses verbalization to aid memory. For example, the phrase “pull, brake, switch, slide” is often used while teaching belay technique in rock climbing.

In skills requiring perception and decision-making, there are often mistakes made and the individual attends to irrelevant as well as relevant stimuli. The motor component is characterized by crude, uncoordinated movement.

With practice the individual develops the knowledge of what to do. When someone is at this stage, they are said to be in the **associative phase**. At this phase, practice is required to perfect the skill and develop the consistent, coordinative movement that demonstrates learning.

When the individual can perform consistently and with little overt cognitive activity, they are said to have reached the **autonomous phase**.

Activity 4

In small groups, discuss and decide on reasons that help explain your answers to the following.

1. Which of the phases of learning are described by:
 - a. economic/efficient movement?
 - b. inconsistent movement?
 - c. practice stage?
2. Why is extrinsic feedback important when coaching learners at the cognitive stage?
3. Distinguish between negative feedback and negative reinforcement when coaching basketball to a learner.
4. Is negative feedback necessary when coaching an elite athlete?
5. Why is positive feedback essential when coaching at the cognitive stage?
6. Why does a learner at the cognitive stage need a mental picture from the coach?
7. Why can a basketball coach focus more on tactics at the autonomous stage of learning?

8. Which phase/stage of learning would you associate with the following in basketball, and why:
- dribbling, keeping the ball around waist height and keeping your head up to scan for where your teammates are?
 - dribbling while focusing on a strategy to beat the opposition?
 - learning to dribble with both hands?

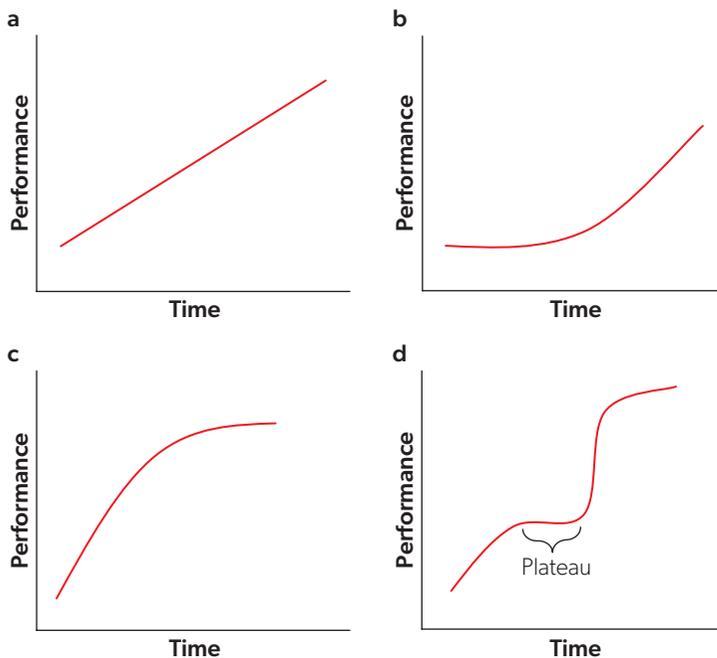
Learning curves

When we learn an easy-to-perform skill, we can often demonstrate what we call a linear learning curve (Figure 11a). It is rare that learning is as easy as this, however.

Many skills are difficult to learn at first. Progress is slow but then we reach a point where performance improves more quickly. This is called a positively accelerated curve (Figure 11b).

Sometimes, however, the opposite happens. We learn quickly at first but then slow down. This is a negatively accelerated curve (Figure 11c).

A fourth type of curve is demonstrated in Figure 11d. Learning is positive and probably fairly quick at first, but then there is a period when we show no improvement in performance. This is called a plateau effect. However, if we keep on practising, there is a breakthrough and more learning is demonstrated. We are, in fact, probably still learning during the plateau phase but it is not being shown in our performance. Remember, performance is not the same as learning.



▲ Figure 11 Examples of typical performance curves: **a** linear, **b** positively accelerated, **c** negatively accelerated, whereas **d** shows a plateau effect



Linking question

To what extent do the training programmes developed by coaches reflect the stages of learning? (A.3.1)

Consider:

- whether coaching methods (for example, type of feedback given) correspond to the stage of learning
- how an individual's current level of fitness can be impacted by their economy/efficiency of movement
- whether the same coaching approach can be used for different stages of learning
- whether the tasks and responsibilities for coaches vary with the athlete's stage of learning
- that stages of learning represent a key consideration for coaches within training programmes, but coaches may also need to consider these alongside other important aims and goals. For instance, coaches may not only be looking to develop movement skills, but also attributes, knowledge, behaviours or outcomes (for example, confidence, perseverance, teamwork, responsibility, goal setting, enjoyment) as part of the programmes.

Motor programmes

Keele (1968) defined a motor programme as being a set of muscle commands that allow movements to be performed without any peripheral feedback. Examples of motor programmes are basically any skill that you can think of. Hitting a tennis ball, catching a netball and doing a somersault are all examples of motor programmes. A number of motor programmes can be put together to form an executive motor programme, such as a roundoff and back handspring (flick flack), or the triple jump (hop, step and jump). Indeed, the executive programme itself can become part of an even greater programme. Many gymnastics routines involve the completion of a number of executive motor programmes in quick succession. To the gymnast they have become one large executive programme.

Perhaps the best example of an executive programme outside of sport is playing the organ. The organist must put together movements from the hands, each of which is carrying out a separate motor programme, as well as movements of the feet, which are also carrying out separate motor programmes to one another. To the organist, however, they are playing one tune with "one" set of movements. We all know from games like tapping the head while rubbing the stomach that it is difficult to simultaneously make two separate movements with the hands, but think of adding two more separate movements with the feet!

Theory of open-loop and closed-loop control

Keele's (1968) model of a motor programme is an example of a movement that uses what we call **open-loop control**. It accounts for the performance of a skill without recourse to feedback. It explains how we can carry out very fast movements. For example, a boxer throwing a straight left will do so at about 60–70 ms. This is too fast for them to use feedback to alter the movement once it

has begun. The same can be said for someone trying to hit a baseball pitched at over 100 kilometres per hour. Once the shot has begun, it cannot be changed.

However, not all movements take place this quickly. Many movements can be altered during their execution. We can alter our movements when hitting a baseball pitched at, say, 50 kilometres per hour or returning a slow serve in tennis. These movements are under what we term **closed-loop control**.

The first to describe how we use closed-loop control was Jack Adams (1971). He argued that as we learn a skill, we develop what he called the perceptual trace. The perceptual trace is memory for the feel of successful past movements. Once we have developed the perceptual trace, we can compare the trace with the feel of the ongoing movement. This allows us to correct inappropriate actions. While the perceptual trace controls an already ongoing movement, the selection and initiation of the movement are under the control of what Adams called the memory trace.

Schmidt's schema theory

Richard Schmidt (1975) set out to develop an explanation of motor programmes that included both open- and closed-loop control. This theory became known as **schema theory**. Schmidt described a schema as being a set of generalized rules or rules that are generic to a group of movements. Schmidt believed that we develop two kinds of memory for movements, which he called the recall and recognition schemas.

- The recall schema is memory with regard to the choice and initiation of action.
- The recognition schema is memory for the feel of a movement, and it allows us to make appropriate changes in the action.

Both schemas require the individual to recall memory of similar past situations from the LTM. These are then stored in the STM and allow the person to decide the actual movement to be used. Remember, the schema is a generalized set of rules, but we must carry out a specific action.

So, comparing what you hold in your STM about the past situations with what you hold with regard to the present situation allows you to decide on the specifics of the movement.

Schmidt called this process deciding the response specifications.

Generalized motor patterns and subordinate motor patterns

Within linear pedagogy, **generalized motor patterns** are fundamental movement patterns, such as running, jumping, throwing, kicking and striking, that serve as the building blocks for more complex motor skills. Generalized motor patterns are typically introduced and taught first.

Subordinate motor patterns are specific variations or refinements of generalized motor patterns. They involve modifications to the basic movement patterns to suit specific tasks or contexts. For example, a baseball swing is a subordinate motor pattern derived from the fundamental striking generalized motor pattern. Subordinate motor patterns often require more fine-tuned coordination, precision and timing compared with generalized motor patterns.

In linear pedagogy, once learners have acquired proficiency in the basic generalized motor patterns, they progress to learning subordinate motor patterns. Instruction focuses on refining and adapting the movements to sport-specific or skill-specific contexts. Therefore, in linear pedagogy subordinate motor patterns are like specialized versions of the generalized motor patterns—we learn how to adapt and improve our movements to make small adjustments to our technique, timing and body positioning as we become more coordinated in our movements, helping us develop a wide range of skills for use in various sports or tasks.

Feedback and learning

Feedback can be a great motivator. We all like praise, particularly from people we think are important. The failure of coaches to praise good performance can have disastrous effects on the athlete's self-confidence. It can also give learners the false impression that they are not improving when in fact they are. However, too much praise can have negative effects. If an athlete only ever hears "well done", "great" and "brilliant" then these words may start to lose meaning, or become so familiar to the learner that they are not perceived at all.

With regards to learning, the main factor is that the performer improves. As we saw above, beginners need to be told what to do to improve performance—this is prescriptive feedback. As they improve and increase their knowledge of the activity, all they require is knowledge of results. If they are making an error, they can resolve the problem themselves by comparing what is happening now with the store of knowledge they hold in their LTM. So we say that they now require descriptive feedback.

Key term

Ecological dynamics theory

A model that describes how individuals continually reorganize the human movement system in response to perceived events. Ecological dynamics theory sees movement as a result of the interaction between the person and their environment (movements are influenced by things like the objects around us, the rules of the game, and the people we interact with).

Non-linear pedagogy approach to motor learning

Ecological dynamics theory and the ecological model

Despite the dynamic changing environments common in individual and team sports, athletes have the capacity to perform consistently and to a high standard across a range of circumstances. To achieve their goals, athletes continually reorganize the human movement system (which involves nervous, muscular and skeletal systems) in response to perceived events. For example, a competent cricket player does not need to think about or receive instruction from a coach about when to use their left, right or both hands to intercept a ball. Instead, according to **ecological dynamics theory** and the **ecological model**, the cricketer can use live, perceptual information, such as ball-flight trajectory, to organize the most appropriate catching action (for example, whether the ball is thrown to their left or right).



▲ Figure 12 Cricket players continually reorganize their movement system in response to events

Dynamical systems theory

Dynamical systems theory is a major contributor to ecological dynamics theory. Dynamical systems theory explains how complex systems with many interacting components **self-organize**. For example, a motor response to a visual stimulus involves the coordination of:

- the eyes
- the visual cortex of the brain
- other decision-making parts of the nervous system
- the muscular system.

The interacting components are known as **degrees of freedom**. This self-organization allows adaptation to the timescale of performance (milliseconds, seconds and minutes), learning (hours, days and weeks) and expertise acquisition (months and years).

Self-organizing in athletes is shaped by:

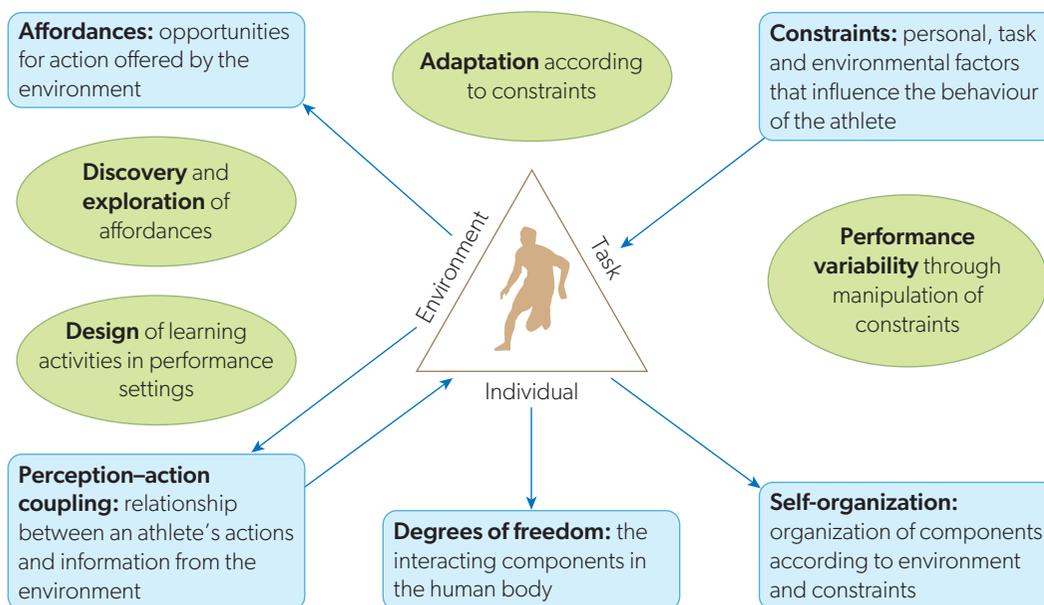
- personal constraints (such as chronotype, height, weight, muscle-to-fat ratio, cognitions, motivations and emotions, injury status, endurance capacity, genotype, goals)
- task constraints (such as rules, size of implements, surfaces, ground areas, boundary markings)
- environmental constraints (such as ambient light, ambient temperature, altitude, wind strength and direction, steepness of a ski slope, movement in air or water, family support, societal/cultural expectations).

Personal, task and environmental constraints influence the behaviours of performers and learners in sport. For example, buoyancy and achieving the preferred, drag-minimizing body position in swimming will be impacted by a

Key term

Dynamical systems theory

An explanation of how complex systems with many interacting components, known as degrees of freedom, self-organize. Dynamical systems theory is more about how our bodies and brains work together to create movement and learn skills. It looks at the internal processes that happen within our bodies. This theory says that our movements are like a complex system with many parts working together. It looks at things like how our muscles, bones and brain coordinate to create smooth and efficient movements.



▲ Figure 13 Pedagogical approaches based on ecological dynamics theory

range of interacting factors including body composition and environmental conditions (such as a sheltered swimming pool versus the sea with waves). Being able to vary motor performance according to the different constraints is an integral part of skill acquisition.

ATL Thinking skills

With self-organization, movement patterns are spontaneously adapted based on perceived environmental changes or circumstances.

For example, a tennis player will adjust their tennis strokes to account for differences in grass, clay or hard court surfaces. Or a skier will self-organize their body position to execute a turn on a ski slope. Internal constraints (such as anatomy) and external constraints (such as visual information) influence the skier's movement patterns in changing environmental conditions (such as the steepness of the slope or whether there is dry, wet or icy snow).



▲ Figure 14 A tennis player will adjust their stroke to account for the playing surface

ATL Thinking skills

The word “complex” describes a network of related interacting parts. Within complex systems these interacting parts are capable of affecting other parts. For example:

- a group of dancers who take on different roles to perform together
- a dancer's muscles contracting in a coordinated way to perform a routine
- one dancer within the group whose performance influences the timing of other members.

For the human movement system, the many interacting parts are known as “degrees of freedom”. For any one movement, according to ecological dynamics, the human body has many more degrees of freedom than it needs (redundancy) and these parts can be organized in countless ways. For example, even when the end result may appear similar, no one golf drive, baseball pitch or dance routine will ever be performed in exactly the same way as the next one.



▲ Figure 15 The human body and groups of dancers can both be seen as complex systems

Adaptation

Adaptation in the ecological model refers to the continuous reorganization of components (degrees of freedom, such as muscle-limb segments) to satisfy the ecological constraints of competition.

For example, catching a fast-moving ball when fatigued in front of noisy spectators in American football (Figure 16a), or teammates adjusting their relative positioning to exploit or cover space when attacking or defending in basketball (Figure 16b). In this way, relations between these system components in athletes and sports teams are continually reorganized to achieve specific intentions and goals during performance. This helps us to understand how an athlete transitions between one state of organization (such as jumping for a two-handed defensive block in volleyball, Figure 16c) and another (such as jumping for a one-handed attacking shot in volleyball, Figure 16d). Additionally, this can help explain some decision-making in team sports, such as how a subgroup of players coordinates its movements to transition from defence to attack and vice versa as the game ebbs and flows between having possession/not having possession of the ball.

ATL Research skills

In the context of the ecological dynamics framework, what is adaptation in sport performance contexts, and why does adaptive capacity need to be promoted in training when preparing for competition?



a



b



c



d

▲ Figure 16 Athletes adapting during sports performance

Perception–action coupling

Perception–action coupling refers to the relationship between an athlete’s actions and information from the environment in which those actions take place. Perception–action coupling is based on the idea that athletes can directly perceive and act upon available environmental information without needing to interpret or process that information. The environment provides opportunities for action, known as affordances, that athletes can directly act on or exploit to achieve their goals. For instance, a gap between defenders in basketball may afford or invite opportunities for shooting, passing or dribbling for the offence (Figure 17a). At the same time, the defence may respond to the offence’s play by closing the gap and limiting space for the offence (Figure 17b). In this way, athletes’ interacting play or behaviour can modify the context creating new affordances, while also closing others.



a



b

▲ Figure 17 Athletes directly perceive and act upon available environmental information without needing to interpret or process that information

The linkage between perceiving and acting implies that learning should focus on helping athletes to identify the most relevant information to act on (such as by training in environments that reflect real-world situations and/or by the coach manipulating constraints).



▲ Figure 18 Haptic (touch) information from the hands and feet on the rock surface can provide information on stability; using this information, climbers can organize and coordinate their finger, hand and foot movements relevant to their interactions with the surface

Indeed, from this perspective, the acquisition of skill in individual and team-based sports will depend on attuning athletes to key information that characterizes useful interactions between athletes and relevant performance environments.

From an ecological dynamics perspective, athlete–environment interactions are a fundamental principle of planning for motor learning. Some examples of interactions include:

- intercepting in ball games
- surfaces (such as skating across an icy surface)
- events (such as the sudden acceleration of another athlete in a 1,500 m race)
- terrain dimensions (such as driving distance to greens on different golf courses)
- features (such as dealing with a crosswind in an archery competition)
- significant others (such as changes in positioning and movements of teammates and/or opponents).

Measurements

Measurements provide a means to record and understand the structure of a problem through the generation of information, or data. It is important not to measure *everything* that is possible, because measuring in itself (no matter how few variables) will influence the performance you are trying to understand.

The goal is to understand without interfering, within reasonable limits. A strong conceptual interdisciplinary understanding of the context, the likely issues that need addressing, the nature of those issues and the intended change (if there is a planned intervention) will typically result in the need for multiple measurements to analyse and evaluate the problem.

An initial orientation stage to any practice or research will seek to distinguish between primary (“need to have”) and secondary (“nice to have”) measures based on this conceptual understanding and its development. Involving a practitioner, or being aware of the sporting demands, will be beneficial to identifying what to measure, how and why.

Multiple measurements could be data collected across outcome, performance and process components of an athlete’s training and/or competition. For a golfer, this might be the overall score achieved (outcome), the number of tee shots hit onto the fairway (performance) and the levels of concentration applied by the golfer on each shot (process). In this way, it is possible to know what an athlete can achieve, but also to realize the characteristics of optimal and suboptimal attempts.



▲ Figure 19

Affordances

Affordances are opportunities or possibilities for action offered by the environment. In sport, affordances capture relations between an athlete and a performance environment. Perceiving an affordance is to perceive how one can act when faced with specific conditions in a performance environment. More recently, affordances have been perceived as action possibilities that *invite* behaviours from individuals, based on past experience, learning and development, for their use in performance. Therefore, the specific skills, experiences, motivations and intentions of each individual athlete guide their performance as they reorganize movements to seek and use affordances in a performance environment.

However, while affordances invite and draw in athletes, individuals can accept or reject these invitations by adjusting the strength of the couplings formed with affordances during practice and performance. Athletes may experience affordances that differ in their invitational strength over time. Hence, for optimal performance, practice task designs should require a significant level of problem-solving, decision-making and selection that simulates demands of competitive environments. This is important because, in many competitive sports, contexts are highly dynamic and variable.



▲ Figure 20 Engaging in activities such as parkour can help an athlete develop athleticism while learning to act on the most relevant affordances in a landscape during interactions with objects, surfaces, ledges, inclines and obstacles; parkour demands innovation in interacting with these properties of the environment, which involves accepting or rejecting invitations to interact in different ways with them

The level to which an affordance invites a response from an individual athlete can vary from instant to instant and could be different within and between performers from occasion to occasion. In parkour, an athlete may jump over a ledge on one occasion or land with the right foot and push off with the left foot on another. Use of affordances, therefore, depends on interacting constraints to do with the individual, task and environment that can be discovered, explored and exploited.

Transfer of learning to performance

An important question that ecological dynamics considers is: what transfers from learning to performance?

Key aspects of a performance environment need to be considered when designing a practice environment for both individual and team sports. The transfer of skill and motor learning occurs more effectively when practice/training in one context shapes performance and learning in a different context. This can involve a transitional period because well-learned techniques/skills may need to be suppressed or changed and new movement patterns need to become more stable with learning (for example, when a skilled badminton player learns to play tennis).

One cannot simply become an elite swimmer by swimming in competitions alone. Research has shown that expert athletes typically participate in more sports during their developmental years and experience a greater number of hours of practice in different sports compared with non-experts. Early specialization in sports practice and training in young children is less beneficial than an early range of diverse experiences in different physical activities (Coutinho et al., 2016).

An ecological dynamics perspective proposes that, early in practice, developing athletes should be exposed to a mix of unstructured and structured play experiences. It recommends less attention to early specialization to prevent potential detrimental effects on athletes (such as burnout).

For example, enjoying the challenge of discovering new individual actions and possibilities in different performance contexts increases engagement with long-term motives for practice, and helps to avoid physical, psychological and emotional problems. So, an ecological dynamics perspective supports the need to develop athleticism in young athletes without forcing them to specialize too early in their development.

Constraints-led approach to skills acquisition

In motor learning and acquiring movement patterns, a **constraints-led approach** is the mind, body and environment continuously influencing each other to shape the emergent behaviours of each individual. A constraints-led approach only promotes the understanding of *how* skills are acquired from a motor learning perspective.

Human learning is non-linear in nature, and both physical educators and sports coaches should reflect this in their pedagogy for optimal motor learning and

ATL Thinking skills

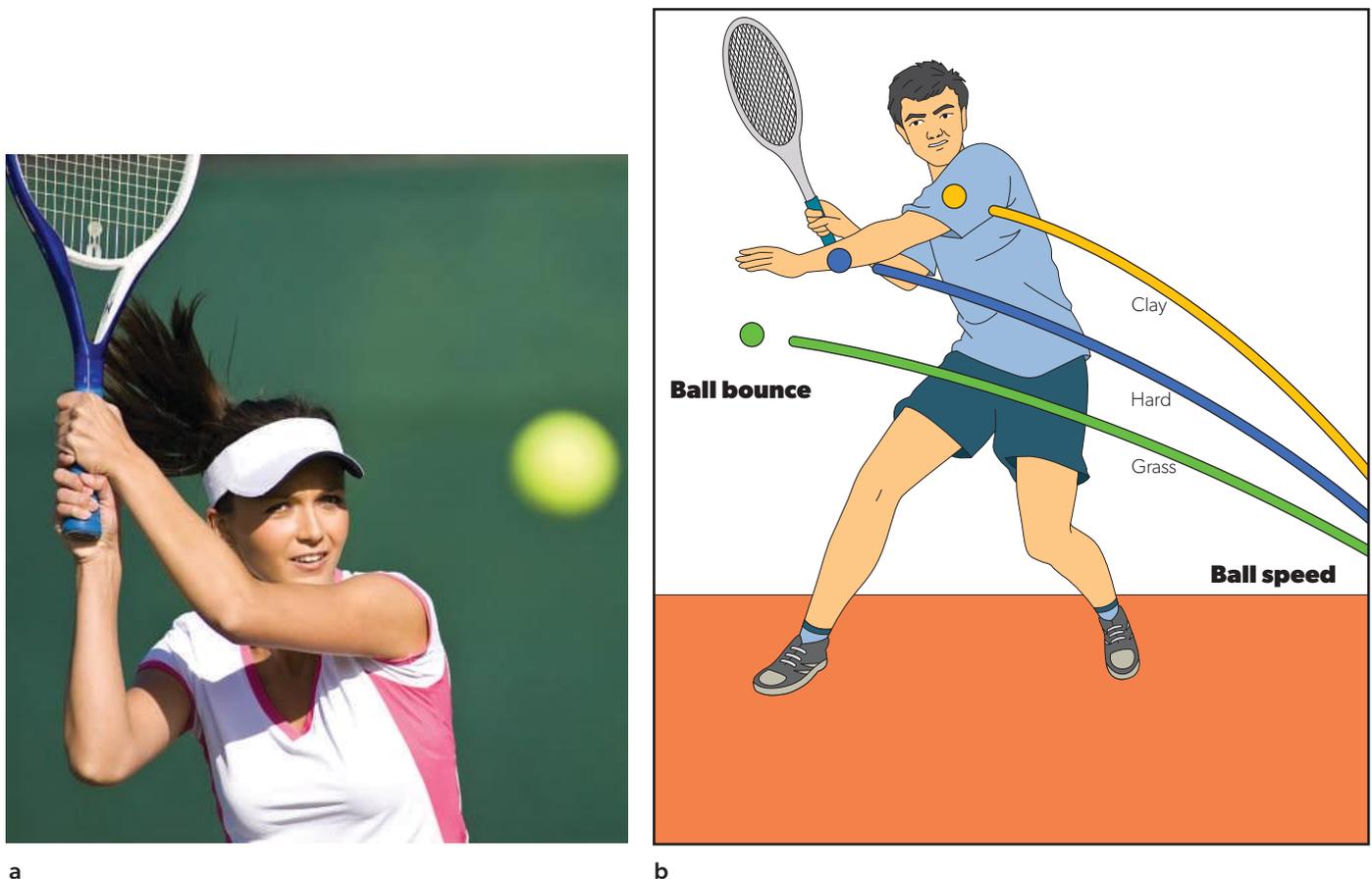
How can soccer coaches adapt and manipulate the conditions to promote the most effective coordination for:

- inside/outside of the foot passes?
- penalty kick shots at goal?
- long/short passes?
- passes along the ground?
- corner kicks high into the penalty box?

performance improvement. In other words, they should adopt a non-linear pedagogy approach to underpin physical education teaching and sports coaching with the constraints-led approach. This includes how to:

- assess performance
- structure practices
- deliver instructions
- provide feedback.

Non-linear pedagogy provides a framework in which learning is situated in realistic learning environments—authentic learning with the focus on the students. For example, tennis players preparing to play in the US Open should practise outdoors on a hard court surface where the natural light and wind will influence decisions about which shot to play. Compare this with practising on a carpeted surface indoors, where the bounce of the ball is different, there is no wind and no direct sunlight in the player's eyes. An intelligent player will understand how important the context of each shot played during practice is.



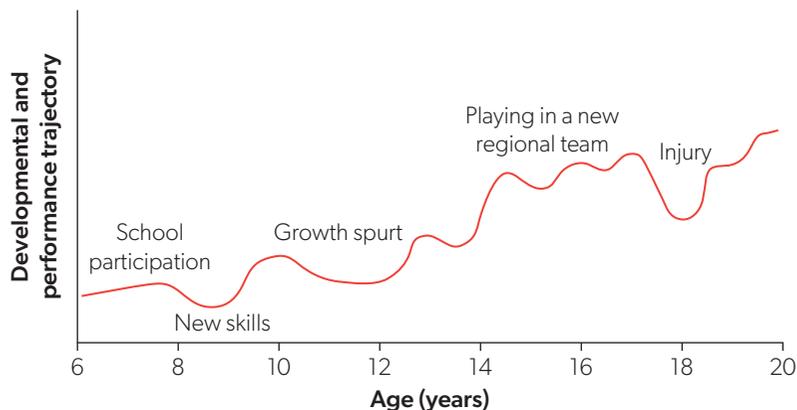
a

b

▲ Figure 21 A tennis player needs to prepare for: **a** environmental factors, and **b** different playing surfaces

Skill acquisition in applied settings needs to be understood over an extended duration to fully appreciate learners' needs. When viewing the performance trajectories of elite-level athletes, one characteristic stands out: their developmental pathway is not smooth.

Figure 22 shows an example of a young athlete's trajectory and demonstrates that progress does not always occur at the same rate. This change in the rate of progress is called a "non-linear" trajectory. As seen in the figure, the non-linearity occurs due to challenges in a variety of different areas of the athlete's life. Other possible challenges also include growth spurts, practice interruption/reduction due to school assessments, injury, changing coach/team and general changes within life (such as a family bereavement).



▲ Figure 22 Example of a developmental pathway showing the non-linear nature of progression

ATL Thinking skills

Movement variability enhancing the acquisition of coordination is seen as a key feature of non-linear human learning. A coach can modify and include variability in practice by altering task constraints. For example, sprinting with the added resistance of a parachute.



▲ Figure 23 Washington Wizards guard Gilbert Arenas does sprints pulling a parachute

Comparing linear and non-linear pedagogy approaches

Research has shown that a non-linear pedagogical approach to a learning environment can provide a context in which learners are intrinsically motivated to learn.

During learning and performance development, the motor system degrees of freedom—that is, the number of separate independent dimensions of movement in a system that must be controlled, such as joints, muscles and legs—are continuously reorganized as a function of learning based on interactions between specific task, environmental or personal constraints.

By manipulating suitable and relevant task constraints, physical education teachers and sports coaches can design learning activities situated in performance settings that cater to individual learning need. This increases opportunities for learners to fulfil their psychological needs (autonomy, competence, relatedness—refer to chapter C.3.2).

For example, when coaching team invasion games (such as basketball, soccer or ice hockey), plan for the students to work in smaller groups (for example, 3 v 3 rather than 5 v 5 in basketball). This will create more opportunities for:

- autonomy (for example, more opportunity to make decisions on their own)
- competence (for example, success at meeting task goals that are less complicated)
- relatedness (for example, more interaction among peers in small-sided games).

Traditional linear pedagogy views of skill learning viewed learning as a separate process that precedes performing. This is in contrast with ecological dynamics, which views learning as an essential part of performing (they are symbiotic processes).

With linear pedagogy, learning is mostly framed around technique drills that allow sub-parts of the task to be acquired and practised separately (mechanical repetition by rote/repetition after repetition) before being put back together again. Linear pedagogy places the physical education teacher or the sports coach at the heart of the instructional process, rather than the learner. This approach ignores that context is everything when teaching/coaching relevant tasks that challenge the skills of a learner.

Physical education teachers and sports coaches should ask themselves: does practice look and feel like the competition?

Take the skill of shooting in basketball, for example. A linear pedagogy approach:

- uses static blocked practice
- has no defenders
- focuses on “correct” stance, ball release height, hand positions on the ball, foot placement.

A non-linear pedagogy approach recognizes that shooting actions vary, dependent on:

- individual constraints (fatigue, height)
- task constraints (preceding actions of the shooter—dribbling, faking)

- type of shot (jump, hook, lay-up)
- body orientation in space
- distance from the basket
- availability of visual information (view of the basket)
- a defender or defenders attempting to intercept the ball.

ATL Thinking skills

Are only non-linear pedagogy practitioners engaging in representative training and simulated environments?

Is there still a place for some of the “reductionist” or traditional methods?

For instance, some drills could be used to help some athletes feel more confident (during learning or returning from injury). Sometimes you just do not have the facilities always to be representative, for example, if the task is dangerous, such as skydiving or ski-jumping. Or you may need to practise unopposed if there is no one else to practise with.

An ecological dynamics approach frames skill as “skill adaptability”, rather than the internal (in the brain or the myth of muscle memory) acquisition of a movement technique or skill. The ecological dynamics approach to the concept of skill provides physical education teachers and sports coaches with guidance in terms of what learners/performers need to learn and know, and how learners/performers can decide what to do. For example, in basketball, when the defender is standing with one foot leading, the attacker can decide to drive past them to the side of the defender’s more advanced foot. Remember—*gardeners do not actually grow a plant; rather, they facilitate an environment to which vegetation adapts and in which plant growth emerges* (McChrystal et al., 2015).

ATL Thinking skills

Globally, there is concern about physical inactivity leading to poor health and lower life expectancy, and the associated high economic costs for governments. Regular participation in quality sports and physical activity throughout the life course can help meet this challenge to sustain healthy and active lifestyles.

Supporters of ecological dynamics suggest this needs a shift away from reductionist approaches to physical activity engagement and maintenance to an ecological dynamics approach that focuses on enrichment to support movement skill learning and development, and the physical literacy journey across the life course.

Unfortunately, today there are large numbers of children who do not engage in physical activity because they do not have well-developed movement skills.

Ecological dynamics is a theory of motor learning/control. But is it an overreach by scholars in this area to suggest that it is the answer to the promotion of physical activity? Does ecological dynamics theory underestimate the role of psychological factors in promoting physical activity?

Key point

The International Physical Literacy Association defines physical literacy as the “motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life”.

Ecological dynamics theory suggests that learning movement skills emerges from the interactions within and between the person, task and environment. Children learn relative to their current intrinsic dynamics (including skill competence and cognitive development) in their current performance environment and for the current task. Furthermore, children do not acquire functional movement skills at a steady rate—this evolves as a non-linear process. Thus, ecological dynamics theory has led to the creation of learner-centred pedagogical principles, which cater for individual needs and emphasize an “explore–discover–adapt” learning approach. Non-linear pedagogy principles and how they can support physical literacy are shown in Figure 13. There is good research evidence that being learner-centred, non-linear pedagogy supports the satisfaction of the basic needs of autonomy, relatedness and competence (self-determination theory), and therefore nurtures the development of motivation to be physically active. Quality, not just quantity, of participation in physical education, sports, exercise and physical activity, will enhance the performance, health and well-being of future generations. Pedagogical approaches based on ecological dynamics theory will be advantageous in supporting individuals to lead a physically literate life.

ATL Thinking skills

Learning Scottish country dances: an interdisciplinary perspective

Basic Scottish country dances, such as the Gay Gordons, consist of movement patterns comprising walking (forwards and backwards), galloping (forwards or sideways), triple-step (pas-de-basque) and hop and three steps (polka).



▲ Figure 24 Learning the steps of the Gay Gordons



Teaching a beginner to learn sequences of these movements in combination with a dance partner and other group participants presents a challenge across multiple disciplines. For example, the learner needs to master the physical steps with precision, rhythmical accuracy and interpersonal coordination. Such complexity brings with it significant cognitive challenges, represented by recalling the correct movement technique under time pressure that is dictated by the musical accompaniment, in addition to perceptual processing demands requiring spatio-temporal awareness to ensure that the learner is in the right place at the right time to avoid collisions. For the beginner dancer the first few classes can be quite daunting and stressful. Therefore, the teacher may take an interdisciplinary perspective to assist the learner to acquire these movement techniques in a way that encourages self-regulation within the practice and a sense of belonging within the group to maintain motivation.

To do this, an approach might include showing the learners a video demonstration of expert Scottish country dancers performing the “Gay Gordons” while directing the learners’ attention towards the nature of the whole performance (for example, dancing with a partner, the patterned movements and the rhythm). Subsequently, the teacher may introduce the basic techniques and supervise the blocked practice of each step until the learners are more competent, followed by progressing the step using changes of direction and then gradually developing the complexity of step sequences. In doing so, the teacher needs to be aware of the physical and psychological potential for tiredness that will affect the execution and learning quality. Introducing some breaks followed by live demonstrations to remind learners of the key step techniques and adjusting the immediate sequence difficulty to enable return to form will help to address this concern across the entirety of the class. In addition, once learners are able to perform the steps and construct a sequence, the teacher might then replay the expert video demonstration to highlight the application of those steps within the group coordination context.

In summary, the approach offered has considered the physical/technical demand when designing the practice structure, the use of attention when observing a video demonstration and executing key technical elements, and finally, the social influence afforded by the status of those modelling the dance.



Linking question

How can video technology be used to monitor or influence progress in acquiring a skill? (Tool 2, B.2.3)

Consider:

- increasing technology options across a range of sensory modalities (such as vision, hearing and touch)
- video-based technologies are becoming easier to access
- smaller, less obtrusive and more robust cameras are enabling video capture in new ways and in previously hard-to-access places, such as strapped across athletes' chests, fixed on kayakers' helmets or attached to the handlebars of cyclists' bikes
- concurrent augmented feedback (feedback from external sources and separate from our natural senses during performance)
- feedback post-performance or concurrently (during performance)
- post-performance review, such as technique in the video could be checked or assessed against the training plans and goals to inform subsequent trials, upcoming tasks or session plans
- past/post-performance video review as a source of self-confidence.

Practice questions

1. What type of transfer occurs from a 3 versus 3 training game to a 5 versus 5 competitive basketball game? (1 mark)
 - A. Skill to skill
 - B. Abilities to skill
 - C. Practice to performance
 - D. Stage to stage
2. Using examples, explain how a coach can use task and environment constraints to increase motivation in novice performers. (4 marks)

Summary

- Skill implies that a specific action has been learned and has a predetermined outcome or goal.
- The information processing model depicts input as the environment that the performer may see, hear and feel. The output is what the performer does. The CNS is between the input and output.
- The senses are responsible for relaying information about the environment to the brain.
- Open-loop motor programmes account for the performance of a skill without recourse to feedback. It explains how we can carry out very fast movements.
- Closed-loop programmes describe how, as we learn a skill, we develop a perceptual trace. The perceptual trace is memory for the feel of successful past movements.
- Schmidt's schema theory is a motor programme theory that includes both open- and closed-loop control. Schmidt described a schema as being a set of generalized rules or rules that are generic to a group of movements.
- Schmidt believed that we develop two kinds of memory for movements, which he called the recall and recognition schemas. The recall schema is memory with regard to the choice and initiation of action. The recognition schema is memory for the feel of a movement, and it allows us to make appropriate changes in the action.
- Learning takes place in three stages: the cognitive, associative and autonomous stages.
- Linear pedagogy is an instructional approach that emphasizes a structured and sequential progression of skills.
- Non-linear pedagogy is a flexible and adaptable approach to teaching and learning that emphasizes the development of skills in context-rich environments.
- Ecological dynamics theory sees movement as a result of the interaction between the person and their environment.
- Dynamical systems theory is about how our bodies and brains work together to create movement and learn skills.

Check your understanding

After reading this chapter, you should be able to:

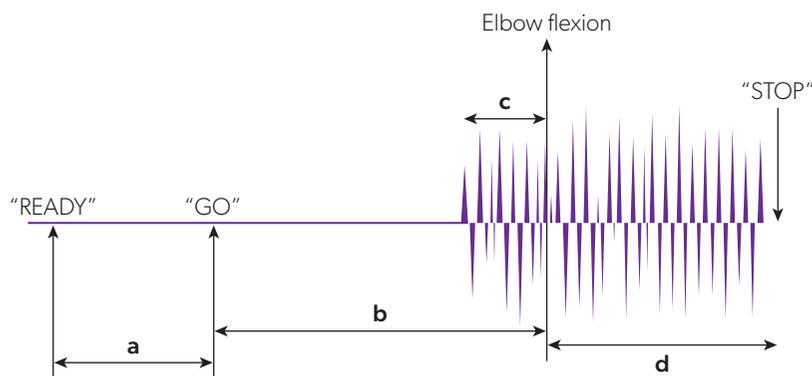
- define skill in sport
- outline learning and performance
- discuss transfer of learning
- describe the information processing model
- describe the psychological refractory period
- outline open-loop and closed-loop theory
- discuss schema theory
- describe the phases of skill learning
- discuss ecological dynamics theory
- distinguish between traditional linear and non-linear pedagogy.

Self-study questions

1. Explain why variability is an important feature of skill learning.
2. Explain why selective attention is important in sports performance.
3. Describe the psychological refractory period, and outline **two** examples from sport.
4. Distinguish between linear and non-linear pedagogy.
5. Explain how ecological dynamics theory can help an exercise leader to support individuals to lead an active life.

Data-based question

Electromyography (EMG) is the electrical recording of muscle activity. Figure 25 shows an EMG profile from one of the quadriceps muscle group of a basketball player recorded during a reaction time task.



▲ **Figure 25** An EMG profile from one of the quadriceps muscle group of a basketball player

1. Identify a, b, c and d. (2 marks)
2. Explain the psychological refractory period using an example from a sport of your choice. (4 marks)

C.2.2

Attentional control

Syllabus understandings

C.2.2.1 The proficient execution of specific skills requires the correct attentional focus.

Introduction

“Attention”, or the concentration of mental activity on the task at hand, is a crucial prerequisite of success in any field of skilled performance such as dance, music or sport. You will probably be familiar with teachers asking students to “pay attention” in class. You need to pay attention to something in order to remember it. Most sports psychologists accept that the hallmark of attention is the concentration of mental activity.

There are three cognitive dimensions of attention.

1. **Concentration** is an athlete’s deliberate decision to invest mental effort on what is most important in any given situation (for example, firm contact with the ball when presented with a goalscoring opportunity in soccer, and not the boos from the opposition crowd).
2. **Selective attention** is an athlete’s perceptual ability to “zoom in” on task-relevant information (such as the velocity of the incoming ball) while ignoring potential distractions (such as the deceptive movement of the goalkeeper).
3. **Divided attention** is the ability, as a result of practice, to coordinate two or more actions at the same time (for example, to look one way while passing accurately in the opposite direction to a teammate).

Within sports, the words concentration, attention and focus are often used interchangeably by coaches and athletes. But there are subtle differences.

- Concentration is “the ability to perform with a clear and present focus”.
- Focus is the central point of your attention.
- Attention is an active awareness of what you are observing.

When put together, an individual who is concentrating is said to have their attention focused clearly and presently on the task at hand. Once an athlete has developed the skills (and physical fitness) necessary for competition, the ability to control their attention in order to concentrate on the demands of the task is vital for highly skilled performance in sport and exercise.

In sport and exercise settings, concentration has several aspects, including:

- focusing on the relevant cues in the environment (selective attention)
- maintaining that attention over time
- having awareness of the situation
- shifting attentional focus where necessary.

Activity 1

A part of concentration is focusing on the relevant environmental cues (selective attention). Learning and practice can help a performer develop selective attention.

Can you think of relevant and irrelevant cues when executing a skill or technique during a sport of your choice?

Being able to maintain attentional focus throughout competition is key to effective concentration. This can help to make a champion.

In 2020, Polish tennis player Iga Swiatek stunned the tennis world when she won the French Open. She was ranked number 54 heading into the tournament, and became the singles champion without losing a set in any of her seven matches. This instantly made her one of the top young stars in tennis, and a significant part of her success was her ability to concentrate and remain unaffected by irrelevant cues such as a bad line call or missing an easy shot. Important ingredients of her training and preparation were how to maintain concentration for competitive tennis, and this included the use of self-talk (chapter C.4.2) and goal setting (chapter C.5.1), and developing a greater mental toughness (chapter C.1.2).



▲ Figure 1 Iga Swiatek's ability to maintain attentional control is key to her success

ATL Thinking skills

Maintaining concentration for long periods of time, such as the NBA Finals in the USA where you need to maintain concentration possibly during 7 matches across a 17-day period, can be challenging. Do you think it could be advantageous for a player to "switch off" and briefly relax when the ball is dead (for example, during a timeout) but switch back on to the game immediately once the timeout is over? Can you think of an example from your own favourite sport where this could happen?





▲ Figure 2 A timeout during the NBA Finals

Situation awareness

An athlete's ability to understand what is going on around them is known as **situation awareness**. This involves the ability to make decisions, often under pressure and time demands, based on the situation, for example, during the last play in a game when you need to score, taking into account what your opponents are doing.

Sports commentators comment positively about competitors who seem to be able to do just the right thing at the right time—they seem to be one step ahead of everyone else in their decision-making and actions.

Often, this type of athlete has "attentional flexibility". They can shift their focus of attention as demanded by the situation. For example, from a broad external focus to a broad internal focus and then to a narrow internal focus (refer to the section later in the chapter on "types of attentional focus").

Shifting attentional focus is easier in situations that are self-paced (such as archery) but more challenging in sports when there are time pressures, such as a 400 m hurdles final (here, the athlete needs to be aware of the next hurdle, their stride length, their position in the race, and their personal race judgement and effort to achieve a personal best).



▲ Figure 3 Archery requires focused attentional control but is self-paced



▲ Figure 4 Running the 400 m hurdles requires challenging shifts of attentional focus

Concentration and distractors

Why do skilled performers “lose” their concentration?

An athlete may experience **internal distractors** (such as daydreaming about their upcoming holiday, or worrying what their coach might think). Other internal distractions include feelings (such as anger) or bodily sensations (such as fatigue).

Athletes may also experience **external distractors**. These tend to be auditory or visual (such as spectator noise or flash photography).

The outstanding research on attention by Professor Aidan Moran (1956–2020) included exploring some principles governing effective concentration. He stated the five key building blocks of effective concentration that should underpin practical work with performers are as follows.

1. Decide to concentrate—it will not just happen by chance. For example, when a badminton player enters the changing room before a game, this reminds them to turn on their “concentration switch”.
2. Focus only on one thought at a time. For example, single-word self-talk, such as “smooth”. (But note that skilled athletes can perform two or more actions at the same time, provided the skill being performed no longer requires conscious control.)
3. Your mind is “focused” when you are doing exactly what you are thinking.
4. You “lose” concentration when you focus on factors that are outside your control (such as weather).
5. Focus outwards when you get nervous—outwards on actions, not inwards on doubts!

Key points

- External distractors refer to irrelevant task information within the environment responsible for diverting attention away from the necessary information required to perform a skill.
- Internal distractions, such as thoughts, are subjective and originate from within. External distractions originate outside of you.
- External distractions can include, but are not limited to, crowd noise, crowd movement, flash photography, officiating decisions, weather conditions, teammate mistakes and opponent intimidation.

Controlled distraction

Athletes employ several methods to overcome the impact of distractions on sport performance. Controlled distraction methods enable athletes to increase awareness of distractors and enhance their understanding of the task-relevant information to execute the skill.

The following example of a golfer teeing-off helps to illustrate attentional processes, distractors and some techniques for exercising distraction control.



▲ Figure 5 A golfer teeing-off in front of a crowd

A golfer who wishes to successfully perform a “drive” (the first shot when playing a golf hole) needs to direct their attention effectively to avoid distraction undermining the successful outcome.

As part of their preparation, the golfer determines the type of shot they will play by locating a target that is advantageous for their second shot. The golfer must direct attentional focus to consider natural features and environmental factors. For example, golfers normally attend to the width and shape of the fairway, and to hazards, such as water, trees and sand bunkers. A golfer may also pay attention to environmental factors, such as the wind and the undulation of terrain.

Once all factors have been considered, the golfer turns attention to the type of shot they plan to execute. In doing so, they formulate the technical requirements needed. They then direct attention to shot execution. This normally involves singular attention on the ball to help with how they swing the club.

Several techniques can be actioned to enable attention to remain on the necessary information for performance.

Deliberate decisions

A **deliberate decision** to invest mental effort can be triggered in identifying the task-relevant information. For example, a golfer can embrace a metaphor for directing attentional control when stepping onto the tee box by metaphorically employing the terms “switch on” and “switch off” in respect to attention. Learning to deliberately access attention increases the golfer’s control for when and how they wish to direct attention during the preparation of the shot.

Performance goals

Performance goals are behavioural outcomes that direct attention towards task-relevant information around desirable, relevant and controllable outcomes. For example, a set of performance goals for the golfer’s “drive” from the tee box might include: “select a target on the fairway”, “plan the first shot considering the second shot”, “visualize the ball in flight after committing to the plan”, or “always keep my eye on the ball during the swing”.

Trigger words

Trigger words can be used to direct attention. For example, using the word “target” when scanning a golf fairway, or “balance” when swinging the golf club can be useful in anchoring attention around the key properties of the skill.

Routines

Routines, when well learned, promote control of attentional resources to focus on relevant performance information. They also prevent over-thinking already well-learned skills, such as a golf swing. Routines are effective in deactivating anxious thoughts. They direct attention away from negative thoughts. For example, cognitive anxiety may arise because the golfer is looking at a water hazard. However, a pre-shot routine that includes visualizing the successful shot trajectory can override this anxiety.



◀ Figure 6 A pre-shot routine may be used to override anxiety about a water hazard

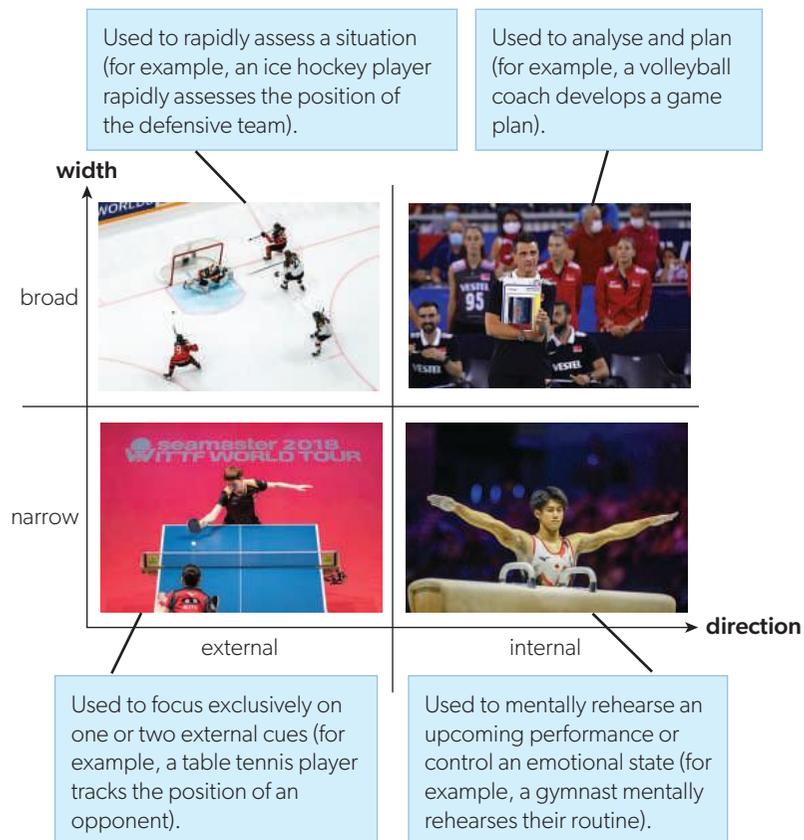
Mental practice

Mental practice involves seeing and feeling a skill in one's imagination before its execution. It brings a form of simulation, whereby different situations can be visualized before needing to perform skills. Mental practice can help the performer anticipate distractors and prevent them from negatively impacting their performance.

Types of attentional focus

It is often necessary to shift attentional focus during competition. This is when athletes alter the scope and focus of attention as demanded by the situation. Various types of attentional focus are appropriate for specific sports and activities. This has led to viewing attentional focus along two dimensions: width (broad or narrow) and direction (external or internal).

- A broad attentional focus allows a person to perceive several occurrences simultaneously. This is important in sports where athletes are competing in a rapidly changing environment (one where they must respond to multiple cues, such as an ice hockey player dribbling the puck along the ice, avoiding and moving past opponents, and trying to shoot at goal).
- A narrow attentional focus occurs when you respond to only one or two cues. For example, the flight of the shuttlecock in badminton.
- An external attentional focus directs attention outwards. For example, an opponent's movements in baseball.
- An internal attentional focus is directed inwards to thoughts and feelings. For example, when a high jumper prepares to start their run-up.



▲ Figure 7 Four types of attentional focus

Activity 2

Potential external visual distractors for elite sportspeople include knowing people in the audience and/or the television camera crews.

Potential external auditory distractors for elite sportspeople include noise from aeroplanes flying overhead and/or mobile phones ringing.

1. Can you think of another powerful external **visual** distractor for your favourite sport?
2. Can you think of another powerful external **auditory** distractor for your favourite sport?

Case study

Focus of attention strategies help with perseverance

Psychobiology sees endurance fatigue as exhaustion that is not related to inability to continue. Rather, it is the individual's decision to "give up".

One study (Comani et al., 2013) of a 20-year-old road-cycling athlete investigated his time-to-exhaustion when using either a dissociative focus of attention strategy or an associative focus of attention strategy. The task involved cycling to exhaustion at an exercise intensity equal to the speed at his anaerobic threshold +10%, while maintaining pedalling at his individual optimal pedalling rate (IOPR).

During one trial, the cyclist used a dissociative focus of attention strategy: he was asked to focus on a metronome that reproduced his IOPR.

During another trial, the cyclist used an associative focus of attention strategy: he was asked to focus on his internal individual rhythm while trying to maintain his IOPR, without the metronome.

The time-to-exhaustion using the dissociative focus was just over 28 minutes. With the associative focus it was just under 26 minutes.



▲ Figure 8 Time-to-exhaustion may be improved using attention strategies

Key term

Level of arousal The level of physical and psychological activation, from low arousal to high arousal.

Arousal and attentional narrowing

Individuals have a limited amount of attentional capacity available at any one time. The attentional capacity that we have at any one time is related to our **level of arousal** (chapter C.4.1).

In sports, arousal levels can range from low (relaxed) to high (intense). Arousal can be influenced by various factors, such as the importance of the competition. When arousal levels are high, athletes experience a state of increased physiological activation, such as increased heart rate, rapid breathing and heightened muscle tension. This state is often associated with feelings of excitement, anxiety and stress.

High arousal can be beneficial for sports that require high levels of strength, speed and power, such as sprinting or weightlifting.

Low arousal can be beneficial for athletes in sports that require fine motor control and concentration, such as archery or golf.

Attentional narrowing is a similar concept to selective attention, but refers to the tendency of individuals to focus their attention on a limited set of cues or stimuli when in a high state of arousal. Conversely, when levels of arousal are low, an athlete may experience too broad an attentional field, leading to their attention being drawn to both appropriate and inappropriate cues.

For example, a basketball player may have their attention simultaneously on things such as teammates, the opposition, where the ball is, instructions from the coach or crowd noise. This could demand too much attention and interfere negatively with their performance. However, as their arousal increases, they may experience attentional narrowing. This attentional narrowing enables the basketball player to focus on relevant cues and filter out distractors—so, attentional narrowing can be advantageous. The basketball player may focus exclusively on the rim and their shooting technique during a free throw, excluding any other distracting stimuli. This narrowed focus helps to enhance concentration, accuracy and decision-making.

However, attentional narrowing can also have negative effects on performance. When an athlete becomes too fixated on a single cue or is overly focused on internal thoughts (for example, they worry about making a mistake), their attention can become excessively narrow. This may lead to a reduction in overall performance. Hence, it is important for athletes to find their optimal arousal level and develop strategies to maintain it.

ATL Thinking skills

Can the effects of attentional narrowing create a handicap for players participating in invasion team games (such as field hockey, rugby, lacrosse, handball) who need to be aware of all that is happening around them?



▲ **Figure 9** Players in invasion team games need to be aware of all that is happening around them

ATL Thinking skills

Research in recent years has identified a relationship between arousal and attentional control. Specifically, in situations that induce high arousal, attention is difficult to control and can result in attentional narrowing.

The process of attentional narrowing reduces the availability of relevant information to the athlete when scanning for task-relevant information. As high-arousal situations result in attentional narrowing, the athlete becomes limited in terms of the amount of available information informing the decision process, leaving them compromised.

As successful decision-making relies on a complete picture informed through multiple sources of relevant information, a high probability exists of impaired performance.

Arousal control, therefore, becomes a necessary skill when attentional control is required. By reducing physiological arousal (for example, via breath control), an athlete can regulate away from an overly fixated narrow attentional field towards a broader focus. With successful arousal control, an athlete can improve their performance by focusing on a greater number of relevant cues from the environment.



Linking question

How can mental toughness training prevent attentional narrowing? (C.1.2)

Consider:

- attentional narrowing, and how it differs from focused attention
- whether mental toughness can help individuals recognize the signs of attentional narrowing
- the relationship between mental toughness and the ability to switch attention between different stimuli and adapt to changing situations

- mental toughness → managing distractions → effective attentional focus
- mental toughness and stress management.

Imagine a soccer player who requires a broad attentional focus to take in, for example, the position of the opposition, where the ball is when in-possession and out-of-possession, and communication to and from teammates. How could mental toughness help this player?

Attentional focus and motor learning

Physical education teachers, sports coaches and athletes need to know and understand:

- how can skill learning be facilitated?
- how can performance be optimized?

Attentional focus has been characterized as either associative (focusing on bodily sensation) or dissociative (blocking out sensations resulting from physical effort), or in terms of its width (broad versus narrow) and direction (internal versus external).

Another distinction has been found to have an important impact on the effectiveness (such as balance or accuracy) and efficiency (such as muscular activity, maximum force production, speed or endurance) of motor performance, and on the speed of the learning process. There is empirical evidence for the benefits of adopting an external focus on the intended movement effect (for example, on an implement) relative to an internal focus on body movements.

Skilled performance is associated with:

- **effectiveness:** accuracy, consistency and reliability in achieving the movement goal
- **efficiency:** fluent and economical movement executions and automaticity, as evidenced by the investment of relatively little physical and mental effort.

The benefit to performance and learning when using an external compared with an internal focus of attention has been demonstrated for a wide variety of sports skills, including in soccer, volleyball, basketball, swimming, running, kayaking and gymnastics. Many studies have shown that an external focus of attention speeds up the learning process so that a higher skill level (increased effectiveness and efficiency) is achieved sooner.



► **Figure 10** Studies have shown that an external focus of attention speeds up the learning process

A person's attentional focus often has a similar influence on both immediate performance (during the practice phase) and learning (a more permanent change in the capability to perform a skill). For example, throwing and kicking accuracy improves with an external focus. In one study, basketball free-throw shooting accuracy benefited from a focus on the basket or ball trajectory compared with a focus on wrist flexion. Interestingly, studies have shown that an external focus during throwing and kicking seems to make performance more resistant to skill failure when under pressure. For instance, when kicking a ball in soccer (for example, shooting at goal), directing players' attention to the part of the ball that they would strike (external) rather than the part of the foot that would contact the ball results in greater accuracy in hitting the target.

Consider another example when assessing performance (rather than learning) from a movement efficiency perspective. A movement pattern is more efficient (or economical) if the same movement outcome is achieved with less energy expended. Indirect measures of efficiency that have been used in examinations of attentional focus effects include maximum force production, movement speed or endurance. The production of maximum forces requires an optimal activation and timing of agonist and antagonist muscles to achieve muscular coordination and speed of movement.

Interestingly, in one study, experienced kayakers were told to paddle a distance of 75 m as quickly as possible under different focus conditions. The study compared the effects of a distal external focus (the finish line) and a proximal external focus (boat stability). The distal focus led to greater racing speed, whereas the proximal focus produced the slowest time.

Open skills (such as kayak racing) are often performed under environmental conditions that are constantly changing and often unpredictable. As Schmidt et al. (2019) highlighted, in those situations it is not possible to effectively plan the whole action in advance, because:

Success in open skills is largely determined by the extent to which the individual is successful in adapting the planned motor behaviour to the changing environment. Often this adaptation must be extremely rapid, and the effective responder must have many different actions ready to implement.

Factors that contribute to changes in the environment may include other performers (such as teammates and opponents) or the natural environment itself (such as the wind, water or weather).

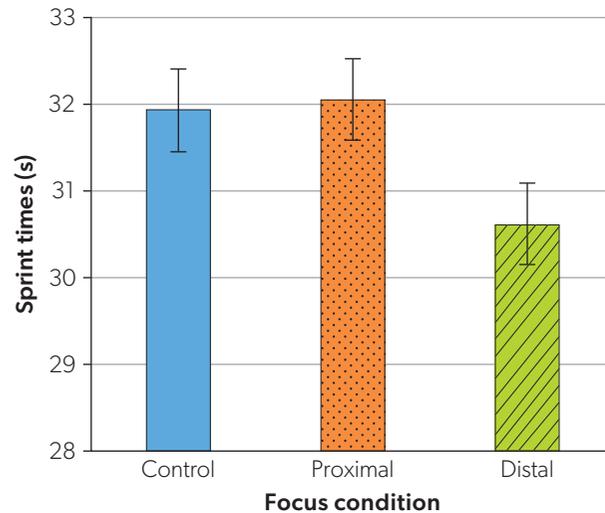
Another recent study examined the potential benefits of an external focus for the performance of an open, continuous skill: wild water kayak sprinting. This was selected as it provided variation in the performance environment (openness), via moving water and river topography.

Other studies have previously shown that a focus on a movement effect that occurs at a greater distance from the body results in more effective performance than a focus on a more proximal movement effect (that is, increasing the distance of the external focus from the body led to greater learning benefits). For example, participants who were asked to concentrate on markers on a balance platform that were away from their feet (distal external focus) demonstrated more effective balance learning than participants who were asked to concentrate on the feet themselves (internal focus). This is a “distance” effect.

Banks et al. (2020) investigated whether a distal focus (“think only about the finish—imagine arriving as fast as you can”) would enhance 100 m wild water racing performance in experienced kayakers, relative to a proximal focus (“concentrate on the paddle—use it as well as you can to sprint fast”). They also included a control condition in which the kayakers were free to adopt their own attentional focus. Their study showed that skilled kayakers performed a 100 m wild water racing sprint more effectively (faster) when they were asked to adopt a distal external focus compared with a more proximal focus or no instructed focus (control condition) (Figure 12).



▲ Figure 11 Wild water kayak sprinting



▲ Figure 12 Average sprint times for the experienced kayakers over 100 m on a “wild” water river

Non-linear pedagogy and attentional control

Non-linear pedagogical strategies (chapter C.2.1) that take into account attentional focus can help physical educators and coaches design learning environments to improve both learning and performance.

For example, it can be beneficial to shift the focus of instructions from internal thoughts and processes to external outcomes or effects of movement. By doing so, learners can tap into their innate ability to self-organize and adapt their movements without relying heavily on conscious control.

Self-organizing processes allow learners to adapt their strategies and behaviours based on their individual needs and the context in which they are learning. They learn to perceive, respond and adapt to the dynamic nature of learning environments, for example:

- feedback can help educate the attention of the learner to perceive and use relevant information sources to enhance both learning and performance
- questioning can be used when the coach wants to make the athlete more aware of the need for their attentional focus to be on a specific source of information.

For example, if a badminton player’s recovery relative to the court centre line is not quick enough, the coach may question the athlete about their position when defending a shot from their opponent, and if there are possibly better positions on the court to do this.



Measurement

Two different coping strategies—association and dissociation—are used by athletes during endurance activities such as distance running.

Association involves focusing attention on internal cues and sensations related to the activity itself (for example, breathing rate, heart rate and muscle tension).

Dissociation involves diverting attention away from the physical sensations and focusing on external stimuli unrelated to the activity (for example, listening to music or thinking about something they are looking forward to).





Despite more than 40 years of investigation, conclusive agreement on the merits (improved performance) of both association and dissociation has yet to be reached. The major method to determine the attentional focus of performers has been self-report using retrospective questionnaires, intermittent data collection, and concurrent data collection during exercise.

However, there are limitations to self-report methods (such as a tendency to forget or not report thoughts with retrospective recall, particularly if the event is of long duration). With intermittent collection during exercise, there may be an inclination to generalize thought content, or report only the most recent thoughts experienced. During concurrent collection, there may be a risk of disruption to natural thought development.

Do you think these data collection limitations may have distorted the reliability of findings and recommendations?



Linking question

How do mentally tough individuals respond to overreaching? (A.3.1)

Consider:

- knowing and understanding the signs of overreaching (listening to your body)
- modifying goals towards realistic target setting (being adaptable and prepared to adjust training loads)
- looking for support from others (such as coach, sport psychologist, teammates)
- ensuring adequate rest, nutrition and recovery time (focus on recovery)
- learning from setbacks (analyse causes of overreaching and identify how to improve)
- maintaining a positive mindset (for example, accept and understand that setbacks are part of the athletic journey)
- accepting and embracing functional overreaching
- maintaining focus on long-term goals.

Practice questions

1. What is the role of selective attention? (1 mark)
 - A. To filter relevant information from noise
 - B. To hold all information for seconds
 - C. To store relevant information for years
 - D. To pass all information to the long-term memory
2. Explain how a sprinter uses selective attention to optimize their start time and improve their performance in a race. (3 marks)

Summary

- Attention on the task at hand is key for success in any field of skilled performance.
- There are three cognitive dimensions of attention: concentration, selective attention and divided attention.
- Concentration is the ability to perform with a clear and present focus.
- Athletes can lose concentration because of internal and external distractions.
- Athletes can employ controlled distraction to overcome the impact of distractions on sports performance.
- Attentional focus can be viewed along two dimensions: width (broad or narrow) and direction (external or internal).
- There is empirical evidence for the benefits of adopting an external focus on the intended movement effect.
- The attentional capacity that we have at any one time is related to our level of arousal.
- Mental toughness training can help prevent attentional narrowing.
- Attentional focus can facilitate skill learning.
- Attentional focus can help optimize performance.
- Non-linear pedagogical strategies contribute to learning environments that improve both learning and performance.

Check your understanding

After reading this chapter, you should be able to:

- outline three cognitive dimensions of attention
- list four aspects of concentration
- describe the five key building blocks of effective concentration for sports performers
- discuss controlled distraction
- explain the different types of attentional focus
- outline the relationship between arousal and attentional narrowing
- discuss attentional focus and motor learning.

Self-study questions

1. State **two** cognitive dimensions of attention.
2. Outline **three** methods an athlete can employ to overcome the impact of distractions on sport performance.
3. Discuss the relationships between arousal, attentional narrowing and sport performance.
4. Distinguish between proximal and distal external focus, providing an example of each in the context of sport.
5. Explain **two** types of attentional focus, using examples from two different sports.

Data-based question

A study aimed to investigate the effects of attentional focus on postural control in older adults (aged 60–74 years). Methods involved the focus of attention, which was manipulated by instructing two groups of participants to hold a glass full of water while focusing on either their hand (internal focus of attention—group 1)

or the glass (external focus of attention—group 2) while maintaining balance on an unstable platform for three 30-second trials. The average scores for their stability/balance pre and post four weeks of practice are shown in Table 1. Higher scores mean lower stability/less balance control and vice versa.

▼ **Table 1** Results of a study aiming to investigate the effects of attentional focus on postural control in older adults

Attentional focus	Stability score	pre	post
internal	overall stability	16.7	14.2
	anterior-posterior stability	12.5	10.3
	medial-lateral stability	11.6	9.8
external	overall stability	16.9	11.4
	anterior-posterior stability	12.8	7.7
	medial-lateral stability	12.2	8.1

Source: Baniyadi et al. (2018).

1. Identify which group had the better overall stability at the start of the intervention. (1 mark)
2. Calculate the difference between pre and post external anterior-posterior stability scores. (2 marks)
3. Discuss the effects of focus of attention on stability/balance in older adults. (3 marks)

C.3

Motivation

What are the psychological processes that drive human behaviour, and how can these be influenced?

This topic begins by defining motivation, outlines types of motivation and then explains the concept of achievement motivation. The topic progresses to discuss self-determination theory and its influence on motivation and performance in sport and exercise. Finally, the topic reviews motivational climate, the need to learn about participants in physical activity settings, and the importance of structuring teaching and coaching environments to motivate individuals.

C.3.1 Achievement motivation

Syllabus understandings

C.3.1.1 Need achievement theory posits that personality and situational factors interact to produce resultant factors, which create emotional factors, which drive behavioural factors.

C.3.1.2 Goal orientation theory assumes that individuals strive to feel successful.

C.3.1.3 High ego orientation can be problematic if task orientation is low.

AHL

Introduction

Sport and exercise offer opportunities to participate in physical activities that enhance cardiovascular health, relieve stress and help maintain healthy minds and bodies. To gain these potential health benefits, individuals need to be motivated to participate. It is, therefore, important for sport psychologists, coaches, teachers, parents and participants to understand motivation, its impact on sports performance and how it influences physical activity levels.

This chapter will begin by defining motivation before outlining some of the most influential motivational theories, including intrinsic and extrinsic motivation, need achievement theory and goal orientation theory.

Definitions of motivation

In simple terms, motivation can be defined as the **direction** and **intensity** of one's effort (Sage, 1977).

- Direction of effort describes whether an individual is attracted to, seeks out or approaches certain situations. For example, a student may be motivated to try to gain a place on the school soccer team but not on the gymnastics team.
- Intensity of effort describes the amount of effort a person exerts. For example, an athlete may attend a training session but not put much effort in, or become too intense and perform poorly in competitions.

Individuals, therefore, differ in both the direction and intensity of their behaviours. Two different people may be motivated to play tennis, but one of them may be more strongly motivated (have greater intensity) than the other. Or one person may be interested (directed) in participating in sport for social reasons, whereas another may be more interested in exercising for health benefits.

Gage and Berliner (1984) use the analogy of a motor car, where the engine is the intensity and the steering is the direction of motivation. For the majority of people, however, direction and intensity of behaviour are closely related and are difficult to separate. For example, athletes who regularly and punctually attend training typically expend good effort during participation.

ATL Thinking skills

Think about your own direction and intensity of effort in different sports or physical activities.

Which sports or physical activities are you directed towards?

Does your intensity vary for these different activities?

ATL Thinking skills

What is your favourite sport and why do you choose to play this sport?

ATL Thinking skills

Think about the sports or physical activities that you participate in and consider whether your motives are more intrinsic or extrinsic.

Key point

Motivation has five behavioural factors.

- Direction—you make a decision to do a particular sport/exercise.
- Persistence—you put in effort and practise the skills.
- Continuing motivation—even if you are injured or stop the sport for some time, you still come back to it.
- Intensity—you try hard during training and competition.
- Performance—you achieve better performance over time.



▲ Figure 1 Individuals need to be motivated to participate in sports and exercise

Others define motivation as an internal process that activates, guides and maintains behaviour over time. In other words, motivation is “what gets you going, keeps you going and determines where you’re trying to go” (Slavin, 2003).

According to Roberts (2001), “the study of motivation is the investigation of the energization, direction and regulation of behaviour”, and motivational theories need to address all three aspects to be recognized as a theory.

Weinberg and Gould (2023) define motivation as the direction and intensity of effort, especially the direction and intensity of one’s effort across time.

Motivational theories ask why we do things, and the history of motivational research has been a search for the “right” theory.

Types of motivation

An important distinction in the types of motives for human behaviour is between **intrinsic** and **extrinsic motivation**.

- Intrinsic motivation comes from within the person. Intrinsic motives for taking part in sport and physical activity include excitement, fun, enjoyment and the chance to improve skills (Deci, Ryan, 1985).
- Extrinsic motivation results from external rewards (such as money, trophies and prizes) and less tangible rewards (such as praise and status).



▲ Figure 2 The players of Elgin City FC, led by Rory MacEwan in the blue boots, celebrate after scoring a last-minute winner against their top of the table opponents (Dumbarton FC) to ensure they were not relegated from the Scottish second division of professional football in 2023



◀ **Figure 3** Ollie—a talented basketball player—with some of his trophies. Trophies, medals and other prizes are common in sports.

Combining intrinsic and extrinsic motivators

The “additive principle” suggests that intrinsic motivation can be boosted by extrinsic motivators. However, contrary to popular belief, this is not always a good idea. In fact, in some situations where the task is being performed because of intrinsic motivation, extrinsic rewards can *lower* the person’s intrinsic motivation.

Deci and Ryan (1985) developed cognitive evaluation theory to explain this phenomenon. This theory states that rewards can be divided into two types: controlling rewards and informational rewards. Controlling rewards include praise and trophies and are given to influence (control) an individual’s behaviour. Informational rewards on the other hand convey information about an individual’s competence at a particular task. According to Deci and Ryan, rewards perceived by the recipient as controlling decrease intrinsic motivation, whereas rewards viewed as informational increase intrinsic motivation.

While some motives are clearly intrinsic (such as, “I go cycling because it’s fun”) and some are clearly extrinsic (such as, “I play professional sport because I get paid to do so”), others are less clear. For this reason, Deci and Ryan proposed that viewing motives as either intrinsic or extrinsic is too simplistic. They developed a continuum of motivation called self-determination theory to explain this. We will study self-determination theory in chapter C.3.2.

McClelland–Atkinson need achievement theory

The link between the desire to achieve and sporting success is an obvious one. A strong need to achieve will be an important factor in determining how hard you train and how much effort you exert in competition.

The **need achievement theory** of motivation was first put forward by McClelland and taken forward by Atkinson (Atkinson, 1974; McClelland, 1961). The theory is that motivation is a balance between the motive to achieve success and the motive to avoid failure. When people enter into a sport or exercise situation, they do so with an approach–avoidance conflict. On one hand, they are motivated because they want to succeed. On the other hand, they are motivated because they want to avoid failure.

ATL Thinking skills

In sport and exercise, it is common to receive prizes, trophies or recognition for superior performance, such as winning a race or competitions.

How does the use of these external rewards influence intrinsic motivation for an activity?

Activity 1

List all the types of rewards an athlete can receive from their sporting achievement.

Discuss if these rewards are useful in enhancing intrinsic motivation for their future participation.

Key point

Intrinsic motivation comes from within the person. It is associated with doing an activity for itself and for the pleasure and satisfaction derived from participation.

Extrinsic motivation results from external rewards such as money, trophies and prizes.

Key point

Need achievement theory argues that motivation is a balance between the motive to achieve success and the motive to avoid failure.

achievement motivation = the desire to succeed – the fear of failure

According to McClelland and Atkinson, achievement motivation is a personality trait.

- For some, the desire to succeed outweighs the fear of failure. These individuals are said to be high in achievement motivation.
- For others, the fear of failure is the more important factor. These individuals are said to be low in achievement motivation.

However, it is not only personality factors that predict behaviour. Situational factors have an effect as well, such as the probability of and incentive for success.

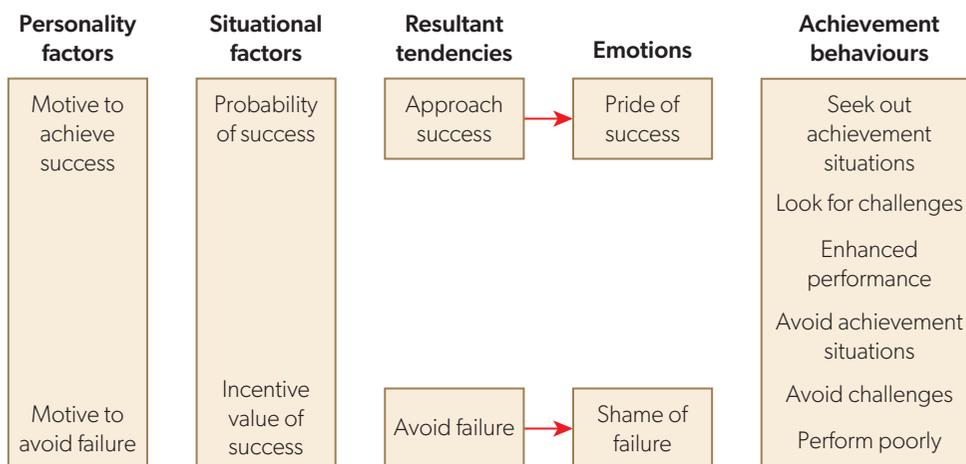
Coaches, sport scientists and health professionals can change situational factors to influence how individuals approach achievement situations. So, if the probability of success is high and the rewards are great, individuals are likely to be motivated to participate even if they have low achievement motivation.

There are five components that contribute to need achievement theory (Figure 4):

- personality factors
- situational factors
- resultant tendencies
- emotions
- achievement behaviours.

Key point

For individuals who are high in achievement motivation, the desire to succeed outweighs the fear of failure. For others, the fear of failure is the more important factor; these individuals are low in achievement motivation.



▲ Figure 4 Need achievement theory

An individual’s resultant behavioural tendency is derived by considering the personality factors in relation to the probability or incentive value of success. Weinberg and Gould (2003) suggested that the theory is best at predicting situations when there is a 50–50 chance of success.

The different behaviour patterns of high achievers and low achievers are outlined in Table 1. In such situations, high achievers seek out challenges because they enjoy competing against others of equal ability and performing challenging tasks. Low achievers, on the other hand, avoid challenges, opting for easier tasks where failure is less likely, or very difficult tasks where no one expects them to win. Low achievers avoid the negative evaluation associated with failure, and a 50–50 chance of success causes them maximum uncertainty and worry. Both high and low achievers want to experience pride and minimize shame, but high

achievers focus more on pride, whereas low achievers focus more on shame and worry. High achievers select more challenging tasks, display high levels of effort, focus on the pride of success and continue to try hard in difficult situations. Low achievers avoid challenging situations, exert less effort and persistence, and focus more on the shame of failure.

▼ **Table 1** Behaviour of high achievers versus behaviour of low achievers

High achievers	Low achievers
select challenging tasks	avoid challenging activities
display a high level of effort	exert less effort when they take part
continue to try hard in difficult situations	exert less persistence when they take part
focus on the pride of success	focus on the shame of failure

Gill (2000) reviewed the research into need achievement theory on the choice of high- and low-difficulty tasks and found strong support for high achievers seeking out difficult tasks and low achievers' preference for easy tasks. However, according to Gill, the theory does not reliably predict sporting performance. That said, this approach has been very important in developing an understanding of motivation and serves as the framework in more contemporary motivational theories.

ATL Thinking skills

Do you seek out or avoid tasks where there is a 50–50 chance of success? Why?

Goal orientation theory

Goal orientation theory (Nicholls, 1989), also known as achievement goal theory, proposes that in achievement settings such as sport and exercise, an individual's main concern is to demonstrate high ability and to avoid demonstrating low ability.

Ability, however, can be viewed in different ways based upon two states of goal involvement: task orientation and ego orientation.

- Task-oriented individuals focus on mastery of the task (the learning of skills, exerting effort and self-improvement).
- Ego-oriented individuals focus on demonstrating superior ability compared with others and on winning in competitions with less effort than others.

According to goal orientation theory, three factors combine to determine motivation:

- achievement goals
- perceived ability
- achievement behaviour.

Nicholls (1989) argued that perceived ability has a moderating effect on an individual's behaviours. This effect depends on whether the individual adopts task or ego goals.

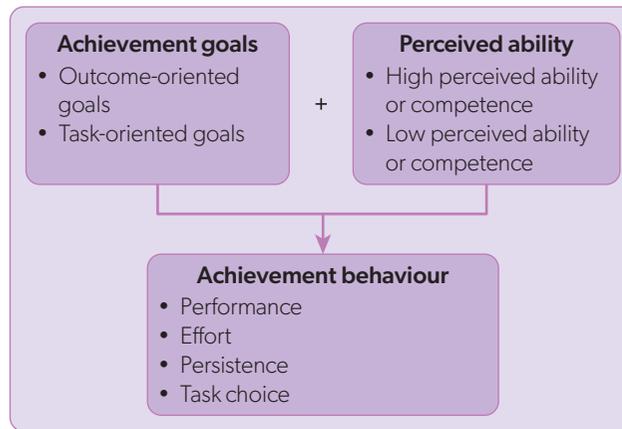
When task goals are adopted and the individual is task involved, perceived ability is not relevant, since the criteria for success are self-referenced rather than comparative to others. In such circumstances, behaviours are most likely to be positive and the individual is predicted to persist in the face of difficulty, exert effort, choose challenging tasks and be interested in the activity.

On the other hand, when an individual adopts ego goals and is ego involved, perceived ability is of greater importance because the demonstration of ability

Key points

- Task-involved individuals focus on mastery of the task—learning skills, exerting effort, and self-improvement.
- Ego-involved individuals focus on demonstrating superior ability compared with others.
- Goal orientation theory states that an individual's goal involvement in a particular situation is the combined result of their achievement goals (goal orientations) and the prevailing situational factors (motivational climate).
- Goal orientations are an individual's proneness to be task or ego involved, which result from childhood socialization experiences at home, in the classroom or from previous experiences of sport and exercise activity. Although there is some evidence that these goal orientations can be influenced over time, they are relatively stable and unlikely to change in the short term. Nicholls argued that task and ego goal orientations are independent dispositional tendencies, which means that an individual can be high or low in either, or both, at the same time.

compared with others is now highly significant to the individual. According to Nicholls (1989), in such circumstances, if perceived ability is high, positive motivational behaviours are predicted, as it is likely that high ability will be demonstrated. However, if perceived ability is low then more negative behaviours such as avoiding challenges, lack of effort, reduced persistence and the devaluing of tasks are predicted.



▲ Figure 5 Three key factors in the goal orientation approach



Linking question

How can an athlete's achievement orientation be manipulated by a motivational climate? (C.3.3)

Consider:

- motivational climate is the context in which a person is motivated to achieve a goal
- achievement goal orientation (mastery or performance orientation) is a type of goal that individuals set for themselves in achievement situations
- achievement motivation (a personality trait) is an individual's drive to achieve success in various areas of their life
- whether the motivational climate is one of competition and winning, or of cooperation and support.



Linking question

How is goal orientation associated with self-determination? (C.3.2)

Consider:

- performance and mastery orientation
- intrinsic motivation, mastery orientation and autonomy
- autonomy-supportive environments.



Linking question

To what extent can technology be used to enhance motivation? (Tool 2)

Consider:

- personalized feedback and encouragement
- supportive communities
- tracking and monitoring progress.



Linking question

How can scientists use control groups to claim causation between achievement orientation and motivational climate? (Inquiry 1)

Consider:

- statistical comparison
- defining variables (achievement orientation and motivational climate)
- random assignment to experimental and control groups
- experimental group intervention (such as a task-oriented motivational climate)
- data collection pre and post.

High ego orientation

High ego orientation refers to a tendency to focus on one's own abilities and accomplishments in comparison with others, whereas low task orientation refers to a lack of focus on achieving a specific self-referenced personal goal or task. In the context of sport, exercise and health, high ego orientation can be problematic if task orientation is low because it can lead to a lack of focus on achieving specific personal goals or objectives. Also, the buffering effects of high task orientation, which would enable a performer to focus on how they can improve when they lose, would not be available to draw upon. For example, if an athlete, exerciser or health-conscious individual has a high ego orientation but a low task orientation, they may become overly focused on winning and comparative accomplishments, and may not be as effective at working towards specific self-referenced goals. This can also lead to a lack of collaboration and cooperation with others in team games, and may result in the person being less effective at achieving their own individual and team goals.

Furthermore, high ego orientation and low task orientation can lead to a lack of enjoyment and satisfaction from the activity. This is because a focus on outperforming others can make the activity feel like a competition, rather than something that is enjoyable and satisfying in its own right. Overall, high ego orientation can be problematic if task orientation is low in the context of sport, exercise and health because it can lead to a lack of focus on achieving self-referenced goals and objectives and can decrease enjoyment and satisfaction from the activity.

An example of when high ego orientation can be problematic if task orientation is low in soccer is when team members are focused on individual performance and accomplishments rather than working towards the team's goals. In this situation, individuals may become overly focused on their own abilities and statistics, and may not be as effective at working together and achieving the team's objectives. For example, if a soccer team player has a high ego orientation and a low task orientation, they may be more concerned with scoring goals or making impressive plays than with supporting their teammates or working together to create scoring opportunities. This can lead to a lack of teamwork and collaboration, and can result in the team being less effective at achieving their goals. Overall, high ego orientation in soccer can be problematic because it can lead to a lack of teamwork and collaboration.



▲ Figure 6 Team sports, such as soccer, require teamwork and collaboration

High ego orientation and perceived ability

High ego orientation refers to a focus on outperforming others. Perceived ability is an individual's belief in their own capabilities. In the context of sport and exercise, high ego orientation is acceptable when one's perceived ability is high because it can lead to confidence and a positive attitude. For example, if an athlete has a high ego orientation and a high perceived ability, they may be more confident in their abilities and more motivated to engage in the activity. This can lead to improved performance and enjoyment of the activity. On the other hand, if an athlete has a high ego orientation but a low perceived ability, they may become anxious, stressed or frustrated when they lose in competitions. This can lead to a lack of motivation and engagement in the activity, and may even result in the person dropping out or making excuses to avoid participating.

Overall, high ego orientation can be acceptable when one's perceived ability is high in the context of sport and exercise, but it can lead to anxiety, dropout or excuses if one's perceived ability is low. This is because a high ego orientation can lead to confidence and motivation when an individual believes in their own abilities to win, but can lead to anxiety and lack of motivation if they do not believe in their own abilities.

When ego is challenged

Consider an example from swimming. Swimmers may seek to protect their ego and become defensive if it is challenged because the ego is closely tied to one's sense of self-worth and identity. In swimming, the ego can be particularly vulnerable because performance and ability are often seen as important markers of success and worth. Further, the individual nature of swimming exposes an individual's ability more than a team sport. For example, if a swimmer is challenged or criticized in a swimming context, they may feel that their abilities or worth as a person are being called into question. This can lead to a defensive response in an attempt to protect the ego and to maintain a positive sense of self-worth. Furthermore, challenging or criticizing a swimmer's abilities or performance can also be seen as a threat to the person's social standing or status within the swimming community. This can also lead to a defensive response, as the swimmer may feel that they need to defend their position or reputation within the group. Overall, swimmers may seek to protect their ego and become defensive if it is challenged because the ego is closely tied to one's sense of self-worth and identity, and because performance and ability are important markers of success and worth in the context of swimming.



▲ Figure 7 Swimming is a sport of an individual nature



Linking question

How does an individual's perceived ability impact their risk of injury?
(B.3.1)

Consider:

- implications of overestimation of ability
- overconfidence, lack of caution and neglect of safety measures
- poor judgement and/or decision-making and risky behaviour
- perceived ability versus actual competence.

Practice question

Outline need achievement theory.

(3 marks)

Summary

- Motivation is defined as the “direction” and “intensity” of one’s effort.
- There are intrinsic and extrinsic motives for participation.
- McClelland and Atkinson’s theory of need achievement is based upon the motive to achieve success and to avoid failure.
- Goal orientation theory considers there to be three factors that determine motivation: achievement goals, perceived ability and achievement behaviour.
- In task-oriented goals an individual focuses on the mastery of the task, whereas in ego-oriented goals the focus is on being better than others.
- High ego orientation can be problematic if task orientation is low because it can lead to a lack of focus on achieving self-referenced goals and objectives and can decrease enjoyment and satisfaction.

AHL

Check your understanding

After reading this chapter, you should be able to:

- define motivation
- discuss intrinsic and extrinsic motives for participation
- describe the McClelland–Atkinson need achievement theory
- describe goal orientation theory
- describe problems that may occur if ego orientation is high and task orientation is low.

AHL

Self-study questions

1. Define motivation.
2. List **two** different theories of motivation.
3. State the additive principle of intrinsic and extrinsic motivation.
4. Distinguish between task and ego goal orientations.
5. Distinguish between a high ego orientation and a low ego orientation.
6. Explain how a high ego orientation can lead to anxiety.

AHL

Data-based question

A study investigated changes in achievement orientation and enjoyment of physical education in students ($n = 394$) from the ages of 12 to 14 years. The mean (\pm SD) scores for task motivational climate, ego motivational climate, task orientation, ego orientation and enjoyment at the beginning and at the end of each year for each age group are shown in Table 2. Higher scores = more/higher, and lower scores = less/lower.

▼ Table 2 Achievement orientation and enjoyment of physical education in students

	12 years old		13 years old		14 years old	
	beginning of the year	end of the year	beginning of the year	end of the year	beginning of the year	end of the year
task motivational climate	4.0 (\pm 0.8)	3.8 (\pm 0.9)	3.6 (\pm 0.9)	3.5 (\pm 1.0)	3.5 (\pm 0.9)	3.5 (\pm 0.9)
ego motivational climate	2.7 (\pm 0.9)	2.4 (\pm 0.9)	2.6 (\pm 0.8)	2.5 (\pm 0.9)	2.7 (\pm 0.9)	2.7 (\pm 0.9)
task orientation	4.3 (\pm 0.6)	4.2 (\pm 0.7)	4.0 (\pm 0.7)	4.0 (\pm 0.8)	4.1 (\pm 0.7)	4.0 (\pm 0.8)
ego orientation	3.1 (\pm 0.9)	3.0 (\pm 1.0)	2.9 (\pm 1.0)	2.8 (\pm 1.0)	2.8 (\pm 1.0)	2.8 (\pm 1.0)
enjoyment	5.4 (\pm 1.3)	5.3 (\pm 1.3)	5.1 (\pm 1.4)	5.0 (\pm 1.4)	4.9 (\pm 1.4)	4.9 (\pm 1.4)

Source: adapted from Barkoukis et al. (2010).

1. Identify which age group enjoyed their physical education most at the end of the year. (1 mark)
2. Calculate the largest difference between task orientation and ego orientation at the beginning of the year. (2 marks)
3. Compare and contrast the motivational climate of physical education lessons across the three age groups. (4 marks)
4. Discuss the relation between motivational climate and enjoyment of physical education lessons. (4 marks)

C.3.2 Self-determination

Syllabus understandings

C.3.2.1 Self-determination theory hypothesizes that humans strive to satisfy needs of autonomy, competence and relatedness.

C.3.2.2 Motivation can be placed along a continuum from amotivation to controlled motivation to autonomous motivation.

AHL

C.3.2.3 Self-determination theory is a meta-theory comprising six mini-theories, each explaining a facet of individual motivation.

Introduction

As we saw in chapter C.3.1, not all motives can be neatly defined as either intrinsic or extrinsic. For instance, how would you classify the motive “I exercise to control my body weight”? It seems more intrinsic than extrinsic but it is not totally intrinsic, as the motive involves reasons for participation other than fun and enjoyment. Deci and Ryan (1985) developed a continuum of motivation called **self-determination theory (SDT)** to explain this.



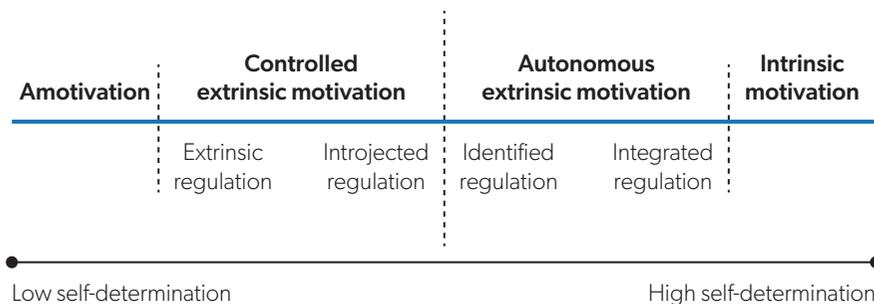
▲ **Figure 1** While some motives are clearly intrinsic and some are clearly extrinsic (such as, “I play professional sport because I get paid to do so”), others are less clear

The self-determination continuum of motivation

At one end of the continuum lies intrinsic motivation, where participation in the activity is for pure enjoyment and pleasure. On the other end of the continuum lies amotivation, which is a complete lack of desire to participate in the activity. In between these two extremes lie the different levels of extrinsic motivation, moving from the less intrinsic to the more self-determined levels (Figure 2).

Extrinsic regulation refers to behaviour that is driven by external forces rather than our own desire.

Introjected regulation is the first level of internalization and at this level we participate because we feel that we should to avoid disapproval or feelings of guilt.



▲ **Figure 2** The self-determination continuum

At the identified regulation level we participate because we feel it is personally important to do so and we value the activity.

At the integrated level of self-regulation we participate because we feel the activity is a key part of ourselves.

Table 1 provides an example for each level of self-determination.

▼ **Table 1** Examples of levels of self-determination in sport and exercise

Amotivation		Harper has no desire to participate in sport or physical activity and avoids doing any exercise.
Extrinsic motivation	Extrinsic regulation	Lee dislikes exercise but participates in walking and cycling because their doctor has advised them to do so to reduce their obesity level and improve their health.
	Introjected regulation	Yuri is in the school tennis team but does not really enjoy it and only participates because their parents and teachers want them to, and they feel guilty if they do not.
	Identified regulation	Nur attends aerobics classes because they want to look good, as this is important to them.
	Integrated regulation	Tal is a keen runner who gets personal satisfaction and achievement when they reach their goals. They identify as a runner when they introduce themselves to others.
Intrinsic motivation		Raha participates in a variety of activities including golf, tennis, running and swimming. They take part for the pure fun and enjoyment of it.

SDT and psychological needs

SDT is based on the premise that there are three psychological needs that motivate all human behaviour (Table 2).

▼ **Table 2** The three psychological needs

Autonomy	Competence	Relatedness
The need to feel autonomous, that is, to make our own decisions and to be in control of our own behaviour. For example, exercising because you want to, not because you are told to do so.	The need to feel competent and able to accomplish things. For example, mastering a sports skill or improving your expertise in an activity.	The need to relate to others and feel a sense of belonging. For example, being part of a team and feeling accepted and valued by your teammates.

ATL Thinking skills

Rate your own levels of self-determination in the sports or physical activities that you currently participate in, or have previously participated in. Think about which ones you are most likely to continue, or why you dropped out.

As individuals, we strive to fulfil these needs to create a healthy psychological environment for ourselves. Sport and exercise activities provide many opportunities to fulfil these needs and, quite often, this does not happen by chance. For instance, a coach can give players opportunities to lead parts of the session or to set their own goals for improvement in order to facilitate their self-determination.

**Linking question****How can motivational climate affect self-determination? (C.3.3)**

Consider:

- autonomy support
- competence development
- relatedness support
- mastery-oriented approach
- controlling behaviours.

**Linking question****How do psychologists decide on an appropriate sample size when investigating the relationships between rewards and motivation?**

(Inquiry 1)

Consider an experiment as trying to spot a difference between two things.

Then, consider:

- effect size—how big is the expected difference between the two things you are studying?
- variability—how much natural difference is there within each group you are comparing?
- significance level and power—how sure do you want to be in your results?

Here are some examples.

Effect size: imagine you are trying to tell the difference between elephants and mice by their size. That is a huge difference (effect), so you would not need to measure many animals to be sure. But if you are trying to tell the difference between two types of apples by their weight, the difference is small, so you would need to measure lots of apples.

Variability: if you are measuring the height of a group of people, you will observe a lot of natural variability—some people are taller than others. If there is a lot of variability, you will need a larger sample size to make sure the differences between two groups are not just due to that natural spread.

Significance level and power: if you want to be extra sure you are not making a mistake in your findings (either by finding a difference that is not there, or by missing a difference that is), you would need a larger sample size.

SDT in sport and exercise

The term motivation stems from the Latin word “movere” (to move), and concerns what moves people to act. Actions are organized movements. Therefore, the study of motivation concerns the energizing, direction, regulation and persistence of behaviour (Ryan, Deci, 2017). In other words, it can explain why we do what we do. Whether an Olympic athlete’s engagement with their training programme across many years, or a recreational exerciser jogging to meet physical activity guidelines, motivation is at the heart of their endeavours.

Consider a young baseball coach. They are unsure how to motivate their team, so seek advice from more experienced coaches in their club. Most of the coaches advise that the athletes will be highly motivated to follow a coach who is in complete control of planning and every aspect of decision-making. However, the young coach finds that the athletes are happier and more engaged in training if they are given a say in decisions that affect their training and games. What is the best advice for the young coach?



▲ Figure 3

Now consider a 50-year-old man who is struggling to stay regularly active. It seems that his motivation for exercise is based on trying to avoid feeling guilty for not exercising. He wants to comply with his doctor’s warning that he must lose weight to prevent health problems in the future, but he finds exercise a “chore” and the gym environment intimidating. What would be the best advice for him?



▲ Figure 4

The six mini theories of SDT

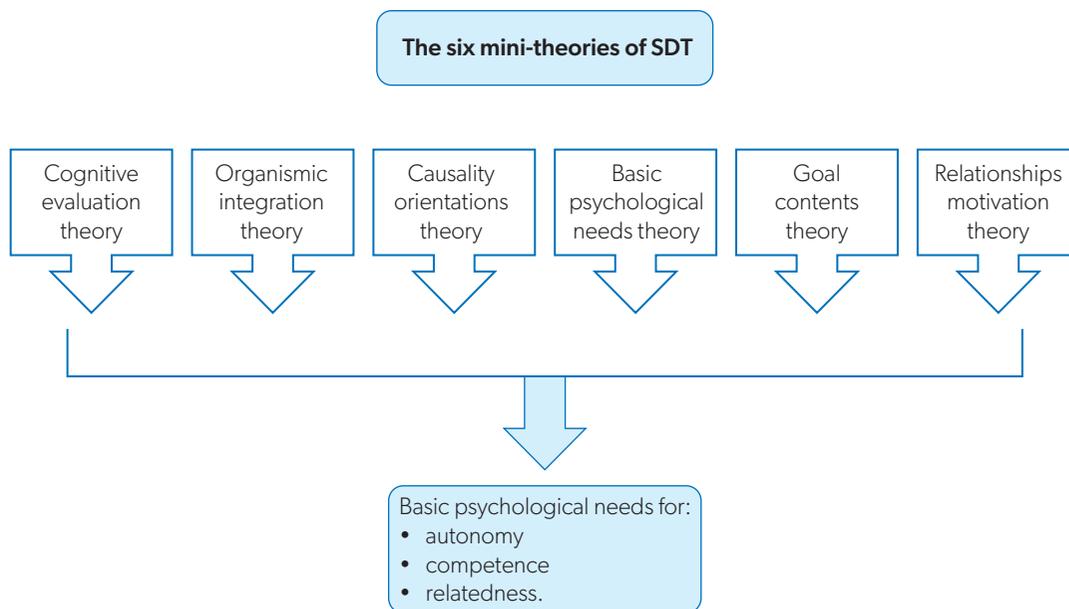
SDT is an **organismic-dialectic** approach to human motivation, psychological development and wellness.

- The **organismic** aspect means that humans have an inner drive to grow and develop and fulfil their potential. This perspective acknowledges that there are certain fundamental psychological needs, such as the need for autonomy (having choices and control), competence (feeling capable and effective) and relatedness (feeling connected to others).
- The **dialectic** aspect means it looks at the interaction between the individual and their environment, and acknowledges that we are influenced by the social and environmental factors around us, such as our family and culture. These external factors can shape our motivation and behaviour.

Therefore, an organismic-dialectic approach to SDT accepts that these two aspects interact and influence each other in understanding why we do what we do.

The six mini-theories that make up SDT are:

- cognitive evaluation theory
- organismic integration theory
- causality orientations theory
- basic psychological needs theory
- goal contents theory
- relationships motivation theory.



▲ Figure 5 The six mini-theories that make up the meta-theory of self-determination

Cognitive evaluation theory

Cognitive evaluation theory is concerned with intrinsic motivation. When people are intrinsically motivated, they engage in activities because they find them interesting, enjoyable and personally satisfying. The theory emphasizes two important factors that contribute to intrinsic motivation: autonomy and competence.

- **Autonomy** is the need to feel a sense of volition and freedom in one's actions. When individuals have autonomy, they perceive that their behaviour is aligned with their personal values and goals. This sense of autonomy enhances intrinsic motivation because individuals feel a greater sense of control and ownership over their actions.
- **Competence** is the belief that one is capable of performing tasks and acquiring the necessary skills to meet challenges successfully. When individuals feel competent, they are more likely to be intrinsically motivated because they have confidence in their ability to master the activities they engage in.

When the basic psychological needs and their intrinsic motivation are supported this will impact positively on the quality of learning, sport performance and

well-being (and vice versa). Cognitive evaluation theory assumes that people are intrinsically motivated by nature. They seek optimal challenges, are curious, want to develop their skills and have the urge to develop personally.

Cognitive evaluation theory suggests that external events can affect intrinsic motivation in three ways.

- The **social environment** provides information, for example, on how well one is doing in sports. This information (if positive) helps the individual to feel competent and promotes intrinsic motivation.
- **Controlling events**, such as rewards (monetary incentives), make people feel controlled by others, which decreases intrinsic motivation. This is known as the **over-justification effect**.
- **Amotivating events**, such as negative performance feedback, foster feelings of incompetence and decrease intrinsic motivation.

Organismic integration theory

Organismic integration theory focuses on the four types of extrinsic motivation that differ in the degree to which they are autonomous or controlled (Figure 2):

- extrinsic regulation (for example, you take part in sport because you want to gain status as a school player)
- introjected regulation (for example, you exercise because your physical education teacher says it is good for you—you exercise to show your teacher you are a good student)
- identified regulation (for example, you do sport because it can improve your fitness level)
- integrated regulation (for example, a basketball player who does resistance exercises because it can improve their basketball jumping ability).

The impact of the social context is important in this process. For example, a young elite athlete participates because their parents push them to engage in the sport (they participate to gain parental approval or to comply with parental pressure).

Causality orientations theory

Causality orientations theory is concerned with the extent to which people are exposed to three types of causal orientations or environments:

- autonomy-supportive
- controlling
- amotivating environments.

The more exposed an individual is to these three environments, the more likely they are, over time, to develop autonomy orientations, controlled orientations and impersonal orientations, respectively. This describes individual differences in how people tend to motivate themselves.

Basic psychological needs theory

As we saw in Table 2, basic psychological needs theory assumes there are three basic psychological needs (autonomy, competence and relatedness) that are required to achieve intrinsic motivation, mental and physical well-being, optimal health and personal growth.

TOK

Theories play an important role in sport and exercise psychology.

Why are theories useful for sport coaches and physical education teachers?

Activity 1

Identify which of the six mini-theories of SDT is described by each number.

1. A theory of general individual differences in motivational orientations
2. A theory concerned with the “what” or content of people’s life goals and lifestyles, and the processes through which these develop
3. Explains the effects of social contexts on intrinsic motivation
4. Concerns the processes that promote high-quality close relationships
5. Explains phenomena concerned with the internalization and integration of extrinsic motivation
6. Addresses the issue of psychological well-being and serves to tie together three other mini-theories

Goal contents theory

Goal contents theory distinguishes between intrinsic (such as maintenance of physical health) and extrinsic goals (such as financial success) to explain their role in satisfying or frustrating basic needs for psychological health and well-being, learning and sport performance.

Relationships motivation theory

Relationships motivation theory focuses on relatedness as a fundamental need. It emphasizes the significance of autonomy and competence for close personal relationships to flourish and support health and wellness.

The six mini-theories comprise SDT’s broad theoretical account of human motivation. The connection between the six mini-theories within SDT is a set of basic psychological needs that can be either satisfied or frustrated by need-supportive or need-thwarting contexts, respectively.

These needs are for:

- autonomy (the need to experience activities as self-endorsed and purposefully enacted)
- competence (the need to interact effectively within the environment)
- relatedness (the need to feel close to, connected to and cared for by important others).

When these three basic psychological needs are satisfied, people thrive and experience physical and mental well-being, and self-initiated positive development. Yet, when these basic psychological needs are frustrated, people experience physical and mental ill-health, fatigue/weariness, and poor functioning and development (Standage, Ryan, 2020).

Applying SDT

Returning to the case of the baseball coach, it is evident that the advice received from the senior coaches involves exercising autonomy-thwarting behaviours (that is, controlling behaviours with the baseball players). We know from research that communicating with athletes in this manner results in frustrated athletes—it is not the best way to motivate players.

However, the observation that the players are more engaged and happier when included in decision-making (an autonomy-supportive way of communicating) leads to autonomy need satisfaction, more self-determined types of motivation and greater well-being.

The baseball players would be better motivated if the coach continued to be supportive of their needs for autonomy, competence and relatedness.

To best motivate the baseball players, the coach should:

- keep including the baseball players in decision-making processes
- try to understand their point of view before making suggestions
- give constructive feedback
- focus on skill improvement

- show the baseball players care and attention
- interact in a way that demonstrates warmth towards them.

In the case of the 50-year-old man who is struggling to stay active on a regular basis, we now know that his reason for exercising is extrinsic. Organismic integration theory explains that attending the gym so as to not feel guilty is reflective of introjected regulation. We also know that guilt might be motivating in getting an individual to exercise in the short term, but unfortunately not in the long term. The good news for him is that introjected regulation is a step towards intrinsic motivation, through which even unenjoyable “chores” such as exercise can be maintained.

Some advice for him, then, would be to:

- seek out activities that he enjoys doing, so that he does not think of them as boring
- work with an exercise instructor at the gym who is supportive of his needs and with whom he can set realistic intrinsic goals and build his levels of competence
- find an exercise partner with whom he enjoys a close friendship.



▲ **Figure 6** Controlling and autonomy-supportive coaching styles

ATL Thinking skills

What are your positive and negative experiences in your sport?

Can you identify something that your coach or physical education teacher did that contributed to these experiences?

SDT suggests that there are different types and sources of motivation that vary in the degree to which they are autonomous versus controlled. Autonomous motivation is more self-determined than controlled motivation and is associated with “better” outcomes. For example, in physical education a more autonomy-supportive pedagogical approach is associated with higher levels of effort, concentration and enjoyment, and a higher quality of learning and performance.

Amotivation refers to a state of lacking motivation or having a diminished sense of drive, interest or enthusiasm towards engaging in activities or pursuing goals. It is reflected in people who report no reason for engaging in the activity (autonomous or controlled) and tend to not engage in sport or drop out of sport.

According to SDT, amotivation can come from:

- a perceived lack of competence
- a lack of interest, relevance or value in the activity.

Key point

Coach behaviour and athlete motivation

Autonomy-supportive coaches foster more self-determined or autonomous forms of motivation (intrinsic and identified), whereas controlling coach behaviour leads to less self-determined forms of motivation such as introjected and external motivation.

ATL Thinking skills

Sport coaches and physical education teachers can either communicate with a controlling style, such as giving directives, exerting pressure or controlling the athletes’ behaviour, or interact in an autonomy-supportive way that enhances decision-making and the athlete’s choice. What type of coach or physical education teacher would you like to be?

Key point

Young people with low perceptions of their athletic abilities do not participate in sport, or they drop out. Young people with high perceptions of their competence participate in sport.

Activity 2

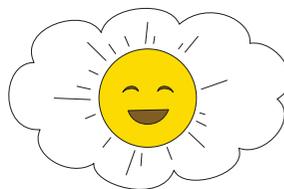
Interview 10 athletes from your school and find out the reasons why they participate in their sports. Can you link their reasons to intrinsic or extrinsic motivation, and if extrinsic, which type of extrinsic motivation (extrinsic, introjected, identified or integrated)?

Extrinsic motivation

doing an activity for external rewards or to avoid negative consequences

**Intrinsic motivation**

doing an activity for the pleasure and satisfaction of the activity itself, comes from within



▲ Figure 7 Extrinsic motivation and intrinsic motivation

ATL Research skills

What does the cognitive evaluation theory tell us about the use of rewards in sport?

Key points

Rewards that individuals perceive as controlling their behaviour (or as suggesting they are not competent) decrease intrinsic motivation.

Rewards that provide positive feedback about competence increase intrinsic motivation.

Extrinsic motivation is the focus of the organismic integration theory. Extrinsic regulation is the least self-determined form of extrinsic motivation because it involves behaviours that are clearly motivated or controlled by external contingencies (such as the promise of a reward or the threat of punishment). For example, a child who engages in physical education activities to avoid being disciplined or punished by the physical education teacher is externally regulated.

Introjected regulation refers to behaviours that are driven by internal pressure about what an individual feels they should or must do. For example, a child who participates in physical education because they fear disapproval from their physical education teacher or their parents if they do not, is operating under introjected regulation (the pressure to participate is internal to the child, but the motivational source of the behaviours of the child—the “shoulds” of teachers/parents—is external to the child).

Identified regulation is an autonomous form of motivation, and refers to behaviours that are done because they produce outcomes that are valued as important and worthwhile. For example, a child who participates in physical education because they understand (and accept) that this will improve their fitness and health. This involves a sense of choice and personal commitment, but it is externally motivated because there is an instrumental outcome.

Integrated regulation is the most autonomous type of extrinsic motivation—behaviours that are identified as important and worthwhile **and** align with the person’s beliefs and values. For example, a child who actively engages in physical education because being active is part of their identity.

Finally, intrinsic motivation is the most self-determined form of motivation.

In summary, SDT describes, explains and predicts sport, exercise and physical activity engagement.

ATL Thinking skills

Motivation for sports participation and physical activity can take the following forms.

“I participate in sport and active games ...

- **Intrinsic:** “... because it is fun”
- **Identified:** “... because I value the benefits”
- **Introjected:** “... because I would feel guilty if I quit”
- **External:** “... because if I do not other people will not be pleased with me”



Linking question

To what extent can the constraints posed by environmental conditions impact motivation? (A.1.2 HL)

Consider:

- availability or scarcity of resources in the environment
- physical environment (such as noise levels, temperature, humidity, altitude, lighting)
- social environment (such as interactions with the coach)
- cultural norms, values and expectations, and alignment with an individual’s expectations.



Linking question

How do the types of rewards help shape the motivational climate? (C.3.3)

Consider:

- types of intrinsic and extrinsic rewards
- if extrinsic rewards will undermine intrinsic motivation over time
- achievement-oriented rewards and a sense of competence
- how social rewards contribute to a motivational climate
- how task-oriented rewards contribute to a motivational climate
- striking a balance between intrinsic and extrinsic rewards.



Activity 3

Identify which of the following are either supportive physical education teacher behaviours or controlling teacher behaviours:

- allows time for a student to work independently
- shows the solution to a problem before the student has time to discover it
- uses language such as should, must or have to
- gives the student time to talk
- praises the student when they demonstrate improvement.

Practice questions

1. Outline why a self-determined athlete is likely to be more satisfied with training. (2 marks)
2. As female youth from refugee backgrounds are forced to migrate and resettle, they face unique challenges. Participating in physical activity may contribute to healthy resettlement. Explain how their experiences in sport and physical education can relate to their sense of belonging, autonomy, and relationships. (6 marks)

Summary

- The self-determination continuum of motivation ranges from amotivation to intrinsic motivation.
- Self-determination theory (SDT) argues that competence, autonomy and relatedness are three basic human needs.
- SDT suggests that the degree to which basic human needs are satisfied goes a long way in determining an individual's intrinsic motivation.
- The six mini-theories that make up SDT are:
 - cognitive evaluation theory
 - organismic integration theory
 - causality orientations theory
 - basic psychological needs theory
 - goal contents theory
 - relationships motivation theory.
- The six self-determination mini-theories help explain the complex interactions of environmental and contextual factors in sport, exercise and health-related activity.
- SDT provides a framework to help individuals make choices and take actions to shape their own lives.

AHL

Check your understanding

After reading this chapter, you should be able to:

- understand the self-determination continuum of motivation
- outline the three basic human needs that SDT is based on
- outline the six mini-theories that comprise SDT.

AHL

Self-study questions

1. Identify the six levels of the self-determination continuum.
2. Explain the difference between integrated and introjected regulation in self-determination theory.
3. Distinguish between an autonomy-supportive coaching style and a controlling coaching style.
4. Outline how self-determination theory can relate to exercise behaviour.
5. Explain why it is important for people who work with young athletes to know and understand self-determination theory.

Data-based question

Motivational characteristics are influential in shaping adolescents' desire to persist in sport or to discontinue their sport participation. Soccer players ($n = 492$) between the ages of 13 and 17 years were surveyed to find out their

scores for amotivation, relatedness, autonomy and competence. Their mean (\pm SD) scores are shown in Table 3, where higher scores = more and lower scores = less.

▼ **Table 3** Adolescent soccer players' motivational characteristics

	Persistent players (that is, want to keep playing soccer)	Dropout players (that is, thinking of stopping playing)
amotivation	0.98 (\pm 1.01)	3.63 (\pm 1.52)
relatedness	7.11 (\pm 1.29)	6.58 (\pm 1.23)
autonomy	6.98 (\pm 1.36)	6.58 (\pm 1.32)
competence	7.16 (\pm 1.29)	7.13 (\pm 1.51)

Source: adapted from Calvo et al. (2010).

1. Identify which group had the least motivation. (1 mark)
2. Calculate the difference between the persistent and dropout players for autonomy. (1 mark)
3. Compare and contrast the relatedness and competence scores for both groups. (2 marks)
4. Using self-determination theory, explain why one group of players want to keep playing soccer and the other group are thinking of stopping playing. (4 marks)

C.3.3 Motivational climate

Syllabus understandings

C.3.3.1 Motivational climate describes the psychological environment that the coach creates by designing sessions that provide instructions and feedback, which will help to motivate the athletes in training or competition.

Introduction

Motivation is a key component of an individual's choice to:

- engage (or not engage) in physical education, sport, exercise or health-related physical activity
- pursue a healthy and active lifestyle throughout their life.

Motivational climate is the environmental factors that lead individuals to view competence in different ways and pursue different goals.

One way of perceiving success is to focus on self-improvement and mastery of skills (personal improvement through effort).

Another way compares one's own ability with norms and the abilities of others (the focus is on doing better than others).

Where sports coaches and physical education teachers create a mastery-based climate, intrinsic and self-determined forms of motivation are more likely. Thus, motivational climate is the social environment that coaches, teachers and peers create and perceive.



▲ Figure 1

Activity 1

Directions: Read the statements in Table 1 and indicate how much you personally agree with each statement by circling the appropriate response. You will revisit your results later in the chapter.

When do you feel most successful in sport?

When do you feel an activity has gone really well for you?

▼ **Table 1** A Task and Ego Orientation in Sport Questionnaire (TEOSQ)

<i>I feel most successful in sport when ...</i>					
	1	2	3	4	5
1 I'm the only one who can do the skill.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
2 I learn a new skill and it makes me want to practise more.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
3 I can do better than my friends.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
4 The others can't do as well as me.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
5 I learn something that is fun to do.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
6 Others mess up and I don't.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
7 I learn a new skill by trying hard.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
8 I work really hard.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
9 I score the most points/goals.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
10 Something I learn makes me want to go and practise more.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
11 I'm the best.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
12 A skill I learn really feels right.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
13 I do my very best.	Strongly disagree	Disagree	Neutral	Agree	Strongly agree

Scoring: Add the task scores (questions 2, 5, 7, 8, 10, 12, 13) and find the mean average. A high score = high mastery orientation. Add the ego scores (questions 1, 3, 4, 6, 9, 11) and find the mean average. A high score = high ego orientation.

Mastery climates and ego climates

Mastery climates (or **task** climates) are motivational climates that reflect an individualized reward structure. They are characterized by effort-based goals and rewards as well as learning and improvement.

Performance climates (or **ego** climates) are motivational climates that reflect competitive reward structures. They emphasize social comparison and reward individuals for outperforming others.

Ames (1992) contended that the perceived motivational climate influences an individual's thoughts, feelings and achievement behaviours. The two types of motivational climate are consistent with task and ego goal orientations (chapter C.3.1).

Research into perceptions of the motivational climate in sport and physical education (such as Carpenter, Morgan, 1999) demonstrates that perceptions of a mastery climate are related to:

Key points

In a **performance/ego climate**, comparison with others is the most important source of information for self-evaluation; the focus is on winning, and improvement is of little or no significance.

In a **mastery/task climate**, success is evaluated in terms of personal mastery and improvement, and not in comparison with others.

- task goal orientation
- intrinsic motivation
- preference for challenging tasks
- beliefs that success is due to effort.

Other perceptions of a mastery/task climate include: a positive attitude, high satisfaction, low boredom and anxiety, high self-rated improvement, continued involvement and self-determined reasons for participation.

In contrast, perceptions of a performance/ego climate include high levels of worry, a focus on comparative ability and a preoccupation with enhancing one's social status.

ATL Thinking skills

An ego orientation focuses on comparing performance with and defeating others.

A task goal orientation focuses on comparing performance with personal standards and personal improvement.

Task-oriented individuals have a perception of ability that is based on their own standards of reference. It is easier for them to feel good about themselves and demonstrate high perceived competence compared with ego-oriented people. Ego-oriented people have more difficulty maintaining high perceived competence, are more likely to reduce their efforts, have negative self-thoughts and feelings when they lose—and this is associated with increased anxiety.

An ego orientation has been linked with low persistence, low effort and attribution of failures to low ability. This contrasts with a motivational climate, which is linked with a positive attitude, increased effort and effective learning strategies.

- What type of mindset (fixed or growth) do you think an ego-oriented person is more likely to have, and why?
- Why is a motivational climate of ego orientation typically more effective in the short term for some individuals?

The TARGET approach

Ames (1992) identified the dimensions of achievement situations that influence the motivational climate as the task, authority, recognition, grouping, evaluation and time structures (TARGET) (Table 2).

Manipulating these TARGET structures to be mastery focused has been found to improve pupils' motivation in physical education lessons, resulting in greater satisfaction with the activities, a more positive attitude towards the activity and a preference for more challenging tasks (Morgan, Carpenter, 2002).

▼ **Table 2** TARGET behaviours that influence motivational climate

TARGET behaviour	Mastery/Task	Performance/Ego
task	self-referenced goals, differentiated	comparative goals, undifferentiated
authority	students given leadership roles and involved in decision-making	teacher makes all the decisions
recognition	private recognition of improvement and effort	public recognition of ability and comparative performances
grouping	mixed-ability and cooperative groups	ability groups
evaluation	self-referenced; private consultations with teacher based on improvement and effort scores	comparative and public
time	flexible time for task completion	inflexible time for task completion

Combining motivational climate theory with attribution theory (chapter C.1.2) may help us to understand why a perceived mastery motivational climate has consistently been associated with positive motivational outcomes.

As Table 2 shows, a mastery motivational climate is associated with effort and self-referenced criteria for success. Attribution theory tells us that effort is seen as internal, controllable and unstable—allowing individuals to view success as achievable in the future with continued application of effort and (perhaps more importantly) to view failure as redeemable with greater effort.

Activity 2

Working with a group, consider the following scenario.

You are a physical education teacher. Your learning outcome is to improve ball-dribbling skills in a soccer lesson. You decide to have a race between groups: the winning group is the first to complete a ball-dribbling relay around fixed marker cones.

In their desire to win, a number of participants cheat by cutting corners or running over the cones instead of around them.

Discuss the following questions.

- Have you achieved your learning outcome?
- Are you promoting a mastery- or ego-involving climate?
- Could you change the session to promote a more mastery-involving climate?
- How might a more mastery-involving climate impact on the learning outcome?



Linking question

Why might an ego motivational climate be anxiety-inducing? (C.4.1)

Consider:

- how success is measured in an ego-involving climate
- pressure to perform well
- fear of failure
- being judged by others
- competition and rivalry among athletes versus cooperation and support
- focus on individual comparative accomplishments
- enjoyment, motivation and engagement
- high-pressure environments and stress.

The TEOSQ

To study differences in dispositional goal orientations in sport and exercise settings, Duda and Nicholls (1989) developed the TEOSQ.

Research has found a consistent pattern of motivational responses for task- versus ego-oriented individuals in sport and physical education settings. Task orientation has been positively related to effort, enjoyment, persistence, satisfaction and interest. In contrast, ego orientation has been negatively associated with enjoyment and interest, and positively related to boredom. Furthermore, task-oriented individuals have been found to be more intrinsically motivated than ego-oriented individuals (Roberts, 2001).



▲ **Figure 2** In an ego motivational climate, comparison with others is the most important source of information. In a task motivational climate, success is evaluated in terms of personal improvement.

Case study**Combined task and ego orientations**

One of the first studies to examine the effects of combined levels of task and ego orientations was conducted by Fox et al. (1994). In this study, four groups were created for analysis based on mean splits of their levels of task and ego orientation, as measured by the TEOSQ. The groups were:

- high task/high ego
- low task/high ego
- high task/low ego
- low task/low ego.

The high task/high ego group emerged as having the highest perceived sport competence and enjoyment in sport.

The low task/low ego group had the lowest.

Fox et al. concluded that children dominated by a task orientation were more highly motivated than those dominated by an ego orientation, but the addition of ego orientation to a dominant task orientation may enhance sport enjoyment and does not appear to be motivationally detrimental. Further, the low task/low ego group was at highest risk of non-participation.

**Activity 3**

Using your class's results from Activity 1, work out the class average score for both task and ego orientation out of 5.

Consider how many of your classmates are high in both task and ego orientations.

The goal orientation theory approach has been criticized for having a Western and male bias, and for only considering the two goals of task and ego. Fontayne et al. (2001) argued that people may hold multiple goals, each of which may influence their level of motivation for a particular social domain. Furthermore, limiting the study of motivation to the study of task/mastery and ego/social comparison goals could be considered reductionist, particularly when unrepresented groups are concerned. Do you agree with these viewpoints?

**Linking question****Can the motivational climate lead to overtraining? (C.1.2)**

Consider:

- overly competitive motivational climates
- pressure to push your body beyond its limits
- importance of rest/recovery.

Practice question

Using examples from a physical education lesson, distinguish between a mastery and an ego motivational climate. (2 marks)

Summary

- There are mastery and ego perceptions of motivational climate.
- The TARGET teaching/coaching behaviours influence perceptions of the motivational climate and the resultant motivational responses.

Check your understanding

After reading this chapter, you should be able to:

- develop an understanding of how motivational climate impacts upon sports performance and participation in physical activities
- outline the TARGET approach
- understand and use a Task and Ego Orientation in Sport Questionnaire (TEOSQ).

Self-study questions

1. Discuss the difference between goal orientations and motivational climate.
2. Suggest strategies that teachers or coaches can use to create a mastery motivational climate.
3. Describe the TARGET behaviours that can influence motivation.
4. Discuss how knowledge and understanding of motivational climate can help promote the physical activity of all participants in physical education lessons.
5. Explain why a motivational climate of ego orientation has been linked with low effort and attribution of failures to (low) ability.

Data-based question

The goal orientations of a group of high school volleyball players were measured using the Task and Ego Orientation in Sport Questionnaire (TEOSQ) (Duda, Nicholls, 1989). The results of three of the players are displayed in Table 3, out of a maximum score of 5. Use these data to answer the following questions.

▼ Table 3

Student	Task orientation	Ego orientation
1	4.53	4.0
2	2.97	4.28
3	4.13	2.69

- a. Describe the goal orientation profile of each of the three students by describing the task or ego orientation as “high” or “low” (for example, high task, low ego). (1 mark)
 - i. Student 1
 - ii. Student 2
 - iii. Student 3
- b. Calculate the mean task and ego orientation scores for all three players combined, to two decimal places. (2 marks)
 - i. Mean ego =
 - ii. Mean task =
- c. Based on your knowledge of achievement goal theory and assuming the players all have similar levels of perceived ability:
 - i. determine which of the players you think is most likely to “drop out” of the team if they lose the majority of their games, even though they are improving in their performances (1 mark)
 - ii. explain the reason for your decision. (2 marks)

C.4

Stress and coping

How do stress and anxiety manifest themselves and affect performance and health? How can specific coping strategies be used to manage this?

This topic discusses the nature of stress and anxiety, as well as some major sources of anxiety and stress and how they can affect performance. You will explore why coping skills are important determinants of performance, and identify and discuss some coping strategies for dealing with competitive stress.

C.4.1 Arousal and anxiety

Syllabus understandings

C.4.1.1 Arousal refers to the level of physical and psychological activation. This impacts on sport performance in the way that individuals attempt to manage their levels of intensity.

C.4.1.2 When anxiety is low, individuals experience positive emotions, such as excitement, desire and elation. High levels of anxiety induce negative emotions such as fear, worry and despondency.

Introduction

In this chapter we are going to look at the relationship between stress, arousal and anxiety, and the effects these have on performance. Sport is a setting that individuals enter voluntarily, and stress and anxiety are experienced regularly in both competitive and training situations. At the elite level it is considered by some that “the deciding factor is not the skill but the ability to perform it under stress” (Patmore, 1986). This idea is often supported by elite athletes themselves, and the occasions on which top-level performers “choke” testify to the fact that athletes must be able to control their internal states, in spite of the stressful situation, to produce peak performances.

The discipline of sport psychology has devoted much attention to understanding what happens under stress and, more importantly, how performers can be helped to perform under stress.

Stress in humans

Although humans are highly developed in many ways, they are still animals and still respond to situations in a way that secures their evolutionary survival. As animals, we are programmed to respond to the **stress** of dangerous situations using rapid and pronounced arousal of the sympathetic division of the autonomic nervous system. This response is understood to be effective in preparing the individual to either run away from danger or to fight, either in self-defence or for food. This is sometimes referred to as the “fight-flight” response and is a highly functional response to prepare the body for high-intensity physical work. For example, increased heart rate assists in the transportation of oxygen while epinephrine (also known as adrenaline) promotes the release of stored energy such as liver glucose (glycogen). Together these increase the availability of energy to working muscles.

Stressful situations in modern life where the need for a highly physical response is less pronounced (think of an office worker being stressed) still prompt some of the same kinds of responses even though physical danger is not prevalent. Some of these responses may even have a negative impact on our performance. Imagine hurrying to school late on a day when you are reading in front of your class; rushing to take off your coat, open your bag and use fine motor control to get out the reading and hold it steady are tasks that would be impaired by the stress of being late.

Key term

Stress A response of the body to a demand made upon it (a stressor) resulting in arousal of the sympathetic nervous system.

Sport is interesting because it can benefit from some of the responses but be negatively affected by others. Even more interesting is that some performers have differential responses, benefitting from some positive changes and with reduced levels of other more negative changes.

Early sport psychologists recognized the stressful nature of sport and sought to apply existing knowledge and research from other areas, such as clinical psychology and medicine, to help them understand experiences and reactions. One particularly important source of understanding was the work of Hans Selye, a medical doctor and endocrinologist who was a pioneer of applied stress research.

Case study

Hans Selye, pioneer of stress research

Selye defined stress as “a non-specific response of the body to any demand made upon it” (Selye, 1979). Using the term “non-specific”, Selye was suggesting that the same sorts of responses would be elicited by any variety of stressful stimuli or stressors. Selye’s initial work (published in the journal *Nature* in 1936) was based on exposing his research subjects to various stressors such as cold, surgical injury, production of spinal shock, excessive muscular exercise or intoxications with sublethal doses of diverse drugs.

These subjects were actually rats, and this is the one key feature that limits the relevance of his work to understanding human responses because our brain contains a huge cortex, which is not present in rats. The cortex is where humans engage in advanced thought processing including future-oriented thinking, worry and interpreting situations with meaning. The activity in the cortex means humans do not respond to all stressors uniformly like Selye’s rats, and as thinking styles also differ between individuals, even the same stressor may produce quite different responses.

Selye’s early work is still important and he contributed two other important points.

First, he defined stress as a response. This is in line with the modern view of stress as a transaction between the individual and the environment.

Second, he introduced the idea that stress was not necessarily a negative response. For example, physiological adaptation through training is a response to stress, as is the sense of enjoyment or exhilaration that some individuals get from taking part in competitive sport or physical activity.

Selye used the terms “distress” and “eustress” to differentiate between negative and positive stress responses. Throughout this chapter keep in mind that while anxiety and worry may be negative consequences of stress, positive consequences also occur.

Psychological and physiological responses to stress

What happens to us when we are stressed? This question assumes that stress is one specific thing. In fact, it is easier to think of different categories of stress (Table 1).

▼ **Table 1** Categories of stress

Category of stress	Description
time-limited “voluntary” stress	amateur-level competition—usually it is just for fun and does not determine other aspects of life
time-limited “compulsory” stress	a selection event to join an academy or gain a sports scholarship—the person feels compelled to take part in order to achieve another distant goal
stressful event sequences	a chain of related events—for example, relocation means moving house, changing schools, losing friends and having to learn your way around
chronic stress	long-term illness or overtraining—pervades life and has an uncertain time course or outcome
distant stressors	an experience (usually traumatic) in the past that retains some impact on future responses

The impact of stressors often depends on the specific type of stressor encountered. The danger of workplace stress to health is well documented in terms of coronary heart disease and is usually attributed to the stress being chronic (lasting for a long period of time). So it is important to remember that while stress is a very commonly used term, it lacks precise meaning.

Furthermore, the word “stress” can be used to mean an external force or influence, such as ambient temperature as a source of stress for desert marathon runners. Or stress can be used to describe an internal response that may be moderated by individual factors, so core body temperature may show that an acclimatized individual is under less stress than a non-acclimatized individual.

Stress can also be considered in terms of whether it involves a physical threat or danger to the individual (or someone close to them), or whether it relates to social evaluative concerns in which the person feels that their status or position will be affected. A high school baseball fielder waiting for a high ball is usually most concerned about messing it up because of social evaluative concerns—they do not want their skill to be shown as inadequate and they want their team to win. When going in to bat against a fast pitcher, some of the concern now may be about getting hurt or injured (physical threat).

Activity 1

Take a blank sheet of paper and list all of the changes that occurred on an occasion when you experienced a time-limited stressor. Think about changes to how you behaved, what you felt, physical symptoms and what you thought.

Activity 2

Find examples of professional sportspeople suffering from the negative impact of stress. You can search websites such as YouTube for clips. One example would be Jean van de Velde in the final stages of the British Open golf championship in 1999.

ATL Thinking skills

Defining stress

The term “stress” is commonly used. But when you hear about the *effects* of stress, ask yourself what kind of stress is present. Different types of stress will have different effects.

When sport psychologists work with elite athletes experiencing stress they must take time and care to accurately identify the type and source of stresses that the performer is experiencing. Interestingly, while it is easy to think just about the key moments in sport—such as a penalty or free throw shot to win the game—reports giving details about elite athletes show stressors are as likely to do with organization (sports team or national institute), relations with their coach, or difficulties with training and lifestyle.

A less intense stressor experienced regularly may be considered much more significant than a stressor encountered just once or twice a year.

ATL Research skills

Interview a friend or family member who plays a sport and has recently been in a competition that was important to them. Ask them about the time leading up to the competition, the day before and one hour before they competed. The interview should take 20–25 minutes. Write down the questions you will ask and take notes on what they say. Timing is important; some approximate times are shown below to help you.

Give them a short explanation of what you would like to talk about, and why. Get their agreement they are happy to do this. (2 mins)

Start by asking them to describe the competition to you and to explain why it was important to them. (4 mins)

Ask them to think specifically about how they were 24 hours before the event. Ask the following questions. (8 mins)

- How did they feel physically?
- What thoughts did they have in relation to the competition? How often during this time did they think about the event?
- What feelings or emotions did they experience?
- What actions and behaviours did they take that were directly a result of feeling or thinking about the competition?

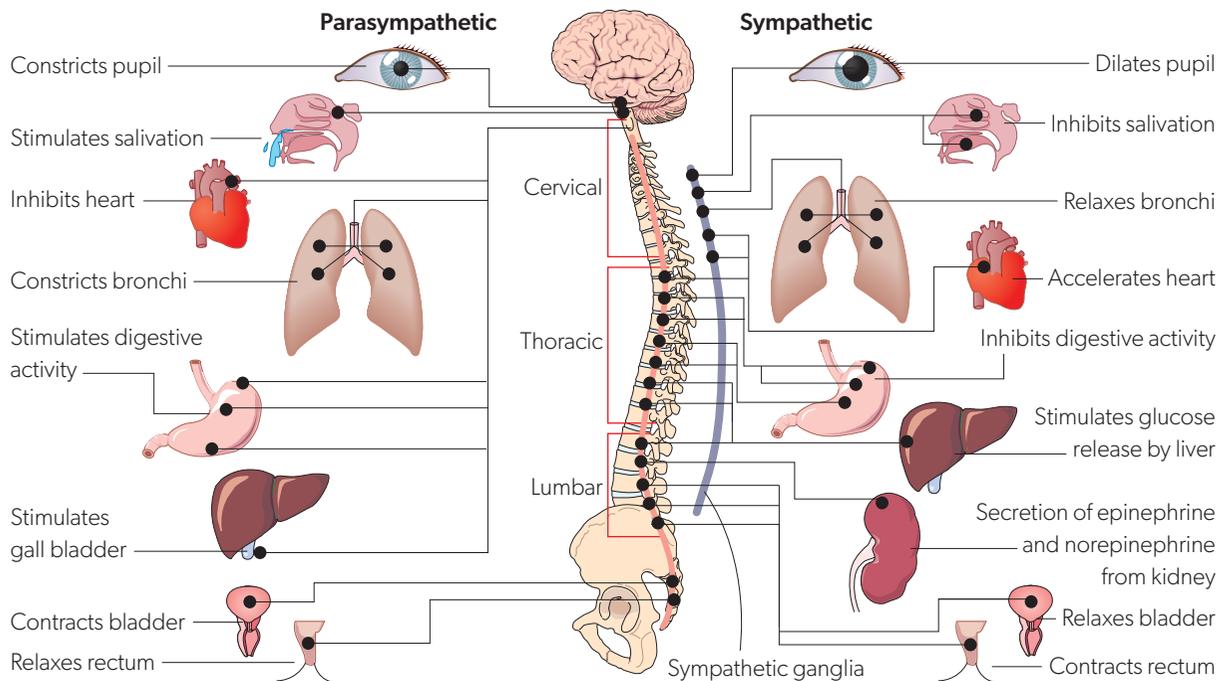
Now ask them to think specifically about how they were one hour before the event.

Ask the same questions as before in relation to this time period. (8 mins)

Thank your interviewee for their time and the information they have given you about their responses to this situation.

Arousal and performance

Under stress, humans usually report symptoms of **arousal**. This concept of arousal exists along a continuum: states range from a very deep sleep-like state to excessive and uncontrolled activation of numerous systems that might be seen in the instance of a panic attack. Arousal is most commonly used to refer to arousal of the sympathetic division of the autonomic nervous system.



▲ **Figure 1** Changes associated with activity of the parasympathetic and sympathetic divisions of the autonomic nervous system

Arousal, or autonomic arousal, is often considered to be the immediate response (“fight or flight”) to a stressor. It is governed by the sympathetic nervous system, and corresponds to the alarm reaction of the general adaptive system. Autonomic arousal causes the sympathetic nervous system to close down any of the body’s physiological systems that are non-essential to fight or flight and accelerates those that are essential. One of the most obvious changes that occurs with arousal is an increase in heart rate, and it remains one of the most frequently measured physical changes associated with an individual experiencing stress. Generally as a consequence all parasympathetic activity is curtailed. There are however some exceptions to this rule, as the last item on the list of arousal symptoms for Second World War combat pilots in Table 2 shows.

▼ **Table 2** Symptoms of fear in combat flying based on reports of pilots during the Second World War

During combat missions did you feel	Often %	Sometimes %	Total %
pounding heart, rapid pulse	30	56	86
muscles tense	30	53	83
irritable	22	58	80
dry throat and mouth	30	50	80
“cold sweat”	26	53	79

Key term

Arousal The response to a stressor by the sympathetic nervous system.

"butterflies"	23	53	76
trembling	11	53	64
a sense of unreality	20	49	69
confused	3	50	53
weak or faint	4	37	41
unable to remember details or events of the mission immediately afterwards	5	34	39
sick to the stomach	5	33	38
unable to concentrate	3	32	35
that you had wet or soiled your pants	1	4	5

Source: adapted from Shaffer (1947).

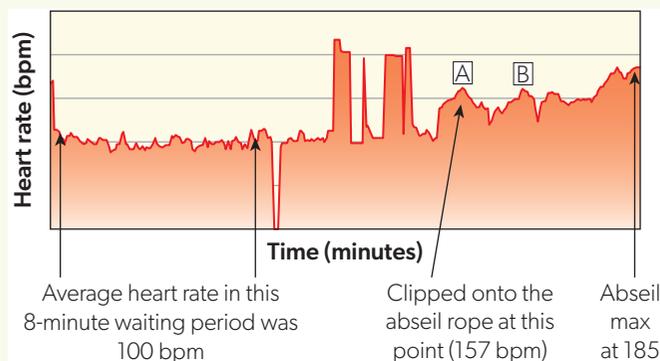
Case study

Heart rate under stress

Imagine standing at the top of a raging waterfall and preparing to abseil off the edge into the clouds of spray and the deafening roar as the water plunges over a rock shelf and falls down 50 m. Imagine too that you have

never abseiled before. What effect do you think this experience would have on your heart rate?

Look at the graph of a 22-year-old facing this exact task (Figure 2).



▲ Figure 2

Note that at points A and B the individual was getting into a harness [A] and then climbing over the protective railings to stand on the rocky edge near the abseil point [B]. Then the performer was clipped onto the abseil rope and moved towards the edge. The small "notch" just before the profile finishes is a momentary "cardiac deceleration" just before going over the edge. This notch has been seen in contrasting situations (golf putting) and is associated with the moment when the performer commits to an action.

What might have been the key features of stress for this performer? Research suggests situations that are novel,

unpredictable and where the person feels they do not have control and that they might be subject to social evaluation are likely to cause psychological stress.

Now consider the heart rate of a 22-year-old rally driver completing a special stage of a major international event, say in ambient temperatures of 24°C (in-car 34°C), with their top speed over rough terrain reaching 130 kph. The driver has to drive a high-powered car, manoeuvring sharply with rapid braking and gear changes.



To do so optimally the driver must combine three sources of information about the stage.

1. The visible ground immediately in front of the car to avoid obstacles
2. The ground 100–200 m further ahead to plan responses
3. The pace notes being read out by the co-driver that describe the stage and pre-planned driving strategy

Now think about the stressors facing this performer and factors that might contribute to an elevated heart rate.

In the first case, the elevation could be due purely to the anxiety associated with the situation. There is likely to be a high perceived risk (though as it is well managed by specialist staff it is actually quite small).

However, there is little physical demand, mental effort or significant environmental load. The heart rate elevation is “metabolically inappropriate” for the situation and would be almost entirely attributable to the perceived stress. Measuring heart rate when there is no other cause for a change can provide a good source of information about anxiety response.

In contrast, the rally driver’s heart rate can be considered a composite of the stressors encountered combined with mental and physical workload. It would be impossible to attribute values in any meaningful way to the array of factors, each of which would be expected to elevate heart rate. In this situation, with so many factors, heart rate cannot provide any clear index of anxiety.



Global impact of science

Ethical principles in research with human participants

The Declaration of Helsinki was made in 1964 by the World Medical Association to attempt to ensure that all medical research conformed to the same ethical principles. It was designed to ensure that the rights of human participants were carefully considered and protected. Most research nowadays, whether medical or not, considers the protection of participants an essential component and follows similar if not the same principles as those stated in this convention.

Search online for “Declaration of Helsinki” to find and read the text. Focus specifically on paragraphs 6, 9, 14, 15, 18 and 24.

A study that set out to induce some stress in participants would need to consider and act in accordance with these principles in order to be ethical.

Is researching stress ethical?

What should be done to protect participants?

What restrictions need to be placed on advancing knowledge?

Traditional theories of arousal

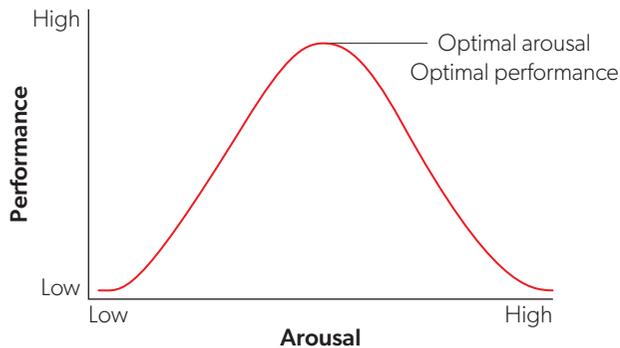
Early attempts to understand changes to performance under stress attempted to describe these in terms of elevations in arousal. These are known as *uni*-dimensional theories because they involve just one dimension.

Drive theory

During the 1960s psychologists thought there was a direct and linear relationship between arousal and performance. This view was called **drive theory**, and it was believed that as an individual’s arousal (or state anxiety) increases, so too does their performance. For example, the more psyched up an athlete is, the better that athlete performs. Today there is very little support for drive theory because there are numerous examples of athletes becoming over-aroused (or too anxious) and then performing poorly.

Inverted-U theory

As far back as 1908 Yerkes and Dodson suggested that for complex tasks there was an optimal level of arousal above and below which performance levels would decrease. Over time this idea has become known as the **inverted U theory** because of the graphical shape of the proposed arousal–performance relationship (Figure 3).



▲ **Figure 3** The arousal–performance relationship proposed by inverted-U theory

The data on which the inverted-U approach was based were collected from a study examining the performance of mice learning to get through a maze under different conditions of electric shock. Surprisingly it is still often presented to explain performance of humans in sport settings even though there is little supporting evidence for this. Conceptually the inverted-U approach provides a simple description, and this simplicity may partly explain why it is often used and remembered. However, there is significant doubt over the value of this model, not least when we consider real-life examples of performers experiencing stress where the decline in performance level is not slow and progressive but rapid and dramatic.

To summarize, there are several limitations to conceptualizing the arousal–performance relationship using the inverted-U relationship and in attempting to use an arousal-based approach to understanding the real-life experiences of sports performers.

The limitations of the inverted-U approach are:

- the lack of a credible weight of evidence on responses in sport
- real-world performances are often comprised of several components, and anxiety may affect different components in different ways
- real-life declines are often sudden and rapid
- descriptions of relationships do not provide explanatory mechanisms for the effects
- arousal is not accurately defined (different elements may change independently of each other)
- anxiety and other important cognitive processes associated with stressful performances are not included.

Sports performers certainly have elevated arousal levels when they experience stress; however, it is evident through systematic interview-based research that the most salient aspect of being stressed is **anxiety**. The construct of anxiety holds much more likelihood for explaining changes in performance, and has been a serious focus for researchers of human performance for the past 60–70 years.

Key term

Anxiety A temporary, ever-changing emotional state of subjective, consciously perceived feelings of apprehension and tension associated with activation of the autonomic nervous system.

ATL Thinking skills

Read this article describing some examples of the impact of stress on performance.



Are bad shots, blown leads at Australian Open “choking”?

The term “choke” is often used when describing a tennis player who misses what looks like an easy shot or loses a match at the Australian Open and other tournaments

Simon Cambers, Howard Fendrich

Tuesday 24 January 2023 14:45

When Matteo Berrettini missed what should have been a simple backhand on match point against Andy Murray in the first round of the Australian Open last week, the crowd inside Rod Laver Arena let out a collective gasp of disbelief.

As Murray moved in the wrong direction, leaving the court wide open, Berrettini dumped the ball halfway down the net. At the most important moment of his day, the Italian—talented enough to be the Wimbledon runner-up in 2021—was unable to hit a shot he might make the other 999 times out of 1,000.

In tennis parlance, he “choked.”

Berrettini smiled right after that blunder but never recovered; Murray went on to win in a fifth-set tiebreaker.

“He had a pretty bad shot on the match point,” Murray said. “I was lucky there, for sure.”

Singles tennis is an individual sport, of course, so there are no teammates to cover for mistakes or provide help at key junctures. The attention falls on one athlete, which translates to plenty of praise for winners and, in certain circumstances, accusations of “choking” lobbed at losers—fair or not.

It’s a versatile term, too. Sometimes, as with Berrettini, it is bandied about when a player flubs what appears to be a gimme shot on a crucial point. It also gets used when a high-ranked player is defeated by someone who is much lower-ranked. Or when someone throws away a big lead, such as when a man takes the first two sets of a best-of-five match at a Grand Slam tournament yet loses—which happened seven times in the first two rounds in Australia. Or when someone is quite close to ending things but fails to seal the deal.

The word “choke” popped up all over Twitter on Monday after No. 9 Holger Rune, a 19-year-old from Denmark, gave away a lead of 5-2 in the fifth set, then leads of 5-0 and 7-2 in the first-to-10 tiebreaker that capped the match, in what became a loss to No. 5 Andrey Rublev.

Famously, Jana Novotna double-faulted when serving at 4-1, 40-30, against Steffi Graf in the third set of the 1993 Wimbledon final and never won another game. Gabriela Sabatini blew a 6-1, 5-1 lead against Mary Joe Fernandez at the French Open in the same year. In the 2004 men’s final at Roland Garros, Guillermo Coria was serving while ahead 6-0, 6-3, 4-4, 40-love, let that huge edge disappear and wasted two match points in the fifth set before Gaston Gaudio took the championship.

“The basic definition of ‘choking’ is the feeling of overwhelming anxiety that the athlete is unable to manage with his or her current defenses,” sports psychologist Tom Ferraro said.

Digging deeper, Ferraro said this sort of thing can occur “when an athlete unconsciously decides to stop focusing and eases up. This may be due to conflicts with aggression, guilt, fears of separating, shame or a repetition compulsion.”

Not surprisingly, many tennis players don’t like to hear about “choking.”

“It’s a harsh word,” said Jessica Pegula, an American who is ranked No. 3 and made it to the Australian Open quarter-finals in singles before losing Tuesday night.

“I think everyone kind of does it to some extent. I think it’s just because you get nervous. Some days there’s no rhyme or reason,” she said. “Some days, you can feel like you’re a little tense and, for some reason, you can feel like maybe the momentum is shifting in a match and you’re just putting a lot of pressure on yourself to do the right thing. I think maybe instead of thinking clearly, you’re panicking a little bit.”



Another point made by Pegula, whose parents own the NFL's Buffalo Bills and NHL's Buffalo Sabres, is that there is a big difference between being in the arena and rendering judgement from afar.

“Sitting and watching, it's very easy to say, ‘Oh, they're choking. They're choking,’” Pegula said.

No. 8 seed Daria Kasatkina lost 6-1, 6-1 to 97th-ranked Varvara Gracheva in the first round in Melbourne, then said she “lost my mental battle with myself” after waiting around through two days of rain delays.

Kasatkina said that, in general, she doesn't like the term.

“It depends how and when you use it, of course,” she said. “But when it's people on the internet, after the bad matches, they say, ‘Ah, you choked’—it's really bad.”

Mark Petchey, a former player who has coached Murray, was a TV announcer for the Murray–Berrettini match when that crucial backhand error arrived.

“It's hard to believe he has missed that,” Petchey said on air. “He just needed to get it over the net.”

Petchey said in an interview later that “choking” is a “complex subject, there's no question about that, because it's not just about mental frailty. It's also about your technique.”

Looking at Berrettini's miscue, Petchey noted that what it might have exposed more than anything are “flaws in his backhand”.

Pivotal lapses can also snowball, resulting in poorer play as a match progresses, because, Petchey said, “you want it too much.”

“Once you see the momentum get away from you,” he said, “it takes a very strong mind to get out of it.”

Players who let an advantage disappear often talk about how their arm felt like it was twice its normal weight or their legs weren't effective anymore.

“Definitely, when you're nervous, you freeze up,” Pegula said. “You don't want to move your feet. You get a little tense on your serve.”

Petchey said the circumstances, the occasion and the opponent should also be taken into account.

“It's always easy to say that they ‘choke’,” he said. “But if you force them to hit their worst shot, is that really ‘choking’? Or is that good play from the opponent on the other side that they force you to actually have to beat them with your least favourite shot?”

Berrettini, for his part, put what transpired simply.

“I had a match point. I missed. ... That sums up the match,” he said.

Case study

Time-to-competition countdown

The countdown to a major sports event is a stressful time for competitors. As the time gets shorter, the symptoms of stress would be expected to increase. Using this logic, time-to-event designs have been used to investigate pre-competition anxiety.

In one such study, 10 international-standard marathon canoeists were divided into groups based on whether they reported, via questionnaire, that they felt their anxiety symptoms were helpful and beneficial to performance (facilitators) or unhelpful and detrimental to performance (debilitators).

The canoeists were then measured for changes in hormonal concentrations at three different points: 24 hours before competition, 2 hours before competition and 1 hour before competition.



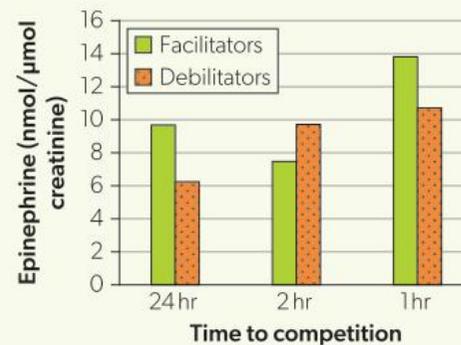
▲ Figure 4

A strength of this study was that the canoeists were in a competition of great importance to them—success would lead to selection for the world championships.

The results showed that facilitators showed a different pattern of hormonal response to debilitators.

Cortisol has often been referred to as a negative stress marker. In other (non-sport) studies it has been shown that extreme cortisol levels (high or low) can impair aspects of cognitive function such as memory, vigilance and decision-making. In this particular study, it would appear that high levels being shown in debilitators means that they are more at risk of impaired thought processes.

In contrast, the epinephrine responses show the opposite effect, with facilitators benefitting from a late surge in this hormone that is positively associated with physical performance—a vital ingredient to a good canoeing performance.



▲ Figure 5

Reference: Eubank and Collins (1997).



Experiments

Examining the ways in which elite performers respond is fascinating. They appear to be capable of achieving incredible levels of performance. This is true of physical feats of endurance, skill or strength, and also of the mental ability to focus under the intense scrutiny of millions of spectators and demonstrate levels of commitment that normal members of the population cannot fully comprehend.

Working with this extraordinary group of people throws up a fundamental question for researchers who adopt a scientific model in attempting to establish theory in order to generalize findings to apply to the population and make predictions. In psychological terms, there is no reason to expect the individuals in this “group” to be similar to one another as attempts to identify the personality of “champions” have consistently failed. The application of designs and statistical tests designed for making inferences to populations and generalized predictions could be challenged as illogical and inappropriate.

Is there any advantage to studying this group? How might research questions be framed and data analysed if there is no wider population to which the elite athletes belong?



Thinking skills

The transactional model of stress

How can two people in the same place, event and time experience different levels of stress?

Imagine two hypothetical athletes in the 100 m Olympic final. One athlete is the returning champion and clear favourite, with 10 years’ experience competing at the top level. The other was a junior last year, was a surprise selection to the team and has reached unexpected levels of performance to reach the final.

The first athlete carries the weight of expectation that they will win. In fact, to win merely meets expectation and any other place is a failure. This situation offers this athlete very little opportunity (apart from staying the world’s top sprinter) and a very large threat, since anything less than a win will reduce their position and status.

The second athlete, however, has already surpassed all expectations to reach the final. Finishing last would not have any significant negative impact. In fact, this athlete has nothing to lose (low threat) and everything to gain (high challenge).

The key difference in these experiences lies in how performers personally interpret the meaning of the situation for them (this is termed the “transaction” between person and situation). The ratio of perceived challenge and threat is thought to lie at the heart of whether a performer feels anxious or excited.

ATL Thinking skills

Zone of optimal functioning

During the 1990s several studies, such as Hanin (1997), reported that elite athletes have a zone of optimal state anxiety in which their best performance occurs. This was called the **individual zone of optimal functioning (IZOF)** model. Others, such as Ruiz et al. (2017), have supported this perspective, but it has also been criticized for its lack of explanation of why individual levels of anxiety may be beneficial or detrimental for performance.

The IZOF view differs from the inverted-U hypothesis in two ways:

- the optimal level of state anxiety varies from individual to individual
- the optimal level of state anxiety is not a single point.

In 2007 Hanin expanded the IZOF beyond anxiety to show how zones of optimal functioning use a variety of emotions and other psychobiosocial states (such as determination) for best performance to happen. He concluded that for best performance to occur, athletes need individualized optimal levels of a variety of emotions (not only state anxiety).

For example, there can be positive and negative emotions that enhance performance (such as confident and nervous), as well as positive and negative emotions that have a dysfunctional influence on performance (such as calm and annoyed). In other words, the IZOF model integrates functional and dysfunctional patterns of emotions related to optimal and poor performances.

Ruiz et al. (2017) suggested four categories for the IZOF model that inform how energy and arousal can be mobilized, adjusted and used to optimize sport performance:

- positive helpful
- positive harmful
- negative helpful
- negative harmful.

This was an important development for the IZOF view, because it acknowledged that a given emotion (such as anger) can be positively associated with performance for an athlete, but negatively associated with the performance of another athlete (individualized athlete profiling) (Ruiz et al., 2016).

How can a sports coach help each individual athlete achieve their ideal mix of positive and negative emotions needed for their best performance?

Hypotheses

Originally, psychologists considered the effect of stress that produced anxiety in performers, as likely to have a negative impact on performance. However, real life observations showed a pattern that important events such as World Championships and Olympics were associated with higher levels of performance. It would be quite logical and consistent to expect these more important events to be associated with higher levels of anxiety among the performers.

The question, therefore, is why these high levels of performance are associated with events where anxiety is also likely to be higher? The following hypotheses attempt to explain the pattern:

One hypothesis, from a practical (strategical) perspective, is that athletes deliberately target and peak at this time.

A second hypothesis, from a psychological perspective, is that high-level performers have developed the capacity to

use their experience of stress so that it becomes facilitative and beneficial to performance rather than debilitating. Such a possibility is consistent with anecdotal reports from elite athletes seen in interviews.

These two hypotheses are not mutually exclusive (both could be true). In addition, the hypotheses do not need to account for every single instance. This means we would still expect to see occasions where an athlete might choke or may not manage to re-appraise their experiences of stress and anxiety. One reason is that applying science to human performance in real-world contexts is less predictable than might be expected in natural sciences, such as physics and chemistry, where theories and laws are based on relatively constant properties and factors.

How do you think further experiments could lead to new hypotheses about the effect of stress and anxiety in elite performers?

Anxiety

Anxiety has been defined as the “subjective evaluation of a situation, and concerns jeopardy to one’s self-esteem during performance or social situations, physical danger, or insecurity and uncertainty” (Schwenkmezger, Steffgen, 1989). Central to understanding anxiety is the view that it is based on the subjective experience, often called “relational meaning”, of an event. In this way a situation is not stressful to an individual unless they perceive it to be so.

Anxiety has been found to be multidimensional, comprising both cognitive and somatic anxiety and possibly also a behavioural component.

Cognitive anxiety is the worry component and has been effectively defined by Borkovec as a chain of thoughts and images negatively affect-laden and relatively uncontrollable (Borkovec, 1993).

Somatic anxiety is closely linked to physiological arousal and is best explained in terms of an awareness of physiological changes that provides a signal to the individual that they are anxious. So a performer who experiences some trembling and nausea may feel more anxious because these symptoms confirm to them that they are becoming anxious. This kind of physiological feedback and interpretation would support and enhance feelings of anxiety.

Determining levels of anxiety has one fundamental problem, which is that it is primarily a cognitive function. Even with the very best technological advancements in brain imaging and scanning there is no immediate prospect of determining specific types of thought from such data sources. Consequently, the only mechanism to assess what a person is thinking is to ask.

In anxiety research, questionnaires and interviews are the primary sources of data collection. Other techniques, such as diaries or real-time think-aloud recordings, all fall into the same general class of “self-report” data.

ATL Thinking skills

Limitations of self-report data

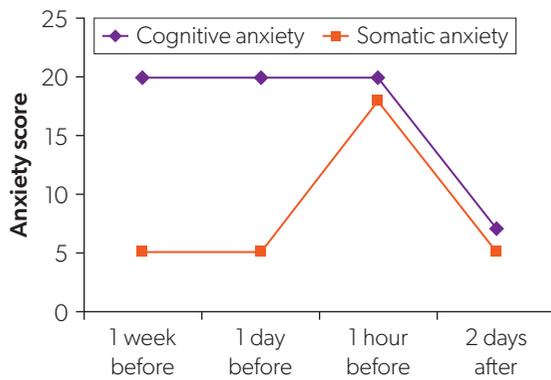
Asking people to report anxiety states carries a number of limitations. Like many scientific measurements it is intrusive and hard to apply in real, time-pressured situations. However self-report data also have limitations if the respondent lacks sufficient awareness to accurately answer the questions.

There is also a danger that respondents may “manage” their responses to appear in a positive light. This is called

social desirability. Questionnaires are also less robust to the effects of language comprehension, reading ability and educational background compared with a simple physiological measure.

There are steps that can be taken to reduce, although not remove, some of the limitations above. Can you think what could be done in relation to each of the issues listed?

In sport several questionnaires have been developed to assess anxiety, and one of the most used is the Competitive State Anxiety Inventory (Martens, 1990). This questionnaire comprises 27 items and measures 3 related constructs: cognitive anxiety, somatic anxiety and self-confidence. Using this questionnaire during the time leading up to a competition has reliably shown that somatic and cognitive anxiety are distinct from each other as they change at different rates over time.



▲ Figure 6 Somatic and cognitive anxiety change at different rates over time



Measurement

When investigation of a topic or area of interest such as anxiety rests on data sources that do not conform to the traditional scientific aim of being completely objective, can they still provide information of value to scientists?

Is there an advantage to assessing anxiety levels of performers before competition and understanding how these change differentially?

Is systematic collection of data through an established method such as a questionnaire sufficiently robust to qualify as scientific research?

If a construct is not open to completely objective measurement, is it worth researching?



Experiments

Researching stress in humans requires that the research participants actually experience stress. In studies conducted in laboratory-style conditions, one common approach to inducing anxiety is to ask participants to complete a short public speaking task. In this design the experimenter creates a stressful situation and measures responses and performance.

In what other kinds of ways do you think it might be possible to create some stress for participants?

Consider stressors experienced as part of a controlled psychological experiment with genuine high-level stressors, such as that featured in the study on canoeists by Eubank and Collins (refer to the case study earlier in this chapter). List the advantages and disadvantages of contrived (laboratory-based) versus real-life research on stress.

Remember the ethical responsibilities of researchers to protect research volunteers from physical and mental harm in line with international agreements (such as the Declaration of Helsinki that you read about earlier in this chapter).

Case study

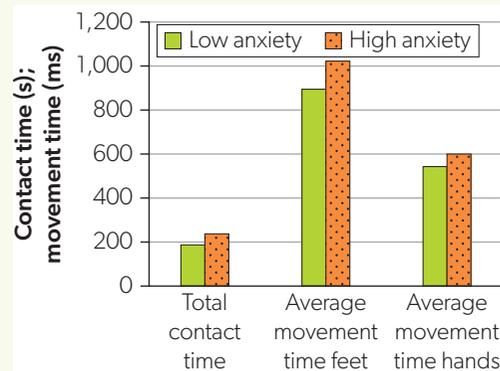
Influence of anxiety on movement behaviour

Research showing that anxiety has a negative impact on performance outcome does not fully answer the question of why this would happen. One theory to explain this effect is that when individuals experience anxiety their movement becomes less fluid and efficient. Pijpers et al. (2005) investigated this by monitoring movement of novice climbers to complete traverses (horizontal climbing) of an indoor climbing wall. To manipulate anxiety they used two identical 3.5 m routes, one high at 4.9 m and one low at 0.3 m. Total climb time was recorded and, using force-induced electrical switches in each separate climbing hold, the total hold time and movement time were analysed.

On average, total climbing time took much longer (22%–50%) when the route was high compared with when it was low. Participants also reported significantly more anxiety and displayed significantly elevated heart rates (145.9 bpm at the greater height compared with 126.3 bpm at the lower).

As well as total time on the climb being longer, Pijpers et al. found that the total contact time (measured in seconds in Figure 7) was significantly longer for the climb at height. Using the pressure-triggered timers on holds it was also possible to determine the time of movement—the time between the hand or foot leaving one hold and triggering the next. For both hands and feet the movement time was significantly longer climbing at height. An earlier study also found that climbing at height stimulated more “exploratory”

movements indicative of the climbers being uncertain and hesitant in their movements.



▲ Figure 7

The effects of anxiety on movement in this study would seem to have not just increased total time, but also had a negative impact on the nature of movements, which were slowed and hesitant. The authors felt these data were consistent with one of the leading theories for explaining performance changes under pressure—the conscious processing hypothesis.

This hypothesis suggests that, when under pressure, performers attempt to increase the degree of conscious control over movement. However—many relatively well-learned movements become less effective, smooth and efficient when tighter step-by-step control is applied. In short, increased efforts to improve performance actually result in worse performance (“choking”).

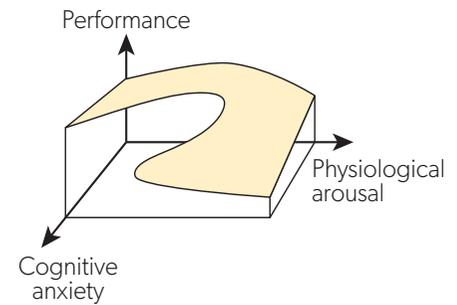
Multidimensional approaches to anxiety

The concept of multidimensional anxiety formed the basis for a stronger understanding of the relationship between anxiety and performance among sport psychology researchers. In 1987 Hardy and Fazey presented **catastrophe theory** to explain the varied effects seen in real-life sports performances. The model presented was three-dimensional and centred on the concept of a “performance surface” to describe the combined effects of physiological arousal (closely allied to somatic anxiety although not the same) and cognitive anxiety on performance levels. The performance surface is best thought of as a soft sheet with a large fold at the front and a small ridge at the back.

Unlike inverted-U theory, the model proposed by catastrophe theory suggested that when cognitive anxiety was high (towards the front of the performance surface), continued increases in physiological arousal would result in a catastrophic decline in performance.

At the back of the model notice how the performance surface is shaped in a gentle inverted-U shape, which suggests that at low cognitive anxiety physiological arousal will influence performance with a gradual increase to an optimal level followed by gradual decline.

One aspect of this model not evident from the diagram relates to what happens following a sudden catastrophic decline. Hardy and Fazez proposed that small reductions in physiological arousal were not sufficient to regain the level of performance. Instead they suggested that significantly reduced arousal was required before the performers could begin to approach the same performance level again. The crucial aspect of this part of the model is that performance does not follow the same path when physiological arousal is increasing as when it is decreasing.



▲ **Figure 8** Model of catastrophe theory (Hardy, Fazez, 1987)

Limitations of catastrophe theory

Catastrophe theory was a significant development in understanding what happens to performance when anxiety increases because it considered the interaction between physiological arousal and cognitive anxiety. However, the contribution of catastrophe theory failed to address two important issues.

- A key requirement of any “theory” is that it identifies a mechanism to explain events. Catastrophe theory, while suggesting a relationship between anxiety, arousal and performance, did not offer any explanation as to why this relationship is thought to occur.
- The model of catastrophe theory presented the idea of a “performance surface” (Figure 8) but did not explain how it would be possible to accurately determine where a performer was on this surface. This significantly limited the potential for this theory to have real-world application.

The failure of catastrophe theory to offer a clear mechanism to explain the consequences of anxiety for performance, or to be practically useful, suggested that an alternative explanation was required. A viable explanation that has been linked to anxiety relates to the changes in attention. For many years it has been recognized that attention changes under conditions of anxiety, with increased anxiety being associated with decreased breadth and flexibility of attention. Under anxiety, people seem to attend to less information, even ignoring information that is useful, and are not able to move attention quickly to different areas even when the situation demands this. However, attention changes are not just symptoms of anxiety but have been suggested as a causal explanation of performance changes.

Measurement of stress and anxiety

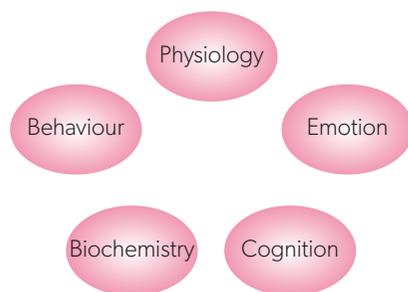
To research stress and anxiety effectively it is necessary to devise ways to measure these “constructs” that are sufficiently valid and reliable to provide valuable information and understanding.

The term “construct” is used to label an idea or concept that does not have a tangible form—you cannot touch or see it. Examples of other constructs include fatigue, aggression or centre of gravity. Each is determined through examining the outcome of, usually, two or more other primary measurements. The construct of anxiety has been measured in several different ways in the research outlined in case studies presented in this chapter.

One way of measuring the anxiety construct is to measure the changes that we know are associated with increased anxiety.

There are numerous physiological indicators of anxiety, such as increased blood pressure. The body produces epinephrine when an athlete is under stress, a substance that raises heart rate and blood pressure. When the athlete feels the symptoms of anxiety, such as increased heart rate or increased blood pressure, the application of a relaxation technique can help in controlling the anxiety and hopefully reduce stress.

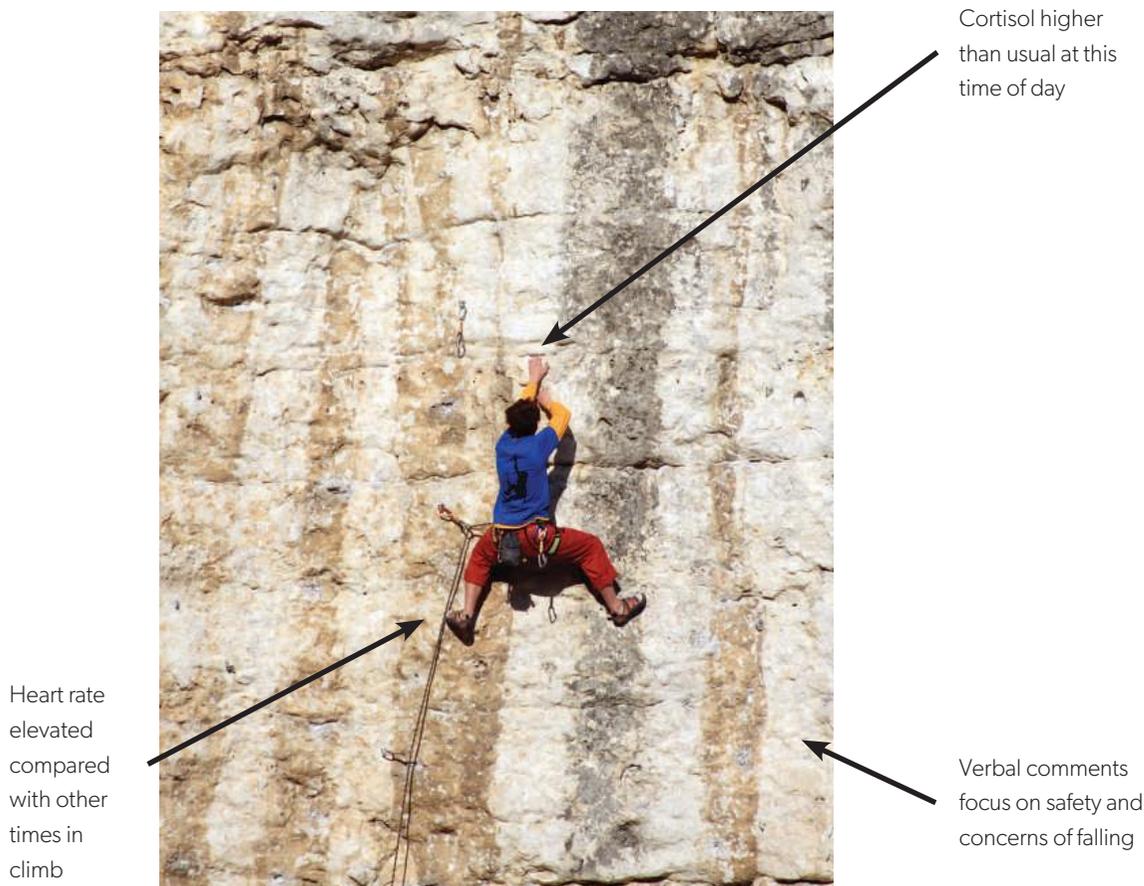
The autonomic nervous system of a human controls the organs of our body such as the heart, stomach and intestines. We know that the autonomic nervous system can be divided into two divisions: the sympathetic and parasympathetic nervous systems. The parasympathetic nervous system is responsible for calming the nerves, whereas the sympathetic nervous system activates the glands and organs for defending the body from the threat. Activation of the sympathetic nervous system can result in an increase in heart rate, an elevated breathing rate, rapid blood flow to the muscles and activation of sweat glands (that is, increased sweating). It is well known that this type of physiological information can be used to identify if an athlete is stressed or not. For example, the electrical conductance of the skin can be used through what is known as the **galvanic skin response**. The galvanic skin response is the measure of the continuous variations in the electrical characteristics (conductance) of the skin caused by the variation of the sweating activity of the human body. If the sympathetic division of the autonomic nervous system is highly aroused, then increased sweating follows. This results in a decrease in skin resistance and an increase in skin conductance. Therefore, this is used to measure human sympathetic nervous system responses that are directly involved in the emotional-behavioural regulation in athletes, such as stress.



▲ Figure 9 Categories of stress responses and symptoms

We can group the symptoms of anxiety very broadly under five category headings (Figure 9—note that, strictly speaking, biochemistry would be a subset of physiology, but it warrants specific attention).

Measuring changes under just one of these symptoms is a weak approach to determining if someone is anxious because changes may be due to other factors. For example, if we measured the cortisol of football players turning up to training in the morning we might find it was higher than during the afternoon. However, high cortisol does not mean the player is stressed or anxious as it is affected by other factors including a significant diurnal (daily) peak in the morning. To overcome this problem good research designs use a combination of measurements. When the results converge to provide a consistent picture, then researchers can be more certain the measurement is valid. This process is often referred to as triangulation. Even though the word “triangulation” suggests three measurements are used, the term is used for any combination of two or more measurements to increase validity.



▲ Figure 10 Triangulating measurements improves the validity of research

Measurement via self-report

Determining what a person feels or thinks (emotion and cognition) is largely dependent on asking them, and usually this occurs via a questionnaire or interview. There are several potential problems associated with this approach that you were challenged to think about earlier in this chapter. There are strategies that can help to minimize, though never remove, the potential for this source of information to be inaccurate. Some of the more obvious problems and solutions are shown in Table 3.

▼ Table 3

Problem	Solution
recall of thoughts and feelings after an event depends on memory	<ul style="list-style-type: none"> • ensure self-report is as close to the event as possible (use field-based data collection or via phone?) • stimulated recall techniques (for example, by film footage) may enhance recall
participants do not want to appear weak or anxious	<ul style="list-style-type: none"> • ensure participant information is treated confidentially, and individuals are not identifiable • build trust with the research team • consider telephone interview with a researcher who does not know the respondent's identity



 <p>the outcome of an event influences how they feel and what they remember (success = positive recall; no success = negative)</p>	<ul style="list-style-type: none"> • measurement “in-event” (especially in sports with breaks) • use quick recorded “diary-entry” style or short single questions to be rated (for example, on a scale of 1–10)
<p>participants do not understand what information is required from them</p>	<ul style="list-style-type: none"> • train participants including giving them feedback on type, quantity and depth of content (but avoid biasing content delivered) • check questions are easily understood

There are several questionnaires that have been developed for use in sport settings that have established reliability and validity; this is important to enhance the quality of information. Non-sport-specific questionnaires should not be used unless they are assessing the general tendency or predispositions of participants that are expected to affect general life as well as sport. Despite the limitations, self-report contains too much information of value to ignore so it has to be used, but with care, to provide the best possible information while accepting its limitations.

Linking question

How can anxiety be managed through psychological skills training? (C.5.1)

Consider:

- learning and practising relaxation techniques
- cognitive restructuring (replacing negative thoughts with positive ones)
- SMARTER goal setting
- attentional control, focus and concentration
- mental imagery
- establishing pre-performance routines
- positive self-talk.

Linking question

How do internal physiological regulatory processes impact anxiety or arousal? (A.1.1, A.1.2)

Consider:

- autonomic nervous system: sympathetic and parasympathetic
- hormone responses (such as epinephrine and cortisol)
- heart rate variability, emotional regulation, self-control and resilience to stress
- rate of breathing.



Linking question

Are certain personalities more likely to be anxious? (C.1.1, C.3.2)

Consider:

- validity of making generalizations about personality
- athletes with perfectionistic tendencies
- trait of anxiety
- introversion factors
- athletes with low self-confidence/esteem
- sensitivity to negative judgement/criticism from others.

Conclusion

Performers in sport will always experience heightened arousal and very commonly stress and anxiety. Performing in such environments is directly associated with meeting challenges, excitement, and later satisfaction and pride at one's achievement. So it seems that we should not strive to reduce or remove the stress or anxiety inherent in sporting situations. Performing in the presence of stress in sports settings may also teach people something that is of benefit to them away from sports settings, in other parts of their life. Viewing sport in this way reveals it as a valuable learning opportunity with which to experience and practise a general life skill.

Understanding stress and anxiety in sport also emphasizes the important distinction between performance situations that require physical and mental factors, such as most sports, in contrast with performance in an office or school setting where there is little physical component. Deep physical relaxation may help counter anxiety but is inappropriate for a sport performer who needs significant arousal levels to perform well. In contrast, physical relaxation before a school exam may actually help performance in this mental task.

Finally, understanding how performers learn to cope effectively with anxiety provides useful information to develop better coping skills training. The research also clearly shows that how people respond to situations is partly dependent on the transaction between them and the stress source(s). This means that it is possible for a person to be taught how to modify their anxiety experiences through their own thinking processes, and by managing and using effective coping responses. In this way, understanding developed through sport psychology research on performers who are good at coping can help provide the basis for helping all of us cope more effectively.

Practice questions

1. List **two** examples of somatic anxiety in sport. (2 marks)
2. Describe the relationship between arousal and sporting performance for a weightlifter according to the inverted-U hypothesis. (2 marks)

Summary

- Stress prompts the physiological system to become aroused through activation of the autonomic nervous system.
- The “fight–flight” response prepares the body for high-intensity physical work.
- Sport performance where skilled execution, accurate timing and clear thinking are required may not be aided by strong arousal-based responses.
- Hans Selye emphasized that stress was a response and proposed that stress could be considered as positive (eustress) or negative (distress).
- Stress can be categorized by time limits of exposure and the extent to which it is voluntarily experienced or not.
- Sources of stress can usually be defined with reference to two broad categories: physical threat or danger and social-evaluative concerns.
- Arousal-based changes (for example, variation in heart rate and blood pressure or galvanic skin response) can be used to indicate a response to stress, but these measures can be compromised in sport research where physical workload masks the stress response.
- Many famous examples in sport show that under high stress performance levels can show sudden and dramatic declines.
- Individuals respond differently to stress and may interpret their perceived anxiety as beneficial or detrimental to performance.
- There are four categories for the individualized zone of optimal functioning model that inform how energy and arousal can be mobilized, adjusted and used to optimize sport performance, namely: positive helpful, positive harmful, negative helpful and negative harmful.
- Cognitive anxiety (worry) is more important than arousal in understanding why and how performance is affected under stress.
- Cognitive anxiety can prompt increased attempts to consciously control movements, paradoxically resulting in less efficient and effective performance.
- Attention-based models provide a strong theoretical explanation for how and why anxiety influences performance.
- Measurement of anxiety in sport requires combined approaches, triangulation and careful use of self-report data.
- Research in stress and anxiety introduces a strong ethical dimension to designing and conducting studies.
- Controlled scientific experiments rarely examine stress and anxiety at intensities equivalent to real-world experiences.
- Sport offers a perfect opportunity to study the impact of stress and anxiety on performance.
- Sport participants voluntarily and frequently experience stress and associated symptoms, have very high motivation to excel and engage in large volumes of practice to become skilled.

Check your understanding

After reading this chapter, you should be able to:

- describe the terms “stress” and “arousal” and their application to human behaviour
- identify the psycho-physiological responses that occur when humans are aroused
- outline drive theory
- outline inverted-U theory
- define the term “anxiety”
- describe the transactional model of stress and anxiety
- distinguish between two types of anxiety (somatic and cognitive)
- evaluate theories of the anxiety–performance relationship including the individual zone of optimal functioning (IZOF) model
- discuss the mechanism of attention in explaining how anxiety influences performance
- evaluate measurement approaches to investigating the anxiety–performance relationship.

Self-study questions

- Provide a definition for these terms:
 - stress
 - arousal
 - anxiety.
- Selye's idea of "a non-specific stress response" does not appear to hold true. What process do humans go through that may account for different responses?
- Outline **three** major criticisms or weaknesses of the inverted-U theory of the arousal–performance relationship.
- Identify **two** symptoms of stress that occur under each of these headings:
 - physiology
 - biochemistry
 - emotions (feelings)
 - cognitions (thoughts)
 - behaviour.
- Explain **two** key issues that are relevant to designing and conducting research in stress and anxiety.

Data-based question

Hardy and Parfitt (1991) examined changes in basketball free throw performance on the day before (high anxiety) and day after (low anxiety) an important competition. They manipulated physiological arousal by getting participants to complete shuttle runs and started either with the participant at near maximum heart rate, decreasing in bandwidths of 10 beats per minute (from maximum

to –10, –20, –30, –40), or with the participant at 40 beats below maximum and increasing. At each bandwidth participants completed a number of free throws to measure performance.

Table 4 shows the basketball shot scores from the day before competition, the high-anxiety condition.

▼ Table 4 Basketball shot scores

Heart rate bandwidths	Arousal increasing	Arousal decreasing
max –40	19.88	21.25
max –30	21.13	20.63
max –20	21.25	12.75
max –10	24.00	12.00
max	11.37	12.63

- Sketch out a graph with the five heart rate bandwidths along the x-axis (max –40 to max) and basketball performance on the y-axis. Now plot one line for increasing arousal (put an arrow on it pointing from left to right) and one line for decreasing arousal (with an arrow pointing in the other direction). (1 mark)
- What performance scores were found when arousal was max –20? (1 mark)
- What direction was arousal moving in to produce the higher performance score at max –20? (1 mark)
- Describe what happens to performance when arousal increases from max –10 to max? (2 marks)
- What do these data suggest would be the best physical arousal state (intensity and direction) for performing in high-anxiety conditions? (3 marks)

C.4.2 Coping

Syllabus understandings

C.4.2.1 A stressor causes psychological strain. This can be positive, such as looking forward to an opportunity, or negative, such as fearing an outcome.

C.4.2.2 Stressors can be considered as either controllable or uncontrollable.

C.4.2.3 Many coping strategies have been shown to be effective for athletes, although the effectiveness of each is specific to the individual and the situation.

AHL

Introduction

When we think about “coping” in sport and exercise, we often think of the most extreme examples, such as:

- the complete focus required to take a penalty kick in a soccer World Cup final
- “digging deep” (pushing yourself to keep going) to endure the pain and discomfort in an extreme adventure race
- committing years of practice to produce a perfect high board dive.

But coping occurs at every level of activity—enlisting support from a friend to start running, researching how to improve diet, joining a new class or taking up a new sport all present change and challenges that require us to cope. In fact, coping is universal, and this is why it is important for us to understand coping in relation to sport and exercise, since it is relevant in many ways, at every level, and for everyone.

In addition, the value of sport, exercise and physical activity is recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) for its potential to impact not only on physical factors but on mental health and well-being. One way in which such wide-reaching impacts can be realized is the development of coping skills through involvement in sport and exercise.

In this chapter, we are going to outline approaches to developing better responses to stress and anxiety through developing coping skills. Throughout the chapter, we will consider some underpinning empirical research and reflect critically on the scientific research used to generate knowledge that has allowed us to develop and advance understanding and practice in psychology since the 1970s.

Defining coping and appraisal

Most people have a general sense of what is meant by the term coping. Psychologists Lazarus and Folkman defined **coping** as “constantly changing cognitive and behavioural efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person” (Lazarus, Folkman, 1984).



▲ Figure 1 Taking up a new activity can be a challenge that requires us to cope

There are four key implications of this definition.

- **Coping can involve thoughts and/or behaviour.** Where thoughts are involved, these can only be investigated by using some form of self-report (for example, think-aloud, retrospective questionnaire, or interview, possibly using techniques to increase recall accuracy and salience, such as video prompts).
- **Coping can be in response to internal demands** (such as self-doubts, injuries, fatigue, distraction), just as much as external stressors. It is not possible to know what stressors an individual is experiencing based only on external circumstances.
- **Individuals have their own perception of the balance of demand and resources.** This may not be objectively accurate or what others might expect. The confidence an individual has in their skills and abilities (self-efficacy) will influence this perception.
- **Coping is about making “efforts to manage”** rather than whether the outcome is successful or not. Of course the outcome is important to study, but coping covers a wide range of responses which may not be equally effective or beneficial. Researchers are interested in both what people do (coping) and what works (coping effectiveness).

Appraisal

Much less well known and understood than coping is the idea of **appraisal**. Appraisal is fundamental to comprehending the stress and coping process.

Appraisal has been defined as “a process through which the person evaluates whether a particular encounter with the environment is relevant to their well-being, and if so, in what ways.” (Folkman et al., 1986).

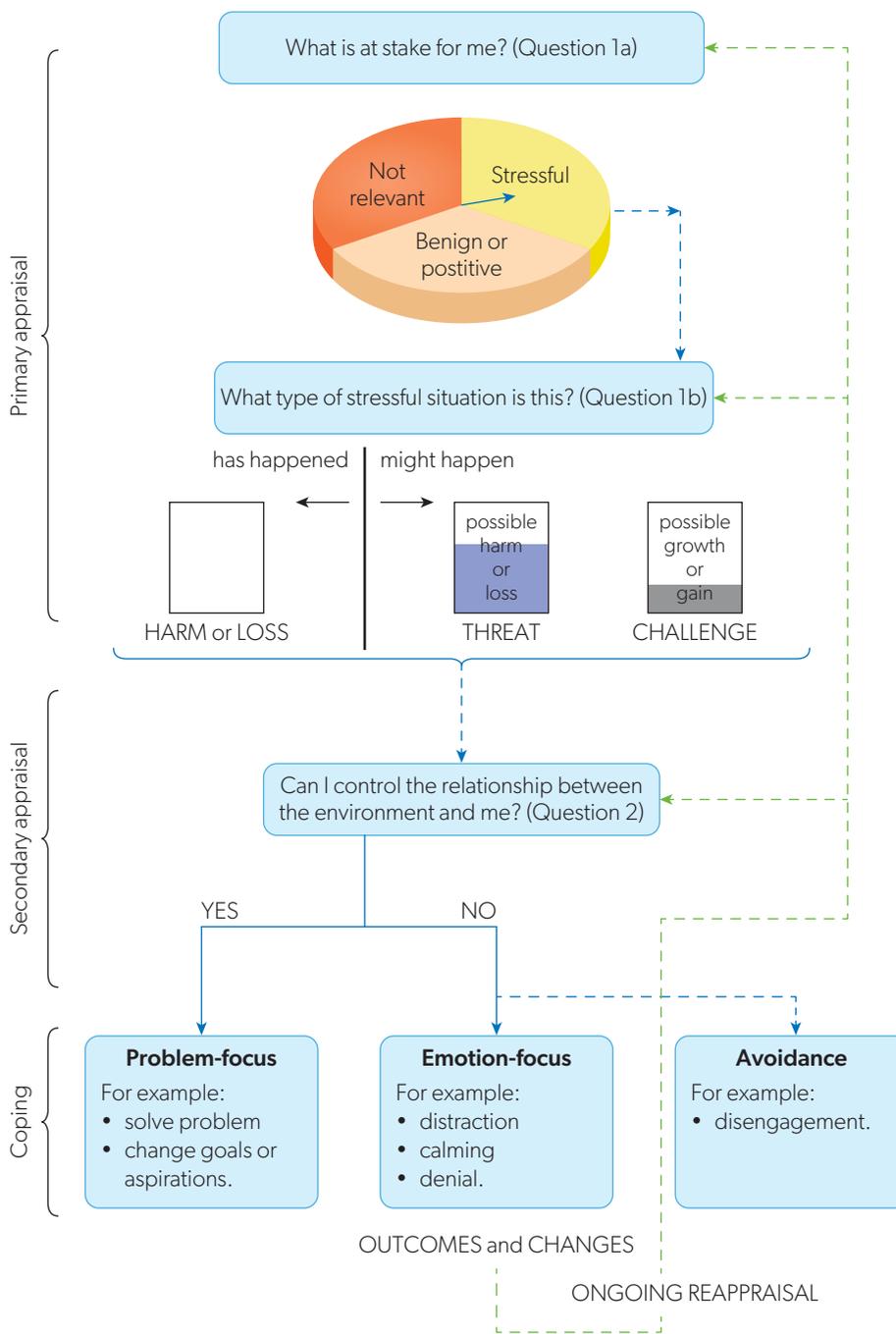
As discussed in chapter C.4.1, research shows that how people respond to situations is partly dependent on the *transaction* between them and the source of stress—a model which is known as the transactional model of stress. It explains why two individuals may experience the same situation in quite different ways, based on how they evaluate, or “appraise”, the meaning to them.

For example, consider two individuals selected to play for their team for the first time in an important championship final. The nature of the external context and setting is the same for both, and the importance of the game and the move up to a higher team are likely to mean they both appraise this as a meaningful situation to them but one that is stressful. However, one performer may see this as a great opportunity to perform at a high level, to show their skills and gain valuable experience early in their career. The other player may appraise the situation much more as a possible threat. They may be concerned not to let their teammates down, see the possibility that if they make a mistake it could cost the team the championship, and because of the importance realize that many spectators will be watching and evaluating their performance. These two very different appraisals will have a significant impact on how the players feel about the event, and this will impact differentially on their responses, both physiological and psychological, and on their performance.

A key implication of the definition of appraisal is that we should consider appraisal as an ongoing “process”, not a discrete event, in order to accurately portray what happens in real life. As an event unfolds, the appraisal process keeps on functioning, which means different appraisals are likely to occur throughout an event, which may influence changes in thoughts and behaviour.

Coping and the appraisal process

The work of Lazarus, Folkman and colleagues on coping, which took place principally in the 1970s and 1980s, has been widely accepted by scientific researchers. It remains the foremost explanation of how individuals react to stress in different ways. They proposed that when an individual encounters a stressful situation or event (remember, this can include internal stressors) two distinct phases of appraisal occur, in which the individual evaluates the meaning of the stressor to them, followed by a coping response.



▲ Figure 2 The coping and appraisal process

Primary appraisal phase

Initially, in the primary appraisal phase, the individual evaluates whether the situation is relevant to them, and if so, whether it is stressful (Question 1a in Figure 2).

If the situation or event is evaluated as stressful, the individual appraises what kind of stressor is involved (Question 1b).

Past stressor: something that *has happened*, for example, experiencing a defeat in a competition.

Future stressor: something the individual is anticipating *might happen*. Future stressors can represent either a threat or a challenge to the individual, although most stressors combine some threat and challenge components.

Secondary appraisal phase

This is followed by the secondary appraisal phase, in which the individual evaluates whether they are able to *control* the transactional relationship between themselves and the environment (Question 2).

In addition, the individual assesses whether their coping resources are sufficient to meet the demands.

Resources might include specific skills, strategies, social support, experience, knowledge, organizational factors, time and money.

Coping response

Finally, following the two phases of appraisal, the individual will engage in a coping response.

The process of appraisal will continue to cycle around, assimilating any outcomes from coping as well as any changes in the perception of events and circumstances that occur over time.



Activity 1

Using Figure 2 as a guide, think of a stressor you have experienced. Choose something that evoked a significant response in you, such as a sports competition, public speaking, minor injury, exam or adventure activity.

Important: Do not choose something that is very significant to you personally or that was traumatic and upsetting.

- Draw out the process of evaluation as it happened to you, in the situation you are recalling.
- Consider each of the key questions in the appraisal process and identify what your responses to these questions were at the time you experienced the stressor.
- Think about what your coping response was. How did your coping or other changes in the event influence your ongoing iterative reappraisal?

Types of coping

Coping strategies relate to any method you use to deal with a stressor to lessen its negative impact. Scientific researchers have long considered ways of grouping coping strategies into categories. Perhaps most well-known is the distinction between problem-focused coping strategies and emotion-focused coping

strategies, as shown in Figure 2. This categorization was suggested by Folkman and Lazarus to illustrate two qualitatively different responses.

- **Problem-focused coping strategies** attempt to influence the person–situation relationship (problem).
- **Emotion-focused coping strategies** attempt to manage the emotional consequences of the stressor (emotion).

A common misconception is to assume that problem-focused coping is synonymous with problem solving. However, problem solving is just one specific strategy that would fit into this category. The category of problem-focused coping responses is broader and includes active coping and planning, as well as changing the person–situation relationship, by reducing personal importance of the situation or adjusting motivation by changing goals.

While the categories of problem- and emotion-focused coping have found popularity in research and practice—partly because of the simplicity they offer—the original researchers themselves stated that, “Although it is tempting to classify any coping thought or act as either problem-focused or emotion-focused, in reality any coping thought or act can serve both or perhaps many other functions” (Lazarus, 1996, p. 293).

Avoidance coping strategies

Avoidance coping strategies include both behavioural and psychological efforts to disengage from a stressful situation. For example, a player who may want to react to the decision of an official may just walk away to disengage from the situation. Avoidance coping strategies have been viewed by some researchers as being less effective among athletes (Kaiesler et al., 2009). However, simple generalizations often overlook specific details, such as different types of stressors, whether stressors are chronic or acute, or whether they might be likely to dissipate spontaneously over time.

For example, an athlete who is moving towards the end of their sporting career may find it difficult to engage with this inevitable occurrence and instead avoid thinking or doing anything about it. Consequently, without adequate planning and preparation, they may find that their athletic retirement is extremely challenging and that they experience poor mental health, lack of adjustment and other negative outcomes. In this situation, the stressor was large and chronic (permanent). Avoidance made the problem worse by leaving less time to take action.

In contrast, the stress an athlete may experience during the 20–30 minutes before an athletic sprint event is qualitatively different. At major events, athletes may be required to gather in a “holding room” so the organizers know they are all present. This time period can be particularly stressful, not just because of the approaching event but also because of the social dynamic of being sat with competitors. One athlete reported feeling unsure where to look or who to look at, and worried that looking away was a sign of weakness. This athlete used avoidance coping to very positive effect: they purchased cheap mirrored sunglasses so they could look anywhere, or nowhere, and the stress of the social situation was avoided.

Models

Ways of categorizing coping strategies

In addition to Folkman and Lazarus's categorization of coping strategies into problem focused and emotion focused, alternative ways of categorizing coping strategies have been proposed. For example, Roth and Cohen (1986) considered coping strategies according to categories of "approach"

versus "avoid". In sport-specific research, Gaudreau and Blondin (2002) developed a questionnaire, assessing 10 different coping strategies, which they organized under 3 categories (Table 1).

▼ **Table 1** Coping strategies and higher-order factors assessed by the ISCCS (*Inventaire des Stratégies de Coping en Compétition Sportive*; Gaudreau, Blondin, 2002)

Task-oriented	Distraction-oriented	Disengagement-oriented
<ul style="list-style-type: none"> • mental imagery • thought control • relaxation • logical analysis • seeking support • effort expenditure 	<ul style="list-style-type: none"> • social withdrawal • mental distraction 	<ul style="list-style-type: none"> • disengagement/resignation • venting of unpleasant emotion

Attempts to identify universal category labels tend to share similar weaknesses. A 2003 paper (Skinner et al.) produced a thorough and empirically based critique and review of different category systems for coping strategies. They identified several requirements for an effective category system that the simple two- or three-category proposals discussed here did not meet. Identified weaknesses of the problem-focused versus emotions-focused category system included:

- conceptual clarity—it is not always clear which coping response would go in which category
- mutual exclusivity—some coping responses might fit in more than one category (for example, social support might be considered emotion focused if it helps an individual feel less anxious, or problem oriented if it generates useful information or offers of assistance to address the problem)
- exhaustiveness—not all coping behaviours are covered (for example, avoidance-focused coping strategies are not included).

The authors of the paper concluded that none of the simple category systems, based on two or three simple categories, is reliably supported by existing data. Instead, using an analysis approach called confirmatory factor analysis (a statistical approach to see which factors vary in similar ways to each other) they identified about 12 categories of coping. The work in this area is ongoing and developing but it is clear that it is more complex and nuanced than can be captured by simple two-category models.

Although categorizing coping strategies as problem-focused or emotion-focused might not be perfect from a theoretical point of view, from a practical applied perspective, there are still advantages to thinking about the different ways in which individuals cope. The different ways of categorizing coping strategies discussed in this chapter can encourage us to think broadly about coping and address both problem and emotion orientations.

ATL Research skills

Research online to find the widely used COPE questionnaire, which was developed by Carver, a world-renowned researcher, as well as the abbreviated version, the Brief COPE, which is intended for when measurement has to be done more quickly.

Carver emphasized that he never attempted to combine scales into higher-order aggregates and generally recommended looking at the scores on each scale separately to see the relationship between these and the other variables of interest in the specific study.

Coping skills and strategies

As outlined earlier in the chapter, the definition of coping includes any thought or behaviour that is used to attempt to manage a stressor. Given such a broad definition it is not surprising that there is a substantial range of strategies and skills that could be referred to as coping. One important feature of developing good coping capacity is to build a wide repertoire of complementary coping strategies.

Common coping strategies in sport include seeking social support, information seeking and increasing effort. Additional coping strategies are outlined in Table 2. These coping strategies are part of an athlete's overall self-regulation range that helps achieve success in high-performance sport.

Some of these strategies are an effective choice in certain circumstances for almost all individuals (such as planning). On the other hand, some individuals will demonstrate a preference for certain strategies, which they may use in a wide variety of stressful situations they encounter. However, over-dependence on one or two strategies means that when a situation arises where these are not suitable, an individual may find they are not able to cope effectively. Consequently, it is helpful to build a toolbox of different coping strategies which will provide stronger coping development.

Involvement in sport and exercise provides an excellent opportunity to help individuals learn how to cope and practise this in a context which offers some genuine but usually manageable stress.

▼ Table 2 Examples of coping skills and strategies common in sport and exercise

Coping strategy	Explanation
logical analysis and problem solving	<p>Using logical analysis and "what if" scenarios can help develop the ability to respond to problems. Problem solving follows several stages:</p> <ul style="list-style-type: none"> • identify the primary goals • identify the problem • generate viable solutions • select the best solution and enact. <p>Problem solving can be used to generate contingency plans for probable events. However, even in response to unexpected events, applying problem-solving stages is an effective coping response.</p>
information seeking	<p>For example, seeking information:</p> <ul style="list-style-type: none"> • about the quality of training in their current environment • from their sports organization • by drawing on past experiences • from literature and the internet • from others (such as a coach or parent) • about one's health.
seeking social support	<p>Relationships that provide social support have an important influence on an athlete's well-being and success. Social support (such as encouragement) from coaches, teammates, family, friends and the organization can affect the cognitive, emotional and behavioural aspects of an athlete's life in both a positive and a negative manner.</p>

pre-performance routines	A common strategy to control attention, helping individuals to focus on the right cues and in the right way. Often include self-talk (next row).
self-talk	<p>Can be used to:</p> <ul style="list-style-type: none"> • direct attention to instructional cues • affect motivational state or generate emotion. <p>A review of experimental research suggested that instructional self-talk was most effective for fine motor tasks; motivational self-talk had similar, though smaller, positive effects for both fine and gross motor tasks (Hatzigeorgiadis et al., 2014).</p> <p>In real-world performance situations, such as athletics, tennis or weightlifting, it is common to see elite performers' lips move as they use self-talk.</p> <p>Refer to the Self-talk section later in this chapter for more detail.</p>
controlled distraction	<p>Deliberately shift attention away from stimuli that may be anxiety provoking, unpleasant or stressful.</p> <p>This can be extremely useful, for example, in the waiting period before an important competition or receiving painful physiotherapy treatment.</p> <p>May also include activities to fill time positively with things that are interesting or enjoyable (such as films, books, music, puzzles, games, socializing, going for a walk, meals, shopping, emails, work/study, phone calls, sightseeing).</p>
thought control	<p>Worry has been described as an uncontrollable chain of negative thoughts and images (Borkovec, 1993). Thought control attempts to break this chain.</p> <p>Traditional thought-stopping techniques involved teaching people to say "Stop!" but actions or images can also be used.</p> <p>Reportedly, the first female gymnast to ever score a perfect 10 in an Olympic competition, would snap a rubber band she wore on her wrist. This quick, painful stimulus helped stop wandering thoughts.</p> <p>More attention grabbing, personally salient or evocative thought stopping will have the greatest impact.</p> <p>It is important to note that stopping thoughts should be followed immediately by attention control, otherwise the distracted thinking will quickly resume.</p>
imagery	A psychological skill with many uses in a sports and exercise context, including as a coping technique or to mentally rehearse specific action sequences (such as the vault in gymnastics or aerial flip in snowboarding). Refer to chapter C.5.2 for more on imagery.
effort expenditure	To cope with stress when under immense pressure, increased effort is used by many athletes to maintain high standards of performance.
relaxation skills	<p>The impact of relaxation skills on performance is discussed later in this chapter. One common relaxation technique is progressive muscular relaxation (PMR), which involves tensing and relaxing body parts in sequence, usually head to toe or vice versa, and which can be learned quite easily using freely available resources. Generally this is considered safe to use and effective, though rare instances of increases in anxiety may occur, as well as very rare experiences of pain or heart palpitations.</p> <p>Refer to later in the chapter for more on relaxation skills.</p>

Activity 2

In pairs, discuss and identify a positive and a negative aspect of social support, providing an example of each in the context of sport or exercise.

To be able to use any of these skills or strategies when under stress, the skill must be well practised, including under conditions of progressive exposure to stress. Just being able to do it under perfect conditions is not enough when it is needed under pressure. Like any skill, start with learning the basics and then move to being able to do this more easily, more quickly and under increasing pressure. During this process each individual should refine the way they use the specific techniques, words, actions or thoughts so it is individualized. It is helpful to consider this in three phases.

- **Adopt:** understand the basic skill or technique, develop motivation to use and practise.
- **Adapt:** review and reflect on how it worked, what to change. Make it individualized.
- **Adept:** become proficient in using, in less time and under increasing demands.

ATL Thinking skills

Learning any skill requires some initial knowledge followed by regular periods of practice with feedback. One of the principal features of a skill is that it responds positively to practice, becoming more effective, requiring less effort and growing more resilient to the effects of pressure. All of these are important for a coping skill, but resilience to pressure is most important. If a coping skill is not resilient to pressure, then when it is needed it will not be available. When skills are learned in an organized setting, consideration is given to practice scheduling (chapter A.3.1 on qualities of training), using different forms of feedback, and with a focus on progressive development. But it is

also possible to learn skills on your own, without structure imposed externally and without others giving feedback.

Think of two skills that you have learned, one in an organized setting and the other self-taught.

1. Compare the different ways in which you practise these skills.
2. What were the different ways in which you got feedback?
3. What do you remember about how you progressed this skill (faster, more complex, in front of others)?

ATL Thinking skills

Typical stressors that might be experienced in sport and exercise settings include:

- making an error
- pain or discomfort
- injury
- observing an opponent playing well
- practical or financial worries
- criticism from a coach or others
- needing to make social sacrifices.

Using the coping strategies described in Table 2, answer these questions.

1. Can you think of which responses you would find useful in relation to each stressor?
2. Discuss and compare your choices with others. Do you find a variation between individuals?
3. Do you think you might be likely to use more than one response to a stressor and, if so, why?
4. Would being able to have a range of options create a more robust coping "toolkit"?

Self-talk

People use self-talk all the time, in everyday life as well as in sports and exercise settings. Self-talk is the communication we have with ourselves, and this inner dialogue is important. What we say to ourselves can help with how we perform in sport and exercise. Self-talk can also affect motivation. Additionally, the communications of sports coaches, physical education teachers and exercise leaders can influence the self-talk of their athletes (for example, positive and negative feedback from coaches can result in either more positive self-talk or more negative self-talk in their athletes). Self-talk can be problem focused or emotion focused. Unintentional self-talk can be negative or positive. Practical mechanisms for self-talk include: recalling how positive experiences in the past felt, using an acronym of helpful phrases and/or describing a physical movement in a simple word.

Some examples of self-talk are given in Table 3.

▼ **Table 3** Types of self-talk

Type of self-talk	Examples
unintentional	<ul style="list-style-type: none"> • “Don’t give up!” (positive)* • “My legs feel heavy...” (negative)
strategic	<ul style="list-style-type: none"> • “Hills are my strength, when I get there increase cadence, cash in on my hill training, break away from the pack.”
goal-directed	<ul style="list-style-type: none"> • “OK, shorten stride length, keep breathing even-paced, dig in, don’t look up.”

(*) You may notice that this self-talk could be considered “negative”, but the important factor to recognize is that it is not what the wording looks like that determines self-talk’s characteristics, but what effect it has on the individual performer. Consequently, performers may vary substantially in the content of what they might use as self-talk. An individual’s chosen phrasing may seem negative and can even include words that might be considered offensive. However, if it is helpful to them then it is the facilitative effect that is important.

Research has also found that using swear words can increase tolerance to pain (for example, Stephen et al., 2020). It is thought that the principal mechanism is an increase in emotional arousal. Although this research has been largely conducted in experimental settings using a cold pressor pain induction technique, there is potential transfer to situations in sport and exercise. For example, painful experiences (minor injury or using a cold bath) or significant levels of discomfort (symptoms of fatigue).

Case study

Let's go!

2007, Paris, France: during the final of the French Open championship, elite tennis player Justine Henin sat down during the changeover.

She had won the competition three times before including the previous two years. She was ranked number one in the world the previous year. Her opponent, Ana Ivanovic, was younger, with less experience of Grand Slam tournaments.

She took an envelope from her bag and pulled out a note which had simply one word: "Allez!" ["Let's go" in French]. She won the match in straight sets, and later won the US Open, finishing the year ranked again as number one.

Although this was written down, Henin also verbalized the word many times in competition and so it can be considered a form of self-talk. Even for a highly experienced, elite player a simple word or phrase can help to focus the mind and galvanize effort and energy in the correct way, at the correct time.



Linking question

How do we learn coping skills? (C.2.1, C.3.3)

When we think about skills in sport and exercise we typically think about physical and psychomotor skills. But some skills, for example how to control attention, are almost entirely cognitive. Can we apply the same principles to learn cognitive skills?

Consider:

- the different phases of skill learning
- scheduling and timing for learning skills
- progressive exposure can help prepare to use skills effectively under pressure
- contrast skill development (gained from training) with knowledge about skill (gained from education)
- modelling of cognitive skills
- simulation
- motivation to learn
- maintaining and protecting confidence in skills as they are learned.

Relaxation and heart rate control

Relaxation skills can, among other benefits, provide greater control of heart rate. Relaxation can be used as a coping strategy in two different ways.

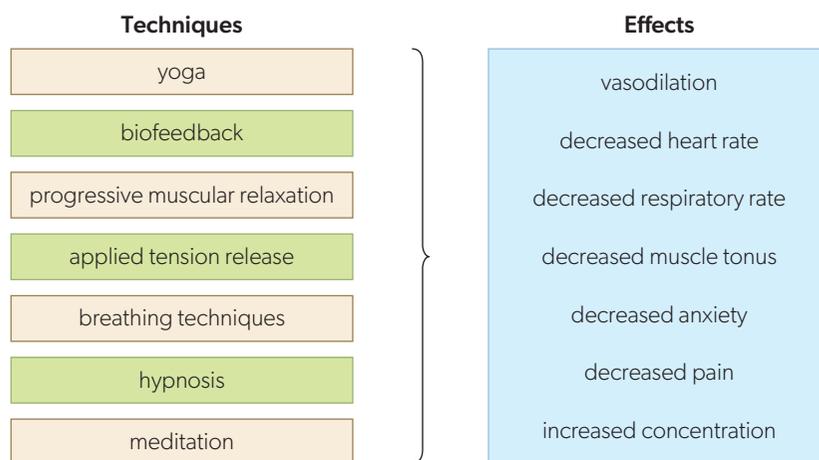
Long term (chronic)

Relaxation skills can be used regularly as a component of rest and recovery strategies to confer long-term benefits to support well-being and cope with training load and challenges.

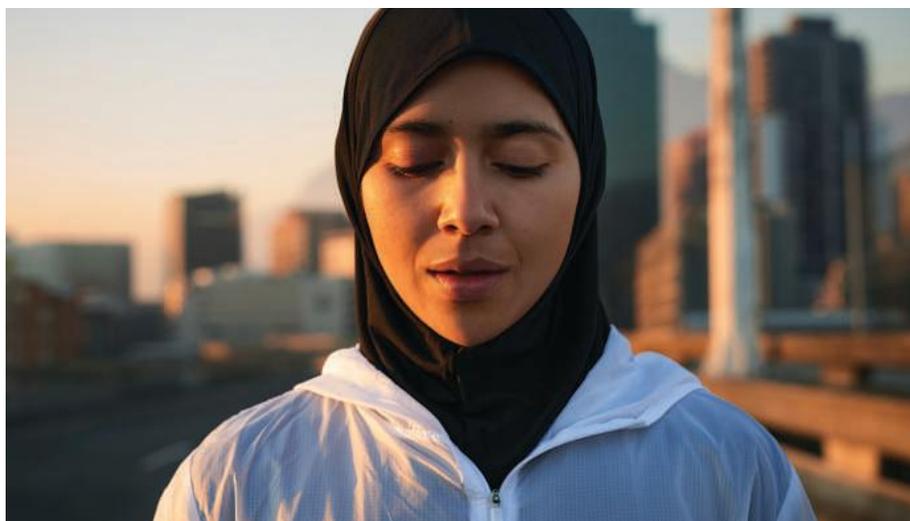
Pre- and during performance (acute)

Relaxation skills can be used close in time to or during performance to avoid excessive levels of stress developing and confer performance benefit. However, the use of relaxation pre- and during performance must be carefully weighed against the need for appropriate activation levels required because of the inherent, significant and specific physiological demands.

In a comprehensive review, Pelka et al. (2016) summarized the types of approaches to relaxation and reported consequent effects. Some of these are summarized in Figure 3.



▲ Figure 3 Different relaxation techniques and associated psychological and physiological effects



▲ Figure 4 Breathing techniques can be used as a coping strategy

ATL Research skills

How does slow breathing decrease heart rate and reduce blood pressure, and fast breathing increase heart rate and elevate blood pressure?

Linking question

Are certain personalities more likely to adopt specific stress responses? (C.1.1, C.1.2)

Consider:

- whether individual differences can exist within any given personality trait
- athletes with perfectionistic tendencies
- resilient individuals and their mindset
- sport settings that introverted personalities may prefer
- sport settings that extraverted personalities thrive in and enjoy
- if individuals can have a combination of various personality traits
- if some individuals respond differently in different sporting contexts.

Linking question

What physiological measurements can we use to measure stress? (A.1.2, Tool 1, Inquiry 1)

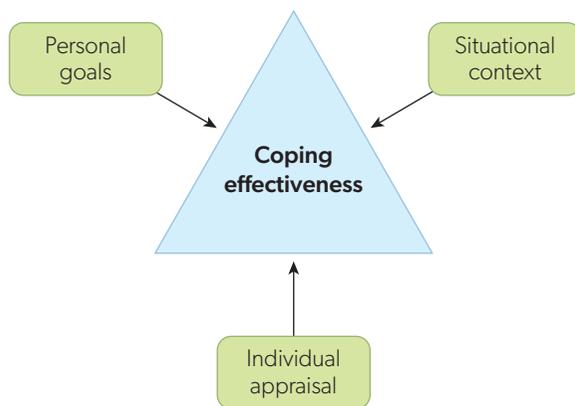
Consider:

- heart rate
- heart rate variability
- systolic and diastolic blood pressure
- stress hormones (such as cortisol level from blood, saliva or urine samples)
- skin's electrical conductance, sweat gland activity and the sympathetic nervous system
- respiration rate (and depth of breathing)
- physiological stress (such as blood lactate level).

Coping strategy effectiveness

In the coming sections, we will consider the effectiveness of popular coping strategies. However, developing a good repertoire of coping strategies and skills requires that the individual be able to choose coping that is suitable to the situation, matches the goal they are trying to achieve and their own appraisal of the situation. As a consequence, it is not possible to simply identify some strategies as effective or ineffective without consideration of the context and the individual.

Consider the strategy of avoidance. Traditionally avoidance has been considered a poor coping response. However, sometimes stressors are short and time limited, and if they can be avoided until they naturally dissipate then this may turn out to be very effective. For example, at a major athletics tournament, one of the athletes indicated that they found interactions with the head coach on the day of their event resulted in them being more anxious and emotionally in the wrong state to perform well. As a consequence, they took steps to avoid interactions with the coach, ensuring they ate at a different time, travelled separately and warmed up in locations where the coach was not present. In doing this they were able to avoid additional and unnecessary stress and focus on their optimal physical and mental preparation. In this case their avoidant coping was very effective. This example demonstrates that it is not possible to determine effectiveness without considering all the relevant factors which are illustrated in Figure 5.



▲ Figure 5 Factors in coping effectiveness

Effectiveness of seeking social support

Seeking social support is a highly effective coping strategy for athletes in the context of coping with the demands, challenges and pressures of sport. Seeking social support can be particularly beneficial for several reasons. Engaging with supportive individuals (who understand and have empathy), such as coaches, teammates, friends or family members, provides athletes with an outlet to express their emotions, concerns and anxieties. This can help reduce stress and increase an athlete's sense of control over their situation. Encouragement and positive feedback from others can boost an athlete's self-confidence and belief in their ability to achieve their sporting goals. Importantly, support from others who have valuable experience may result in practical advice and help with problem-solving strategies. Further, when an athlete perceives they are part of a social network within the sporting community, this can foster a sense of belonging and identity, and enhance an athlete's motivation and commitment to their sport. It is important to note that seeking social support should be balanced with other coping strategies.

An effective coping strategy often involves a balance between problem-focused and emotion-focused approaches.

Problem-focused social support

When an athlete seeks support from coaches, trainers or sports psychologists to tackle specific challenges or improve performance, it becomes a problem-focused coping strategy. Examples of problem-focused support in sport include:

- seeking technical, tactical and/or training adaptation (to optimize preparation and performance) guidance from their coach or other athletes
- consulting medical professionals for effective injury management and rehabilitation.

Emotion-focused social support

Emotion-focused coping involves managing emotions and psychological responses to stressors rather than directly resolving the stressor itself. In this context, seeking support from friends, family, coach or squad/teammates can be considered emotion-focused coping. Examples of emotion-focused support in sport include having the opportunity to express feelings of frustration, anxiety or disappointment to someone who can listen and offer empathy, reassurance, encouragement and motivation.

Seeking social support as a coping strategy is often a combination of both problem- and emotion-focused coping. For example, a coach may give an athlete task-relevant instructions and motivation to persevere with practice. A physiotherapist may provide clear rehabilitation exercises and develop the confidence in an injured individual that recovery and a full return to play is possible. A paradox of social support is that it can be beneficial for individuals without actually being used. For example, knowing that access to social support (for emotion- or problem-based reasons) is available can help an individual feel less stressed, even if they do not actually call on the support.

Effectiveness of relaxation

The use of relaxation training and techniques to counter the effects of anxiety is common in clinical psychology settings, where it can be hugely advantageous and has good evidence of effectiveness. Relaxation is also an effective coping technique in many sport and exercise settings, though research suggests this varies according to the context and the specific relaxation techniques used.

In Pelka et al.'s previously mentioned review, 21 high-quality randomized control trials investigating acute effects on performance in sports settings were considered to identify the most effective strategies within each approach at the acute level (pre-performance or during performance). Biofeedback and hypnosis showed the most impact on performance. Biofeedback was taught over an average of 19 sessions whereas hypnosis took 3. Surprisingly, PMR did not show positive performance effects when used at acute level. The authors commented that the variable reporting standards of studies did not enable a full meta-analysis. They also raised the point that PMR and autogenic training, both with strong evidence in clinical settings, are complex interventions that require sufficient training. Both of these observations suggest some limitations in the existing research on the relationship between relaxation and performance. This review did not assess the effectiveness of relaxation applied at chronic level for rest and recovery.

An interesting factor to consider is also the specific match between performance demands and proposed effects of relaxation. Sports involving aiming, when the physiological load is relatively low (such as archery, target shooting, snooker and curling), may be more likely to benefit from factors such as cardiovascular changes that may enhance accuracy performance. Within some highly dynamic sports, with high physiological demands, there may also be performance elements that may benefit from down-regulating physiological activation momentarily (such as penalty taking in football or rugby).

Perhaps one of the most extreme contrasts in sport exists in the biathlon in which the endurance performance requires extreme physiological activation to cope with large aerobic demands. This is immediately followed by demands of accurate target shooting where elevated heart rate and postural sway negatively impact on performance.

Effectiveness of distraction

Distraction can be a useful short-term emotion-focused coping strategy in the context of coping in sport, providing a temporary escape from stress, anxiety or negative emotions associated with sporting challenges. Distraction (for example, taking a holiday away from training) can help divert an athlete's attention away from the stressor, improve emotional regulation and result in decreased stress levels and enhanced well-being.

However, while distraction can be beneficial in the short term, it has limitations when it comes to reaching goals. Distraction alone is not effective for achieving goals.

Although distraction can provide temporary relief from stress it does not address the underlying stress issues. After the distraction, athletes may still need to confront the original stressor(s).

Therefore, relying solely on distraction might lead to the avoidance of confronting and resolving the actual problems, and this may hinder an athlete's development. Furthermore, distraction does not specifically contribute to skill development or performance improvement, both of which require investing time and effort in training and competition. Thus, distraction could interfere with an athlete's commitment to their goals, and successful performance is associated with dedication, perseverance and sustained focus on goals. Distraction can be a useful short-term emotion-focused coping strategy for immediate stress reduction and emotional regulation, but by itself this approach is not enough to achieve goals in sport.

Effectiveness of disengagement

Coping strategies involving disengagement, such as mental or physical withdrawal, venting unpleasant emotions and self-blame, are considered strategies that are unlikely to support an individual's good health and achievement. Disengagement coping strategies do not address the root causes of the stress, and this results in not seeking solutions to or avoiding the issue(s).

It is obvious that not training or competing will have a negative impact on an athlete's performance, and over time this can lead to increased emotional distress. It is important that athletes do not alienate significant others (such as their coach or teammates) by disengagement because they, in turn, might withdraw their social support and make it more challenging for an athlete to cope with stress.

Disengagement can also weaken an athlete's motivation as their self-efficacy and belief in their abilities diminish, leading to decreased motivation to persevere and achieve their goals. There can be serious implications for an athlete's resilience and mental health and well-being, that is, an inability to effectively cope with challenges creates a cycle of distress and continued impaired performance. This is of concern because all of this can be overwhelming for some athletes. Therefore, to promote positive outcomes in sport, athletes should focus on developing adaptive coping strategies, such as seeking social support and problem-solving, which can lead to better performance, improved health and well-being, and increased resilience.

- I**dentify what you want to achieve
- M**atch self-talk to needs
- P**ractise different cues
- A**scertain which cues work best for you
- C**reate specific self-talk plans
- T**rain self-talk plans (to perfection)

▲ **Figure 6** The IMPACT acronym for effective self-talk

Effectiveness of self-talk strategies

Many scientists have conducted research into the most effective strategies for self-talk in a sports and exercise context. Weinberg & Gould (2003) developed the acronym IMPACT to outline stages to developing effective self-talk. Their research found that different sorts of self-talk can be more effective when it fits the situation, and that cues have more power when they are meaningful and personally relevant.

Hardy et al. (2009) found that instructional self-talk for fine motor-skill tasks seems to be more supported in research than motivational self-talk for gross motor-skill tasks.

Mallett and Hanrahan (1997) investigated the effects of a specific cognitive race plan on 100 m sprint performance. They segmented the 100 m sprint race into three phases and assigned a cue word for each phase:

- acceleration phase: “push”
- maximum-velocity phase: “heel”
- speed endurance phase: “claw”.

They found mean race time was improved by 0.26 s when the race cues were used.



▲ **Figure 7** A study found that using specific self-talk cues during different phases of a 100 m sprint improved performance

Measurement

As included in the definition, coping is a constantly changing process. Therefore, the most appropriate measurement strategy would be to assess coping changes over time. However, measurement of coping primarily relies on self-report data, which cannot be constantly accessed with low-intrusion technology (unlike, for example, heart rate).

Some researchers (Schomer, 1986; Welsh et al., 2018) have used “think-aloud” protocols to access self-report data during events such as marathon running or snooker, where there is the possibility for individuals to speak aloud during the performance.

Interestingly, in other performance domains, such as surgery and advanced driving in police, think-aloud is routinely used within their training practices.

Although think-aloud may not be exactly “continuous”, it is far superior in terms of accurately capturing the changing nature of coping, to completing a single rating on questionnaire items at the end of an event.

Researching any construct requires careful consideration of what needs to be measured, how and when. Creative solutions coupled with good awareness of what is practically viable in demanding contexts, as found in sport and exercise, can produce important insight and understanding.

Controllable and uncontrollable stressors

A prominent way of thinking about stressors and effective coping is to consider the difference between **controllable stressors** and **uncontrollable stressors**. The traditional view is that problem-focused coping is more effective for controllable stressors and emotion-oriented coping is effective when the stressor is uncontrollable.

Is this view correct? The answer is partly “yes”, but it depends, as we will discuss more below. Following the view of Lazarus et al. it should be about whether the “person–situation transaction” could be controlled.

For example, consider the case of Matt Hampson discussed in the case study box. Given the uncontrollable stressor of his accident, he used problem-focused coping strategies to set new goals, which changed his person–situation transaction.

It may seem counter-intuitive that giving up on a goal is problem focused, but it fits into this category because it has direct bearing on the relationship between the person and the situation.

Case study

Getting busy living

Understanding how coping can operate positively is exemplified by the remarkable case of Matt Hampson.

He was an aspiring young rugby player, a member of a leading professional club and had already represented his country at his age group level. However, his rugby career ended following an accident during training which caused him to be paralysed from the neck down and breathing with assistance from a ventilator.

After his accident, Matt focused his efforts to establish a foundation to support individuals who, like himself, experienced catastrophic injuries through sport. Six years later the Matt Hampson Foundation gained full charitable status and it has now operated for more than a decade providing support and promoting the ethos

espoused by Matt to “*Get busy living*”. The success of the foundation, and his efforts to raise money, which helped to establish a dedicated physical rehabilitation centre, have been nationally recognized by a leading sport’s governing body, an honorary doctorate from a university and being awarded a national honour.

The example of Matt Hampson demonstrates an extraordinary level of coping with extreme stresses associated with his life-changing injury. His previous aspirations in sport were no longer possible, but he set himself completely new and different challenges which he has achieved with considerable success, while simultaneously coping with the ongoing personal demands of life after spinal injury.



▲ **Figure 8** In response to his accident, Matt Hampson set new goals and has promoted the ethos to “get busy living”

It is important to develop individuals' awareness of how to make effective choices on which coping skills and strategies to use. This should be explicitly included within coping development programmes.

One approach to this has been referred to as the *goodness-of-fit* approach in which a good fit is thought to occur when problem-oriented coping is used when there is a degree of control in relation to the person–situation transaction. When there is no perceived control, emotion-oriented coping would be better. A study involving a large cross-cultural sample of athletes from the USA and Korea showed some significant, though low-magnitude, support for this idea (Kim, Duda, 2003). However, the authors concluded more evidence was required and several approaches to evaluate effectiveness should be adopted.

This idea has also been used in settings other than sport and exercise. Chang et al. (2012) developed coping training programmes suitable for workplace stresses. They compared programmes that just taught coping skills, with programmes that taught the same skills but also included teaching individuals how to choose appropriate skills based on the *perceived controllability* of the situation. The authors found that individuals taught how to choose which coping skills to apply, which they referred to as “coping flexibility”, experienced greater benefit from the coping than individuals who were only taught the skills, without being taught how to choose.

Both goodness-of-fit and coping flexibility ideas seem to increase the ability of individuals to make good choices about which type of coping might be used to best effect. However, both of these approaches are based on the simple typologies of coping which we know have limitations. The ideal solution would be for individuals to be taught self-regulatory skills (chapter A.3.3 on fatigue and recovery). Reflecting on what worked, when and for what reason can, over time, build a much more refined awareness and understanding of how to utilize your repertoire of skills and cope effectively.

ATL Thinking skills

Determining which coping response will be the most effective response in a particular situation depends on a number of factors. These might include:

- whether the person–situation relationship can be controlled (suggesting problem-oriented coping) or not (suggesting emotion-oriented coping)
- what the individual is trying to achieve
- the nature of the task and situation.

Imagine a player is listening to their team's selection being announced for the end of season cup final game. Despite regular training and selection throughout the season, and quite unexpectedly, they discover they have been dropped! They are aware of teammates casting glances at them as they try to contain feelings of shock, disappointment and anger.

- Can you think of three different types of coping response this athlete could choose from each of the three broad categories of problem, emotion and avoidance?





- Can you think of benefits and drawbacks to each type of response?
- Do you think it is possible to say with certainty that one type of coping would be more effective?



Global impact of science

Cross-cultural research

In some branches of science there is a dominance of published research conducted by researchers in Western and/or economically developed countries. This has had the effect of building an understanding of issues seen through a very specific “cultural lens” and applied to samples drawn from specific populations. However, it does not follow that this knowledge is accurate or valid when considered in relation to people in different parts of the world. Furthermore, the “cultural lens” of researchers influences the entire research process (what is studied, how it is studied, and underlying assumptions and beliefs that influence research questions and methodological choices). These research biases and specific influences have been referred to by the acronym WEIRD (Westernized, Educated, Industrialized, Rich and Democratic; Henrich et al., 2010). This does not mean that research evidence from one region is not generalizable, but it is important the transfer and application are done with careful consideration of the problem. In the future, more comparative studies and international research collaborations would have considerable benefits to address this issue.

TOK

Science is interested in establishing the relationships between variables.

When the outcome variable is broad and multifactorial, is it possible to meaningfully attribute the impact of a single factor to a distal outcome that relies on so many other factor influences?

For example, if a player can cope with stress sufficiently, does this mean they will win the match, or the World Cup?

Is it reasonable to judge the benefit of science on specific outcomes? For example, would better coping allow the player to strike the ball with force and accuracy into the net?

How can we accurately answer the question of whether time and effort will be well spent on attempting to improve performance through training and interventions?



Linking question

How do effective coping strategies enable more proficient kinematic aspects of movements? (A.1.1, A.3.1)

Consider:

- anxiety and stress and muscle tension/stiffness and movement kinematics
- concentration and focus on the task
- self-confidence, a relaxed state during performance, and efficiency of movement
- self-regulation, optimal arousal and technique
- effective motor learning
- integration with technical proficiency and/or physical conditioning, and/or tactical understanding.



Linking question

How can psychological interventions be made reliable? (Inquiry 1)

Consider:

- evidence-based approaches
- targeted/personalized/individualized assessment
- the difference between “effectiveness” (intervention works in ideal controlled settings) and “efficacy” (intervention works in practice, where perfect delivery is not possible)
- unique needs analysis of each athlete
- use qualified professionals with expertise in psychology/sports psychology
- standardizing interventions
- long-term development, support, reinforcement and follow-up sessions
- regular evaluation and feedback
- involvement of the various stakeholders in an athlete’s development
- efficacy of online training methods or pre-recorded materials
- the “therapeutic alliance” between client and professional, which is known to be important in other fields (counselling, clinical psychology)
- the balance between long-term development of the individual and immediate performance outcomes.

Conclusion

At the beginning of this chapter, we discussed the importance of coping in sport and exercise settings. At the same time, we emphasized the potential for the skillset of coping, which can be used in all parts of our lives, to be developed through experiences in this setting.

There are many of coping skills and strategies that can be developed, though attempts to place these in broad “types” can be overly simplistic. However, the range of skills can be learned, much like motor skills, to support performance under stress.

Application of coping strategies must recognize the balance between the individual, their specific goals and the situation.

Finally, the role of appraisal and potential to modify this (reappraisal) can offer a different approach to contending with stress that has shown valuable performance benefits.

Practice questions

1. Using examples from sport, distinguish between emotion-focused and problem-focused coping. (2 marks)
2. Sports officials are essential in upholding rules and safeguarding athletes. However, they frequently experience abuse from players and spectators. Describe how a sports official could use coping strategies to help prevent stress and anxiety. (4 marks)

Summary

- Primary and secondary appraisal are integral to determining response to stress and the likely approach to coping attempts.
- Coping is the response, and coping effectiveness is whether the response produces or supports a desirable outcome.
- There is a range of commonly used coping skills and strategies that can be learned and developed.
- The relative effectiveness of coping skills and strategies varies between individuals and according to goals and context.

AHL

Check your understanding

After reading this chapter, you should be able to:

- define coping
- define appraisal
- explain the process that links appraisal and coping
- consider different types of coping strategy and evaluate limitations of categorizing strategies
- outline a variety of coping strategies including self-talk and relaxation skills
- consider the difference between controllable and uncontrollable stressors
- evaluate the effectiveness of different coping strategies.

AHL

Self-study questions

1. Define *coping*.
2. Outline the stages of primary and secondary appraisal that are thought to precede coping responses.
3. Describe how self-talk strategies can help an individual manage the demands of an endurance run.
4. Discuss the benefits of learning how to manage demands of sport or exercise with regard to transferable life skills.
5. Distinguish between emotion-focused and problem-focused coping, using examples from a sport of your choice.

AHL



Data-based question

Resilience is important for sportspeople to achieve success and overcome adversities that they meet. A study investigated the differences in coping strategies in adult athletes (team and individual sports) with different levels of

resilience. The mean (\pm SD) scores for four different coping strategies for three groups of athletes with low, medium or high resilience are shown in Table 4. Higher scores correspond with more effective coping.

▼ Table 4

Coping strategy	Low resilience (group 1)	Medium resilience (group 2)	High resilience (group 3)
logical analysis	3.26 (\pm 0.58)	3.38 (\pm 0.58)	3.37 (\pm 0.76)
seeking support	3.35 (\pm 1.02)	3.41 (\pm 1.05)	3.31 (\pm 1.56)
relaxation	2.93 (\pm 0.72)	3.15 (\pm 0.78)	3.42 (\pm 1.37)
imagery	3.08 (\pm 0.75)	3.50 (\pm 0.62)	3.67 (\pm 0.73)

Source: Secades et al. (2016).

1. Identify:
 - a. which coping strategy was the most effective for athletes with high resilience (1 mark)
 - b. which coping strategy had the greatest variability across all groups. (1 mark)
2. Distinguish between the groups for the effect of relaxation as a coping strategy. (2 marks)
3. Discuss the effects of different coping strategies in athletes with low, medium and high resilience levels. (3 marks)

C.5

Psychological skills

How can sport psychology interventions enhance sporting performance?

This topic begins by placing goal setting in the context of developing psychological skills before outlining types of goals and describing how to set effective goals. The topic progresses to introduce and explain the purpose of imagery, including Paivio's imagery framework, and concludes with the PETTLEP model of imagery and how to develop an imagery training intervention.

C.5.1 Goal setting

Syllabus understandings

C.5.1.1 Goal setting directs attention to a specific task. It is regularly used to enhance motivation in sport, exercise and health.

C.5.1.2 The goal-setting paradox explains that elite athletes often feel less satisfied when a higher goal is achieved than an easier goal. This is thought to be the result of feelings of deflation after success.

AHL

Introduction

Even highly successful performers are sometimes affected by pressure during competitions. One big difference between performers who succeed and those that do not is the way they manage their emotions and actions in difficult situations. One aim of a sport psychologist is to help athletes learn skills that they can use to take control, cope effectively and perform well under pressure.

However, the application of sport psychology also has a major role to play in helping athletes manage their development, training and lifestyle over the course of their careers. This chapter examines psychological skills and the use of goal setting to enhance performance and motivation.

Developing psychological skills

What are psychological skills?

Many people think that highly successful athletes are born winners or just happen to have the right type of personality to thrive. In fact, research into personality and sport performance has shown that personality factors account for only a small percentage of eventual success. For example, a study by Rowley et al. (1995) concluded it was less than 1%.

Many researchers have shown that psychological skills can be learned in formal teaching settings through consistent training, as well as more informally through life or sport experiences. In other words, anyone can learn and improve their ability to use mental skills effectively, at any stage in their life.

Given the differences between personality and psychological skills, it is important to clearly define what “psychological skills” are. Vealey (1988) made an important distinction by highlighting the difference between useful psychological states (such as confidence, motivation and concentration) and the skills that can be applied to help improve them (such as goal setting, imagery, self-talk and relaxation). This is important because it is difficult to “be confident” without guidance, especially when someone feels low in confidence. For example, coaches often assume that athletes know how to “concentrate” or “relax” when they are told to do so from the touchline. However, they have probably never thought about how the athlete can do those things, or trained them in these skills. Because of this, it is important that athletes (and coaches) know what practical steps need to be taken to improve psychological states, and take time to practise them.

TOK

Discuss this quote by Henry Ford: “Those who believe they can and those who believe they can’t are both right.”

Key point

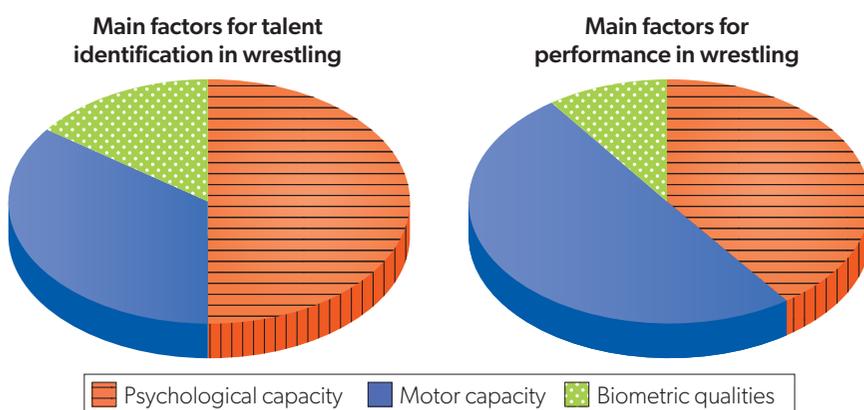
“Psychological states” describe the athlete’s state of mind or attitude.

“Psychological skills” are more tangible steps taken by the athlete to improve their psychological state.

What evidence is there that they work?

While the evidence shows that psychological skills can be taught, it is necessary to understand the importance of psychological training in improving performance. Anecdotally, it is clear to see that our mental state has a big role to play. For example, there are often stories in the media about sports people choking under pressure, and many top sports stars have been quoted highlighting psychology as one of the most important features of their sport.

However, while research supports the contention that psychology is important, the evidence shows the need to take a more balanced, interdisciplinary view. For example, Kunst and Florescu (1971) highlighted the need to recognize that a range of different factors were important, with psychology accounting for approximately 35% of performance variance in wrestling.



▲ **Figure 1** Relative importance of psychological, motor and biometric factors in talent identification and performance in wrestling

Research into the impact of psychological interventions in sport generally shows they have a positive impact on performance, and many Olympic athletes place a high importance on psychological preparation for success (Gould et al., 2002). While not all coaches and sports performers place a high value on sport psychology (Pain, Harwood, 2004), there has been an overall increase in athletes seeking out sport psychology training over the last decade (Schinke et al., 2020; Stambulova et al., 2021).

The development process

For the most effective results, psychological skills must be trained systematically. In fact, they are acquired in much the same way as physical skills are and normally lots of commitment and perseverance are needed to make permanent changes.

Research by Pain and Harwood (2004) highlights a number of common misconceptions about sport psychology support.

These are four common misconceptions.

- Psychology is a quick fix.
- It is only required for problem athletes.
- It is only pertinent for elite athletes.
- Psychology is not useful in a sport context.

Key point

Psychological skills need to be learned in the same way that physical skills in sport are learned. The skills must be tailored to the needs of the individual athlete and it takes time and practice to develop them.

There are three phases to the process of developing psychological skills: general education phase, acquisition phase and practice phase.

Phase 1: General education phase

It is important to incorporate a general education phase into psychological skills training (PST). This can be used to clarify what psychological skills are, how they can be trained, what role and level of commitment are required on the behalf of the psychologist, coach and athlete, and what improvements such training can bring. This helps to clarify expectations and understand the potential usefulness for any given individual.

Of course, every person has specific needs and circumstances. PST can be adapted to best suit each individual. Equally, PST is not for everyone (chapter C.1.2, which considers psychological skills training, mindfulness and self-compassion training approaches).

Phase 2: Acquisition phase

The acquisition phase focuses on learning and understanding specific strategies and skills that will help to develop positive change where required. This phase will typically involve a thorough needs analysis of the athlete in their development and performance environment to ensure that PST is targeted at the athlete's needs. It will also focus on teaching the athlete how to implement strategies within the context of why they work. This is important because helping athletes to understand themselves, their emotions and behaviour in different situations will enable them to become independent problem-solvers when new or novel challenges arise. This forms part of the process of helping athletes self-regulate effectively (Richards, 2011), which is an important overriding aim for many sport psychologists, and one that ultimately enables the athlete to function independently.

Phase 3: Practice phase

The final phase of the PST programme is the practice phase which, according to Weinberg and Gould (2011), has three primary objectives:

- to automate skills through over-learning
- to teach athletes to systematically integrate psychological skills into performance situations
- to simulate skills athletes will want to apply in actual competition.

It is well documented that psychological skills cannot be taught effectively in isolation from the context in which they need to be applied (MacNamara et al., 2010). This is why, in more formal PST settings, "homework" is set where the athlete practises different strategies under more realistic, sometimes increasingly pressured, situations. Regular evaluation is important, as are meetings with the sport psychologist, and personal reflections (such as a logbook or journal) on the effectiveness of the strategies. These enable the athlete to gain feedback, identify improvements, and adjust and develop the strategies over time.

In addition to formal PST education, more informal experiences can occur through life and sport, leading to the development of increased mental toughness. For example, Bull et al. (2005) found that in young cricketers, a number of experiences facilitated psychological growth, including parental

Activity 1

What experiences do you have from the non-sport areas of your life that help you in training or in a match or performance?

Activity 2

Write down five goals you have for different areas of your life, such as school, home life, hobbies.

influence, exposure to foreign cricket, opportunities to survive setbacks and needing to “earn” success. More recent research has highlighted the need for a more explicit use of real-life challenges to teach and embed coping skills (MacNamara et al., 2010), as well as the need for sport coaches (and significant others) to help develop mental resilience in athletes through the experiences they set up in their development environments (Martindale, Mortimer, 2011).

Types of goals

There are many anecdotes highlighting goal setting as an essential activity for success in life. As such, it will come as no surprise that goal setting is a well-established cornerstone technique in sport psychology.

Essentially, a goal has broadly been defined as “what an individual is trying to accomplish; it is the object or aim of an action” (Locke et al., 1981). Locke and Latham (2002) highlighted that goals stimulate motivation and improved performance through one or more of the following mechanisms.

- Goals focus attention.
- Goals mobilize effort in proportion to the demands of the task.
- Goals enhance persistence.
- Indirectly, having goals encourages the individual to develop strategies for achieving them.

In other words, goals help direct and mobilize effort, while encouraging a problem-solving approach. Alternatively, goal setting has been shown to indirectly facilitate performance through knock-on effects on other psychological states. For example, Burton (1989) showed evidence of the positive effects of goals on performance through the manipulation of confidence and anxiety levels.

Activity 3

Break down your goals over time and identify what you need to do to make them happen.

What do I want to achieve?

Are there any milestones I need to reach along the way?

Long term: _____

Medium term: _____

Short term: _____

What do I need to do to give myself the best chance of achieving these goals?

1 _____

2 _____

3 _____

Two different types of goals have been identified: **outcome goals** and **learning-focused goals**. Learning-focused goals can be further categorized as either **performance goals** or **process goals** (Table 1).

▼ Table 1 Three different types of goals

outcome goals	relate to the outcome of an event, and usually involve a comparison with others norm-referenced and use an objective result as the target	winning a race being selected for a team
performance goals (learning-focused)	relate to a specific product of performance relatively independent of others (self-referenced)	swimming a certain race time jumping a certain height
process goals (learning-focused)	relate to the processes that a performer will focus on during the performance self-referenced and focus on the technique or strategy required to successfully execute a skill	high knees long stride pattern

There are clear distinctions between the nature of these three types of goals, for example, the extent of control the performer has over reaching their goal. Each of these goal types has its own advantages and disadvantages within different contexts. For example, outcome goals can be useful for facilitating motivation in training, but have been shown to increase anxiety and irrelevant thoughts if used just prior to competition (Weinberg, Gould, 2011). On the other hand, performance goals can help provide specific feedback about progress, and process goals can help provide a relevant focus in the middle of a race. Given these differences, it is perhaps unsurprising to see that using a combination of goal types has been shown to be more effective than using one alone (for example, by Filby et al., 1999).

Learning-focused goals

Learning-focused goals, including both performance goals and process goals, are goals that prioritize the acquisition of knowledge, skills and understanding rather than solely emphasizing the outcome or end result. In the context of learning-focused goals, both performance and process goals are vital for athletes' development and improvement.

- Performance goals revolve around achieving measurable milestones. For example, setting a personal best time. They provide athletes with clear objectives to strive for, helping to motivate and drive their efforts, often serving as benchmarks for evaluating success and progress, and can provide a clear benchmark for assessing achievement.
- Process goals concentrate on the actions, behaviours, strategies and effort required by athletes to enhance their skills and performance. These goals are oriented towards the learning process itself and focus on aspects within an



Activity 4

Distinguish between the role of outcome, performance and process goals.

athlete's control. For example, improving technique, increasing endurance, refining a skill or actioning an effective training routine. Process goals prioritize the steps needed to achieve success and emphasize the importance of continuous learning, practice and skill development.

By emphasizing progression, learning-focused goals foster a growth mindset (continuous improvement, perseverance and mastery of content) compared with a focus on achieving a specific outcome or result. The combination of both performance and process goals can create a well-rounded approach to the development of athletes, provide athletes with a sense of direction and a target to strive for, while ensuring that they focus on the necessary steps and efforts to enhance their abilities. This combination encourages athletes to value the learning process, seeking continuous improvement and personal development rather than solely fixating on outcomes—that is, a more balanced approach to learning and development. This is important because emphasizing solely performance goals can sometimes lead to undue pressure, anxiety or a fixation on results, potentially hindering an athlete's progress. By including process goals, athletes can maintain focus on the learning journey, enjoy the process of skill acquisition and enhance their performance in the long run.

Research into goal setting suggests that it is a technique that generally works very well. However, it has also been shown that if goals are not set properly, they can impair the athlete's progress and be a major source of stress. Having said that, a broad review of the goal setting literature with collegiate, youth and Olympic athletes revealed that almost all of the athletes used goal setting of some sort and found it to be effective.



Global impact of science

If the goals are not set out carefully, a goal-setting intervention could in fact become a source of stress. When carrying out psychological interventions with humans, we are often focused on potential benefits they will bring. However, just as an intervention can have a positive effect, it also has the potential to have an adverse effect. From an ethical standpoint, it is very important for researchers to consider this when recruiting volunteers for research projects that involve the implementation of a psychological intervention. It is important to get informed consent from participants.

Consider the methodology you would use to recruit volunteers. How might you inform them of the risks? What information might be useful to know in terms of the mental health of the participants? Might there be inclusion and exclusion criteria in terms of whom you recruit?

SMARTER goal setting

- ① Specific
- ② Measurable
- ③ Achievable
- ④ Realistic
- ⑤ Time-based
- ⑥ Exciting
- ⑦ Review

▲ Figure 2 The SMARTER acronym for effective goals

Setting effective goals

The acronym SMARTER is often used for guidance when setting effective goals. While there are some merits in following the SMARTER guide (for example, it is easy to remember), rather confusingly, many authors often use the acronym differently.

Also, SMARTER guidelines do not present a full picture of the evidence, providing a rather simplistic overview. For a fuller review of the goal setting literature refer to Hardy et al. (1996). Having said this, summary guidelines are still very useful, so a more substantial set of evidence-based goal-setting principles is presented next.

1 Set specific goals

Research has shown that specific goals often lead to better performance than “do your best” goals or no goals (such as Tenenbaum et al., 1991). The more well defined you can make your goals, the better. For example, “I want to be better at golf” can be made more specific, observable and measurable by changing it to “I want to lower my handicap from 5 to 3, by improving the accuracy of my iron play to the green from 100 yards”. The more specific the goals, the more easily you can plan, practise and identify when you have been successful.

2 Set moderately difficult but realistic goals

Kyllo and Landers (1995) found that “moderately difficult” goals lead to the best performance, but they must be accepted by the athlete. However, Bueno et al. (2008) warned that if goals are perceived to be too difficult it can lead to learned helplessness. As such, it is important to try to find the right balance for the individual and adjust your goals when necessary—you will probably know if you are challenging yourself to the right level.

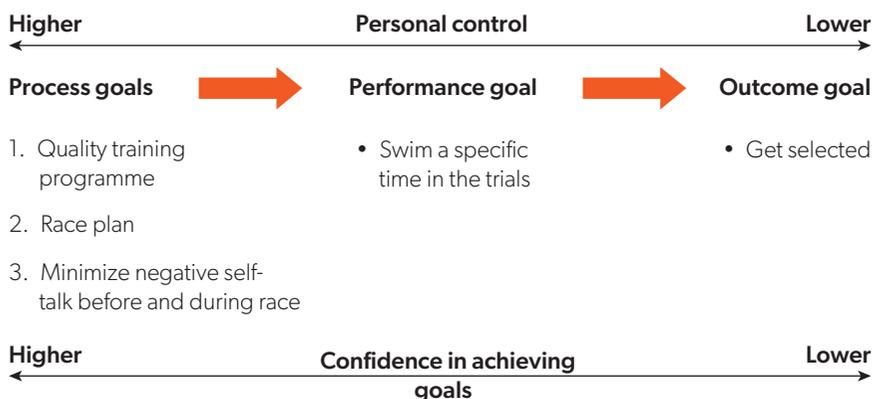
3 Set both short- and long-term goals—stepping stones to success

A combination of short- and long-term goals has been shown to be most effective (Kane et al., 2001). This is particularly true if long-term goals are broken down into relevant short-term goals that act as stepping stones, providing more regular feedback, ongoing focus and success experiences. Starting with a long-term goal in mind, then working backwards in time to form stepping stones to achieving your long-term goal is a common technique. Leading on from this, it is important to finish by identifying relevant practice goals and a good understanding of “what I want to achieve today”.

4 Set a combination of outcome, performance and process goals

For every outcome goal that an athlete sets, there must be a range of different performance and process goals to support and underpin it (Filby et al., 1999).

Remember: the outcome goal (such as winning, getting selected or beating someone) often drives motivation. The process goals (such as technical, tactical, mental or physical tasks) and the performance goals (such as specific times or distances) provide feedback and focus for day-to-day activities.



▲ Figure 3 Process goals can help improve a performance goal which, in turn, can lead to reaching an outcome goal



Evidence

Swann et al. (2023) criticized the SMARTER goals approach. For example, they have suggested that it is not based on scientific theory, and with this approach to goal setting there is some evidence that insufficiently active individuals experience less enjoyment, pleasure, motivation and lower perceptions of performance, as well as significantly greater pressure to be active. Do you think we need more research to generate stronger evidence for the most effective goal-setting approaches in physical activity promotion?

Key point

Setting goals is a useful tool for athletes. The best way to use them is to set a range of different types of goal.

5 Always have training and competition goals

Athletes spend a lot of time practising and relatively little time performing. Given the importance and specific nature of the deliberate practice required to improve (Ericsson et al., 1993), it is crucial that training goals are set in addition to competition goals. Interestingly, Orlick and Partington (1988) found that one of the factors that differentiated between successful and less successful athletes was “setting practice goals”. Doing this will ensure you remain focused and motivated through training and in competition.

6 Record your goals and make sure you get feedback on your progress

Research has shown the importance of recording goals and placing them where they can be seen as constant reminders. Furthermore, getting regular feedback on progress is an essential part of the process, enabling athletes to build confidence and motivation effectively over time. This will ensure you recognize and understand any progress and success on a regular basis.

7 Always identify strategies to help you be successful

Locke and Latham (2002) highlighted that goals work by encouraging someone to develop a plan of action. As such, this is a crucial part of the process of goal setting. It is common for sporting careers to have plenty of ups and downs, where challenges and barriers are encountered regularly. As such, identifying potential barriers, problem solving and perseverance become crucial skills for negotiating the journey successfully.

8 Foster individual commitment to your goals and ensure you have adequate support

It is important that the aspirations of the individual are developed through goal setting in order to foster intrinsic motivation and commitment. As such, it is important to understand what an athlete really wants, encourage choice and enhance perceptions of ability through the process. Furthermore, Dishman (1988) found that good support networks facilitated adherence to goal pursuit. As such, both of these aspects should be incorporated into the goal-setting process.

Goal setting, the individual and achievement motivation

Goal setting is widely used by coaches, sport psychologists and athletes. Early goal-setting theory suggested that:

- harder goals result in better performance than less demanding goals
- specific goals give rise to better performance than having no goals or vague goals such as “do your best”
- using a combination of short-term goals and long-term goals will lead to better performance than using only long-term goals.

However, in practice there are problems with the above. For example, the first point assumes that difficult goals will encourage effort, but not all individuals try when the situation or task becomes challenging.

As studied in chapter C.3.1, achievement motivation theory emphasizes the

meaning of personal goals. Two major types of achievement goals are:

- a task-involved goal—with an emphasis on demonstrating self-referenced competence, such as personal improvement
- an ego-involved goal—superior competence relative to others.

An individual who has a focus on task-involved goals (a task-oriented person in a task-involving/mastery motivational climate) will more likely perform up to their ability level, try hard, and prefer and persevere with challenging tasks.

An individual with a focus on ego-involved goals (with a high perceived ability) will be committed to the activity—as long as things are going well and they are demonstrating superior performance. Such a person is likely to reduce both their commitment to the activity and their effort when their competence is inferior relative to others.

With respect to the goal-setting process, the motivational climate to work towards and achieve goals depends on whether the goal setting was done in either a task-involving/mastery motivational climate or an ego-involving/performance climate. For example, in a task-involving climate, the goals set would be improvement-focused and effort-dependent, the feedback would be self-referenced and the athlete could be involved in the evaluation of goal accomplishment. On the other hand, goal setting in an ego-involving climate would have outcome-oriented norm-referenced goals, and feedback would be more judgemental with social comparison. If this is overlooked the effectiveness of goal setting may be compromised.

Consider this in the context of developing “grit” in athletes. Grit could be defined as “the tenacious pursuit of a goal despite setbacks”. Grit has been associated with a willingness to engage in difficult tasks, and effort, in pursuit of their goals over time. That is, with high levels of grit athletes will exert high levels of effort over long periods of time without losing focus on their goals. In contrast, athletes who lack grit, when engaged in difficult tasks, are more likely to put in less effort or be less focused on their goals over time.

Achievement motivation theory has three primary constructs:

- perceived motivational climate (either task-involving or ego-involving)
- mindset (growth or fixed)
- goal orientation (task-oriented and ego-oriented).

According to achievement motivation theory, task-involving or ego-involving motivational climates are perceived through a combination of an athlete’s goal orientations and the learning environment created by physical education teachers and/or sports coaches. Within task-involving sport environments, athletes receive positive feedback from their physical education teacher/sports coach when they work hard, demonstrate improvement and learn in cooperation with their peers. Athletes training/competing in task-involving environments report higher levels of persistence, self-esteem, competence, enjoyment and intrinsic motivation. On the other hand, in ego-involving sport environments, athletes receive messages from physical education teachers and/or sports coaches that poor performances and mistakes are bad, athletes with the most ability receive more positive attention (from the physical education teacher/sports coach), and performing better than others (winning) is more important

TOK

On 24 June 2023, Zharnel Hughes set a new personal best and UK national record when he ran the 100m in 9.83 seconds. The previous evening, he had predicted he would run this exact time in his diary along with the words “Have faith.”

What is the role of faith in setting and pursuing goals?

than personal improvement. Athletes’ perceptions of ego-involving climates are associated with extrinsic motivation, lack of motivation and sport dropout (when their own perceived ability is low).

Athletes develop schemas about whether or not their ability can change, and these schemas are called mindsets. From a fixed mindset perspective (as in an ego-involving climate), ability is thought of as stable and difficult to develop or change regardless of athletes’ efforts. However, from a growth mindset perspective (as promoted in a task-involving motivational climate), ability is viewed as something that can be developed and improved over time through hard work and effort.

Therefore, the effectiveness of each type of goal depends on the perceived motivational climate, the athlete’s mindset and their goal orientation—that is, the effectiveness of each type of goal depends on the individual and their achievement motivation.

**Linking question**

How might individual differences mean that goal setting is less effective for some people? (C.1.1)

Consider:

- different goal orientations
- the motivational climate created by the teacher/coach
- different personality traits and how individuals respond to goals
- varying skill levels and capacity for achieving certain goals, such as novice, recreational, semi-professional and professional athletes
- diverse learning preferences, for example, written goal-setting instructions may create difficulties for an athlete who learns more effectively via model performer demonstrations
- different individuals are motivated by different factors, such as competition, recognition, personal improvement or social interaction
- physical attributes, such as height, weight, strength, power, endurance and flexibility, can vary significantly among athletes, and can influence the possibility and practicality of certain goals.

The goal-setting paradox

As discussed in this chapter so far, it is commonly believed that goal setting has several benefits, such as increasing motivation, improving athletic performance and enhancing function. This is why goal-setting practices are viewed as essential and key components of successful sports performance. For example, to optimize an athlete’s recovery after injury, SMARTER goal-setting practices are often used. However, one study surveyed the goal-setting practices of 570 collegiate athletes, participating in 18 sports at 4 universities in the USA. Interestingly, although over 99% of all athletes surveyed set goals, they typically rated these goals as only moderately effective (Burton et al., 1998).



▲ **Figure 4** Goal-setting practices are used to optimize an athlete's recovery after injury

From a sporting perspective, there is some research evidence that goals are likely to be more successful if they are difficult to achieve. As stated by Weinberg and Gould (2015):

Effective goals are difficult enough to challenge a participant yet realistic enough to achieve. Goals are of little value if no effort is needed to achieve them, and participants soon lose their interest in the goal-setting program. But goals that are too difficult to achieve lead to frustration, reduced confidence, and poor performance. The secret is to strike a balance between goal challenge and achievability...

It has been reported that the athlete feels *less* satisfied when a difficult goal is achieved than when an easier goal is achieved. This phenomenon—which seems counter-intuitive—is known as the **goal-setting paradox**. One explanation is that, once the higher goal has been attained, the athlete may feel deflated with a negative mood state (a subjective outcome; the athlete feels low).

Returning to the example of the injured athlete, where goal-setting negotiation during recovery from injury between the athlete and their physiotherapist (and others such as the coach) is involved. The goal-setting paradox should encourage the physiotherapist (and coach) to question their goal-setting approaches with their athletes. Should they set higher goals but face the possibility of the athlete feeling deflated once the goal is met? Or should they set lower goals that could result in the athlete feeling better? From an injury recovery perspective, this is important because professionals working with athletes have a duty of care to preserve and optimize the athlete's sense of well-being.

Goal adjustment

Generally, striving to achieve a goal is portrayed positively within society, but giving up is seen as a weakness. Consider what happens when an athlete is unable to achieve their goal—this is likely to be very stressful.

Research suggests that the capacity to disengage from unattainable goals and to re-engage in other new goals is a valuable quality in athletes. This is because, for example, individuals get emotional benefits from avoiding repeated failure and pursuing new meaningful activities. It is well known that personal goals structure people's lives, motivate adaptive behaviours and contribute to high levels of subjective well-being. At times, however, individuals meet challenges that make the attainment of desired goals impossible and compromise their subjective well-being. For example, consider the setback of being rejected by a soccer academy. For an individual to thrive they need to be able to disengage and withdraw effort and commitment from an unattainable goal, and re-engage in alternative goals (identify, commit to and pursue an alternative goal that is achievable). Such goal re-engagement capacity has been associated with, for example, higher levels of positive emotions and increased subjective well-being.

Nicholls et al. (2016), assessed how goal adjustment capacity predicted well-being in the lead up to and during a competition. Two-hundred and twelve athletes from the UK and Australia, who played team or individual sports, and competed at international, national, county, club or beginner levels participated in this study. The athletes also completed well-being questionnaires within three hours of their competition ending. The study found that the way an athlete responded to an unattainable goal was associated with their well-being in the period leading up to and including the competition. Goal re-engagement was positively associated with well-being, whereas goal disengagement was negatively associated with well-being. Goal disengagement refers to withdrawing effort and commitment from achieving an unattainable goal, whereas goal re-engagement involves:

- identifying alternative approaches to achieve the same goal
- identifying different goals that relate to the overall goal
- developing a completely new goal.

This involves athletes in self-regulating their behaviours. Therefore, in terms of the future performance and well-being of athletes it is important to consider how athletes respond to unattainable goals.



▲ Figure 5 Venus Williams has often spoken about how goals have helped her reach success

“Do your best” goals

The most common version of non-specific goals is **do-your-best goals**. Goal difficulty has been identified as an important consideration for goal setting, with some suggesting that difficult goals are more effective than “do your best” goals. As seen throughout this chapter, goals that are too difficult can negatively impact motivation and persistence, and goals that are too easy may result in complacency and a lower investment of effort. Goal difficulty is also related to the commitment to, and performance in, a goal. One previous analysis of the goal commitment literature concluded that difficult goals lead to greater performance than “do your best” goals (supporting goal setting theory), and that it is important that individuals commit to difficult goals to be successful. However, this should be interpreted with some caution, because others have found moderate goals to be more effective than difficult goals in sport (for example, consider the goal-setting paradox). Therefore, while goal difficulty is clearly an important consideration when goal setting, the findings are perhaps not as conclusive in sport as within other contexts (such as business).

Others have recommended setting specific goals because when compared with “do your best” goals, specific goals were considered more effective at changing behaviour, and more powerful in enhancing motivation and performance, as well as more clearly communicating expectations of athletes. However, other researchers have stated that a reliance on specific, challenging goals should be questioned for several reasons, based on the findings from more recent reviews of the available research literature. For example, in a review of the goal-setting process in 2023, Bird et al. concluded that:

Reviews of empirical evidence in sport and exercise indicate that specific goals are not necessarily better than nonspecific goals (e.g., do-your-best) for enhancing performance (Jeong et al., 2021). Furthermore, meta-analytical evidence in sport and exercise indicates that specific, difficult goals were less effective than specific, moderate goals (Kyllo and Landers, 1995).

Additionally, as we have seen, there are differences between learning-focused and outcome goals. Learning-focused goals, which include process and performance goals, are focused on developing task-relevant strategies, whereas outcome goals are focused on the attainment of desired results.

Take the example of a swimmer.

- Process goals can focus on learning specific skills or techniques (for example, one goal might be to swim a length in a given number of strokes).
- Performance goals are about improving their performance standards (for example, a goal aiming for a personal best in their race).
- Outcome goals refer to strictly focusing on the outcome of a competition (for example, the goal is to win the event).

These three goal types are mainly distinguished by their controllability, as the learning “process” and individual “performance” standards are dependent on one’s goal commitment, but a certain “outcome” (such as winning a tournament) could be dependent on the opponents and/or other external factors regardless of one’s goal commitment.

Key term

Clutch state A performance increment that happens under pressure. Clutch performance (making it happen) has been defined as “any performance increment or superior performance that occurs under pressure circumstances” (Otten, 2009).

Open goals

The concept of **open goals** was first reported in a study (Swann et al., 2016) of 10 professional (elite) golfers when they were describing their exceptional performances (such as winning a professional tournament). Open goals are a form of non-specific goal, and examples reported by athletes and exercisers include to “see how well you can do”, to “see how big a lead I can build”, and to “see how fast I can run 5 kilometres”. Their open-ended, exploratory nature is in contrast to specific goals as well as other forms of non-specific goals such as to “do-your-best”. Recent studies of golfers, athletes and exercisers suggest that open goals are necessary for the occurrence of enjoyable, effortless **flow states**. In contrast, specific goals are necessary for more effortful and deliberate **clutch states**. Further, open goals differ from “do-your-best” goals in that open goals are not tied to a previous personal best performance (a specific goal).

ATL Thinking skills

A primary goal for many sport psychology practitioners and coaches is to help athletes achieve optimal levels of performance, and to do so more consistently. “Flow” has been defined as “a harmonious and intrinsically rewarding state characterized by intense focus and absorption in a specific activity, to the exclusion of irrelevant thoughts and emotions, and a sense of everything coming together or clicking into place, even in challenging situations” (Csikszentmihalyi, 2002). Flow (*letting it happen*) has frequently been associated with a range of positive outcomes such as elevated well-being, increased self-concept and improved peak performance.



▲ Figure 6 Flow refers to a state of focus and absorption in a specific activity

Activity 5

When promoting physical activity, by asking healthy adults to walk as far as possible in six minutes, do you think the following instructions will have the same meaning to the participants?

- Do your best.
- See how far you can walk in six minutes.



Linking question

How does goal setting affect success in periodized training? (A.3.1)

Periodization relates to the long-term design and implementation of training over a series of planned training and competition cycles. Periodization affords a rational, evidence-based model for manipulating training variables, particularly volume and intensity, to develop relevant skills, attributes and qualities. A key psychological skill that can influence the effectiveness of such periodization is goal setting.

Consider:

- what outcomes, skills or attributes is the plan aimed at developing?
- can periodization be useful for technical, psychological and tactical capabilities?
- what psychological factors might be relevant for periodization?
- why might process goals be the most beneficial for performance and self-confidence?
- what goals are within the control and capability of the performer?
- what aspects of goal setting might be useful for informing micro-, meso- and macro-cycles within periodized plans?

Practice questions

1. State an example of a performance goal in sport. (1 mark)
2. In the context of the goal setting paradox, discuss why athletes and their coaches could set higher goals but face the possibility of the athlete feeling worse, or set lower, more achievable goals that could result in the athlete feeling better. (4 marks)

Summary

- Sport psychology is useful for performance enhancement as well as for managing training and a sporting lifestyle.
- Two important concepts within psychological skills training (PST) are psychological states (for example, confidence, motivation) and the psychological skills that can be applied to help improve them (for example, goal setting).
- While there is a range of factors associated with good performance, psychology has been shown to play a significant role.
- Psychological skills are acquired in much the same way as physical skills, and as such, specific training is required.
- Common misconceptions about sport psychology include:
 - psychology is a quick fix
 - it is only required for problem athletes
 - it is only pertinent for elite athletes
 - it is not useful in a sport context.
- Psychological skills can be developed through both formal teaching as well as more informal experiences. However, PST often has three phases: 1) general education phase, 2) acquisition phase and 3) practice phase.
- Goals work through one or more of the following mechanisms: focus attention, mobilize effort in proportion to the demands of the task, enhance persistence and encourage the individual to develop strategies for achieving goals.
- It is best to use a combination of different types of goals (that is, outcome, performance and process goals).
- The acronym SMARTER provides a simple way to remember some key aspects of effective goal setting; however, more in-depth guidelines are preferred.
- Goals are likely to be more successful if there is a balance between goal challenge and achievability.
- Athletes may feel less satisfied when a difficult goal is achieved than when an easier goal is achieved; this is known as the goal-setting paradox.
- The capacity to disengage from unattainable goals and to re-engage in other new goals is a valuable quality in athletes.
- Difficult goals lead to greater performance than “do your best” goals.
- Open goals are a form of non-specific goal, and some think that open goals are necessary for the occurrence of enjoyable, effortless flow states.
- Open goals differ from “do your best” goals.

Check your understanding

After reading this chapter, you should be able to:

- discuss what is meant by psychological skills training and identify four key misconceptions about sport psychology
- outline different types of goals and their uses
- understand why goal setting works
- discuss the goal-setting paradox.

Self-study questions

1. Describe why goal setting works.
2. Outline **three** types of goals that Olympic athletes might use.
3. Describe guidelines for setting effective goals in a training programme.
4. Explain the goal-setting paradox.
5. Distinguish between open goals and “do your best” goals, using examples from a sport of your choice.

AHL

Data-based question

A study examined the impact of goal setting on enjoyment during a six-week exercise programme. Sixty recreational exercisers (mean age = 31 years; 33 males; 27 females) were randomly assigned to a process goal group ($n = 15$), an outcome goal group ($n = 15$) and a no-goal control group ($n = 30$). Participants completed a survey at the beginning (pre) and end (post) of the six-week exercise programme to find out their mean (\pm SD) scores for enjoyment of their exercise programme, as shown in Table 2 (higher scores = more, and lower scores = less).

▼ Table 2 Group enjoyment scores

Group	enjoyment	
	pre	post
process goals	6.01 (\pm 0.11)	6.11 (\pm 0.12)
outcome goals	5.47 (\pm 0.11)	2.44 (\pm 0.12)
control (no goal setting)	3.73 (\pm 0.8)	2.72 (\pm 0.09)

Source: adapted from Wilson and Brookfield (2009).

1. Calculate the difference in mean scores for enjoyment between the process group and the outcome group post the six-week exercise programme. (1 mark)
2. Compare the enjoyment scores reported between the groups from pre to post. (2 marks)
3. Discuss the link between goal setting and intrinsic motivation. (4 marks)

C.5.2 Imagery

Syllabus understandings

C.5.2.1 Imagery is an experience that mimics real experience. It involves using a combination of different sensory modalities in the absence of actual perception.

Introduction

In a recent study (Koehn, Díaz-Ocejo, 2016), **imagery** was used as a vehicle to increase flow state in middle-distance runners based at a high-performance academy in Doha, Qatar. All participants had at least three years of experience in training and competition, and competed in national championships in Qatar and internationally during training camps abroad.



▲ **Figure 1** Koehn and Díaz-Ocejo chose the 60 m sprint as a performance task to improve movement and flow experience

The 60 m sprint was chosen as a performance task to improve movement and flow experience. The short distance allowed athletes to closely focus on the specific performance element that they aimed to improve, and coaches confirmed the relevance of the task to improving middle-distance running times. The aim of the study was to increase flow state of three elite junior middle-distance runners (aged between 14 and 18 years) on this performance task in a training setting, over a four-week period. Each imagery session took approximately 10 minutes, and was conducted at home in a comfortable environment. Athletes were asked to imagine their 60 m running performance; that is, imagine the speed and rhythm of the movements, for five performances.

There was a positive effect of the four-week imagery intervention on flow state in a training setting for all three participants. In other words, imagery enhanced the experience of flow in elite junior athletes.

This is important because flow is associated with effortless movement and optimal performance.

Purpose of imagery

Imagery involves as many senses as possible—kinaesthetic, visual, auditory, tactile and olfactory.

Additionally, recreating emotions (such as anxiety, anger, joy or pain) or thoughts (such as confidence or concentration) through imagery can help an athlete control these states.

Why do athletes and exercisers use imagery? To help answer this, Paivio (1985) distinguished between two functions of imagery: motivational and cognitive.

Paivio suggested that imagery plays both cognitive roles and motivational roles in mediating behaviour, each capable of being oriented towards either general or specific behavioural goals (Figure 2).

Imagery is “using all the senses to recreate or create an experience in the mind” (Vealey, Walter, 1993). It is sometimes known as mental practice or mental simulation.

	Motivational	Cognitive
Specific	<p>Goal-oriented responses For example, imagine winning the 100m sprint at the Olympic Games</p> 	<p>Skills For example, imagine successfully negotiating a downhill ski slope</p> 
General	<p>Arousal For example, lie down and relax in a quiet place where you will not be disturbed</p> 	<p>Strategy For example, imagine carrying out a strategy to win a competition, such as a full-court press in basketball</p> 

▲ Figure 2 Imagery can be motivational or cognitive; specific or general

ATL Thinking skills

According to Paivio's (1985) classic theory, imagery serves two roles: cognitive and motivational.

The cognitive role involves:

- learning and performing movement skills (such as basketball free-throw shooting)
- planning and memorizing in-game strategy (such as offensive tactics in football)
- enhancing understanding.

The motivational role involves:

- adapting thoughts and emotions
- regulating physiological responses (such as anxiety or heart rate)
- enhancing psychological skills or attributes (such as motivation or confidence).

With these roles in mind, how might you use imagery in your favourite sport as an athlete or coach?

How might you use imagery in your daily life (for example, for your academic studies or any hobbies you might have)?

In considering this, reflect on the characteristics of the two roles of imagery according to Paivio.

For instance, in what scenarios might you need to learn, improve or relearn a movement skill?

In what situations might you need to manage your heart rate or enhance motivations?

Theories

Psychologists use theories to help understand, explain and predict human thoughts, emotions and behaviours. Although the early 20th century often focused on theories and research of observable and directly measurable behaviours, there has been increasing interest and recognition of mental states and processes in the years since. In sport psychology, theories are typically built upon or comprise psychological **constructs**—consistent and logical concepts or principles—that can facilitate understanding of human behaviours, thoughts and emotions. These constructs typically help to provide consistency, structure and logic to theories. Constructs lack physical form and cannot be directly measured because they are human-conceived, intangible and hypothetical principles. This does not mean, however, that constructs necessarily feel or are considered to be unimportant or artificial, as some constructs can become so established and familiar that their existence is widely accepted and unquestioned. For example, Paivio's (1985) imagery framework represents a theory that explains, and makes predictions regarding the impact of imagery interventions on the psychological constructs of *cognition*

and *motivation*. Although neither cognition nor motivation can be directly observed or measured, many of us will accept that cognition and motivation exist and that their existence can be inferred (for example, through self-report questionnaires or observed changes in behaviour following the imagery intervention).

Other well-known psychological constructs include confidence, intelligence and anxiety. Again, these are human-constructed and intangible concepts that cannot be directly observed or measured, but many of us can readily understand or recognize these (for example, if we observe an athlete fidgeting, sweating profusely and breathing quickly before a basketball free throw, we might conclude that they are experiencing anxiety).

Reflecting on your own thoughts, behaviours and emotions or on your observations of others, can you think of other psychological constructs that you have come across or experienced (for example, in sport, education or life more generally)?

Imagery is a “central pillar” of applied psychology practice (Perry, Morris, 1995) and has been shown to enhance motor task performance, increase muscular strength and increase movement speed (Yue, Cole, 1992; Pascual-Leone et al., 1995).

The questions relating to “why” and “how” imagery works have intrigued researchers for decades. Numerous theories have been proposed to explain the phenomenon (including psychoneuromuscular theory, symbolic learning theory, attention-arousal theory and bio-informational theory). The Latin motto “*Possunt quia posse videntur*” (Virgil, 19 BCE), which can be translated as “They can because they see themselves as being able”, has been around for centuries. This suggests that imagery can have a positive effect on self-belief and intrinsic motivation.

Currently, one of the most favoured theoretical stances for how imagery works is Lang's bio-informational theory (1977). This theory proposes that the same neural pathways in the brain used in performing skills are activated during the use of vivid imagery. This carries important implications for applied interventions because the same areas of the brain should be activated during imagery as during performance itself.

Key point

Lang's bio-informational theory proposes that the same neural pathways in the brain used in performing skills are activated during the use of vivid imagery.

PETTLEP model of imagery

Holmes and Collins (2001) suggest the extent to which this happens will determine the success of the imagery technique. They went on to devise seven elements to consider in the delivery of motor imagery-based interventions: Physical, Environment, Task, Timing, Learning, Emotion, Perspective (PETTLEP).

The **PETTLEP model of imagery** is built on Lang's theory, but still requires testing and is far from complete. Nevertheless, this model provides a way of incorporating all the relevant senses into an imagery intervention.

▼ **Table 1** The PETTLEP model—a judo example

PETTLEP element	Description	Judo example
physical	imagery should resemble as closely as possible the actual physical performance	<ul style="list-style-type: none"> stand on the mat with full judo kit on; observe the session and attempt to take part in your mind simulate competition fatigue by using imagery after a hard session
environment	should resemble as closely as possible the actual performance environment	<ul style="list-style-type: none"> complete imagery training session in the judo hall rather than at home use photos or video of new venues
task	mirror the attention demands and changes of the actual practice	<ul style="list-style-type: none"> focus specifically on performance and the internal feeling and emotions experienced
timing	prepare for and execute movements in real time	<ul style="list-style-type: none"> experience the rhythm that you would normally use in performing throwing techniques
learning	if difficulties are envisaged, these should be included to keep it realistic	<ul style="list-style-type: none"> you can still try new techniques in mental simulation it is important to change your imagery accordingly as real skills develop
emotion	try to experience the feelings and emotions that you would if you were doing it for real	<ul style="list-style-type: none"> feeling of butterflies in your stomach as the fight begins use music to help facilitate these emotions
perspective	from the inside looking out as if you were actually performing (internal perspective) or viewing from the outside as if you were watching a recording of your performance (external perspective)	<ul style="list-style-type: none"> use internal perspective for planning and executing techniques use external perspective to experience the aesthetic quality of the execution



◀ **Figure 3** It is recommended that the environment for an imagery intervention should resemble the actual performance environment

Of course, individuals will use imagery techniques differently depending on what type of activity is being performed (for example, number of natural breaks in play and frequency of set plays/shots) and what level the athlete is performing at (novices may image a specific aspect of the skill, whereas experts may image the whole skill).

Similarly, there may be many reasons why an athlete is using imagery as part of their preparation or performance. It may be for concentration enhancement, self-confidence, skill acquisition, emotional control, practice strategy or coping with pain and injury—refer to Table 2.

Activity 1

Can you think of examples for each PETTLEP element of mental imagery using another sport?

ATL Thinking skills

Can you think of other examples for each of these uses of imagery? Do you think using imagery would help athletes to perform to their best?

TOK

The English men's national soccer team has only won two out of eight penalty shootouts in major competitions. This has led to the stereotype that English football players are bad at scoring penalties.

A recent study (Brinkschulte et al., 2020) analysed the performance of a large sample of penalty takers during all World and European Championships ($n=696$) since 1976. The results revealed no significant differences between the success rates (on average between 71% and 79%, depending on the type of penalty kick and on the type of competition) of penalty takers from different nations.

Based on the findings of this study, what would you conclude about the English men's national soccer players' performance in penalty shootouts?

▼ Table 2 Various uses of imagery

Imagery use	Example
concentration enhancement	rugby kicker using imagery as part of a pre-performance routine
self-confidence	judo player seeing themselves throwing their competitor
skill acquisition	novice tennis player imagines performing a serve before completing the task
emotional control	golfer mentally practises making an important putt under pressure
practice strategy	mountain biker mentally rehearses the route and how they will approach each part of the course
coping with pain and injury	an injured swimmer sees themselves completing the next part of their rehabilitation successfully

Imagery may be integrated with other psychological skills as part of a wider performance intervention. For example, imagery may feature as part of a pre-performance routine along with relaxation and self-talk techniques.

ATL Thinking skills

▲ Figure 4

Many people think the outcome of penalty shoot-outs in soccer is a "lottery". They suggest that luck, rather than skill, is key to success. A study (Wood et al., 2015) reported that not knowing who is going to take the penalties and the kicking order is a major stressor for players immediately prior to taking part in the shoot-out. They also reported that shooting practice that promotes target-focused shooting to each corner of the goal could be a beneficial warm-up routine (before a match starts) in preparation for taking a penalty kick during a penalty shoot-out. Also, during the walk to the penalty spot Wood et al. highlighted the importance of the soccer player remaining focused on their performance, by using positive self-talk such as, "If I shoot accurately the goalkeeper has no chance."

Based on this information and any other relevant information you can find, what pre-performance routines do you think would help players to learn to score penalties under pressure?



Linking question

How can imagery be used to reduce the risk of overtraining? (A.3.1)

Overtraining—where excessive training loads and inadequate recovery disrupt bodily systems, mood, motivation, focus, sleep and more—represents a significant concern for athletes, coaches and physical educators.

Consider:

- performing functional, physical behaviours, and the appropriate use of psychological skills to manage or shape thoughts, emotions or physiological responses
 - imagery has a range of uses, including enhancing motor learning and control; increasing confidence and motivation; regulating arousal, emotion and physiological responses; and assisting in injury prevention and recovery
 - effective imagery uses a range of senses including visual, auditory (hearing), olfactory (smell), tactile (such as the feel of a golf club in your hands), kinaesthetic (such as the feel of the movement when swinging the golf club) and emotional (such as excitement or anger)
- critical characteristics of imagery include perspective (first-person or third-person viewing), angle (such as viewing from above, below and behind when using third-person perspective), agency (imaging one's self or another person performing the skill) and deliberation (whether imagery was planned or spontaneous)
 - how imagery frameworks such as PETTLEP assist coaches and athletes to develop more effective imagery that addresses the context or environment, the preferred responses (such as physical or technical performance, use of psychological skills) and the meaning (perceived importance of the behaviours).



Linking question

To what extent can an athlete use training in psychological skills to regulate their heart rate? (Tool 1, Inquiry 1, C.4.1, A.1.1, A.1.2)

Consider:

- psychological skills have a range of purposes
 - athletes can use psychological skills and strategies to regulate their physiological responses, such as heart rate, to a range of circumstances or experiences, including pressure, fear or boredom
 - can athletes use psychological skills to lower, maintain and even elevate heart rate?
 - what scenarios can you think of where you might want to lower, maintain or raise your heart rate?
- biofeedback
 - individual zone of optimal functioning (levels of anxiety and arousal for performance vary from athlete to athlete)
 - the value of practice (for example, pre-performance routines or breathing exercises for free throws in a basketball practice session)
 - PETTLEP.

Practice questions

1. Identify two benefits of using mental imagery in psychological skills training. (2 marks)
2. Explain how the PETTLEP model of imagery can help an athlete improve their performance. (6 marks)

Summary

AHL

- Imagery is “using all the senses to recreate or create an experience in the mind” (Vealey, Walter, 1993), and it is also sometimes known as mental practice or mental simulation.
- Paivio (1985) distinguished between two functions of imagery—motivational and cognitive—each capable of being oriented towards either general or specific behavioural goals.
- Holmes and Collins (2001) devised seven elements to consider in the delivery of motor imagery-based interventions: Physical, Environment, Task, Timing, Learning, Emotion, Perspective (PETTLEP).
- Imagery can be used for concentration enhancement, self-confidence, skill acquisition, emotional control, practice strategy and coping with pain and injury.

Check your understanding

After reading this chapter, you should be able to:

- distinguish between cognitive and motivational, and specific and general functions of imagery
- evaluate the uses of mental imagery and provide examples of how it may be implemented in practice.

AHL

Self-study questions

1. Distinguish between internal and external imagery in sport.
2. Outline **two** examples of what imagery can be used for in an exercise setting.
3. Discuss why imagery works according to Lang's bio-informational theory (1977).
4. Explain what the acronym PETTLEP (Holmes, Collins, 2001) stands for when using imagery.
5. Discuss how you would use PETTLEP imagery guidelines as part of imagery training.

Data-based question

A study investigated imagery ability (imagery vividness, which is the clarity and realism of the image) in 169 (male = 90; female = 79) youth athletes (mean age 16.6 ± 3.0 years; range 12–21 years) from a variety of sports.

The youth athletes completed a questionnaire that resulted in their scores for external visual imagery (EVI), internal visual imagery (IVI) and kinaesthetic imagery (KI).

The mean (\pm SD) scores by age group are shown in Table 3.

▼ **Table 3** Imagery scores for youth athletes

	Age group				
	12–13 years	14–15 years	16–17 years	18–19 years	20–21 years
EVI	2.53 (± 0.82)	2.62 (± 0.78)	2.62 (± 0.77)	2.34 (± 0.81)	2.50 (± 0.81)
IVI	2.21 (± 0.62)	2.51 (± 0.71)	2.21 (± 0.74)	1.93 (± 0.71)	2.00 (± 0.76)
KI	2.61 (± 0.91)	2.50 (± 0.72)	2.39 (± 0.72)	2.34 (± 0.75)	2.01 (± 0.64)

Source: adapted from Parker and Lovell (2012).

1. Identify the age group with the greatest difference between their mean scores for EVI and IVI. (1 mark)
2. Describe the trend for KI scores as the youth athletes progress from 12 to 21 years. (2 marks)
3. Discuss the imagery ability of the youth athletes as they get older. (4 marks)

Mathematical tools

Introduction

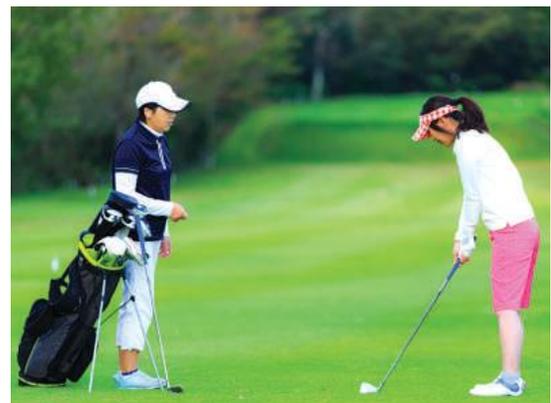
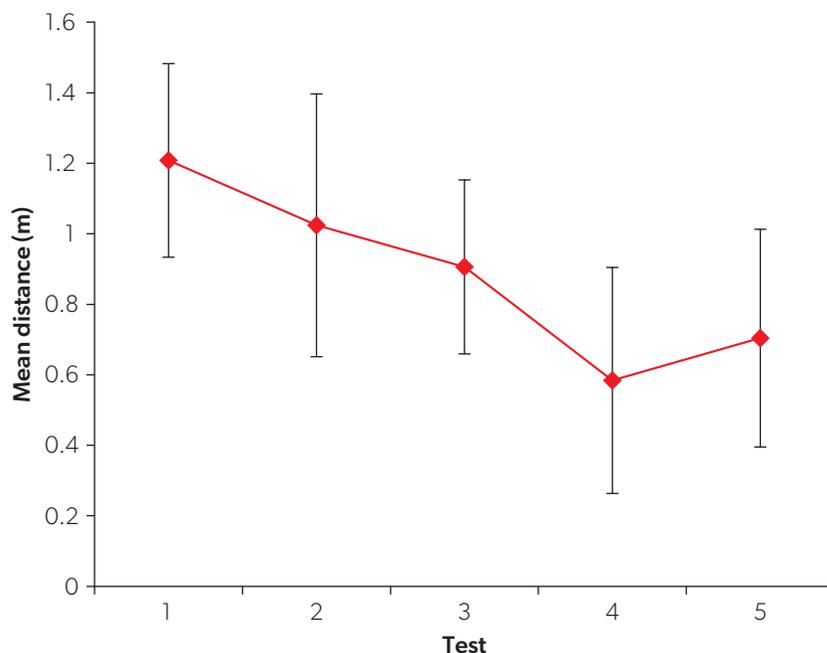
Mathematical skills are a key part of your toolkit when you study sports, exercise and health science. Mathematical skills are particularly important when collecting and processing data, and interpreting results.

Standard deviation

The standard deviation (SD) is the spread of scores around a mean average.

For example, consider an individual's performances on a golf putting test, measured by distance from the hole, over a period of five lessons. The golfer had 30 test putts at the end of each lesson.

To show how the golfer was progressing, their coach plotted a graph, as shown in Figure 1.

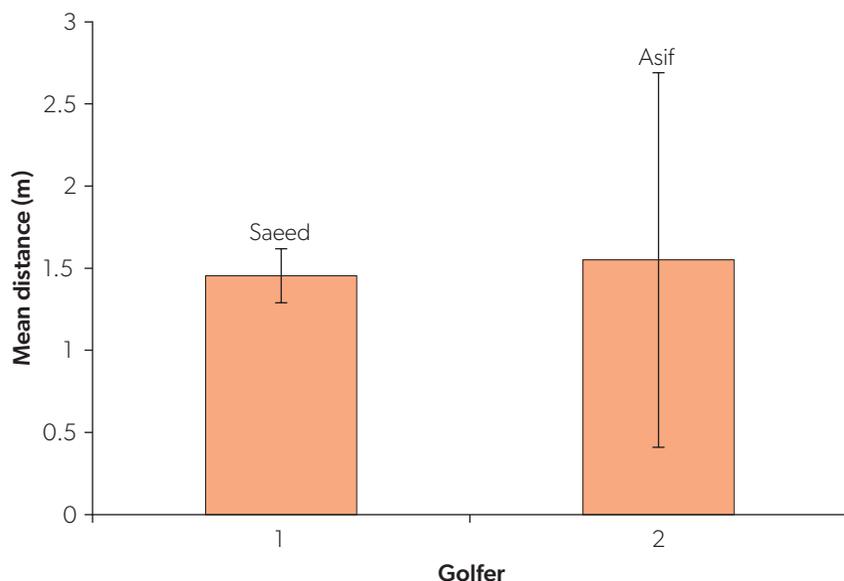


▲ Figure 1 Mean (\pm SD) distance from hole of a learner golfer's putts over five sets of 30 trials

The coach calculated the mean average of each set of 30 trials. These are shown in the diagram, represented by the red diamonds. However, mean averages only provide limited information about how a person has performed. On the graph, the coach has added error bars. Error bars represent the *variability* of the data—they show the standard deviation from the mean. They can add valuable information for the coach and learner.

As you can imagine, the golfer is not consistent when making their putts. The standard deviations can tell us something about that inconsistency.

Figure 2 shows the mean averages and standard deviations of two sets of 30 trials on a test of putting for two beginner golfers, Saeed and Asif.



▲ Figure 2 Mean (\pm SD) distance from the hole of two learner golfers' putts over 30 trials

Key point

The standard deviation is the spread of scores around the mean. When the data are normally distributed, about 68% of all values will lie within ± 1 standard deviation, while 95% will be within ± 2 standard deviations.

The graph shows that the means are very similar but the standard deviations differ greatly. If you only knew the means, then you might think that both golfers were equally as good as one another. But Saeed's standard deviation is much smaller than Asif's, meaning that Saeed is much more consistent than Asif. Each of Saeed's attempts was not far from their mean, but Asif's varied greatly. This would affect the way in which the coach would train each of the golfers.

Calculating standard deviation

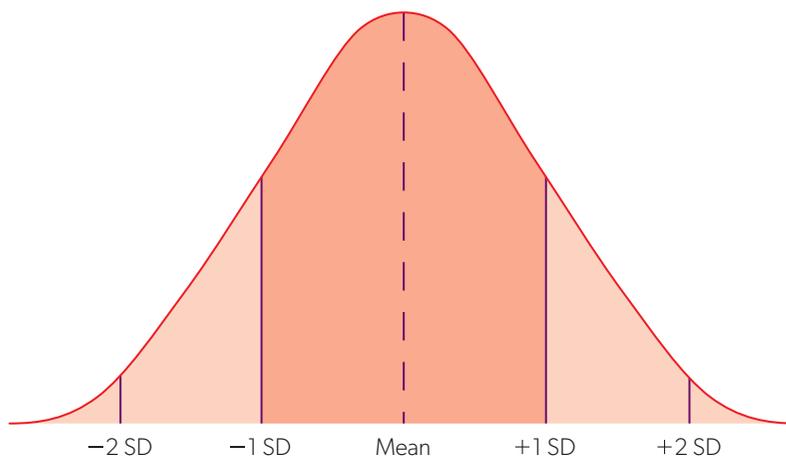
Standard deviation is calculated from the spread of scores around the mean. The terms s , SD and the Greek letter σ (sigma) are often used for standard deviation. Sometimes, the mean is given with the symbol \pm followed by the standard deviation. So, mean = 1.71, SD = 0.89 is the same as mean = 1.71 \pm 0.89. The use of \pm is because the standard deviation is the spread *around* the mean.

A graphic display or scientific calculator can compute the mean and standard deviation. For example, another beginner, Caterina, performed one set of 12 trials on the golf putting test. Table 1 shows their results.

▼ Table 1 Caterina's mean error and SD

Trial	1	2	3	4	5	6	7	8	9	10	11	12	mean	SD
Error (m)	1.23	2.03	0.97	1.67	2.00	1.89	1.58	0.67	1.88	2.01	4.01	0.59	1.71	0.89

The table shows that the distance from the hole in some of Caterina's putts was more than the mean, while others were less than the mean. Statisticians have found that, when the data are "normally distributed", about 68% of all values will lie within ± 1 standard deviation, while 95% will be within ± 2 standard deviations. Figure 3 shows normally distributed data.



Note: SD = Standard deviation

▲ Figure 3 Typical bell curve for normally distributed data

Coefficient of variation

Another useful measure of variation is the coefficient of variation, V .

The coefficient of variation is the ratio of the standard deviation to the mean. It is expressed as a percentage. The formula for the coefficient of variation is:

$$V = \frac{100 \times \text{SD}}{\text{mean}} \%$$

So, the coefficient of variation for Caterina would be:

$$\begin{aligned} V &= \frac{100 \times 0.89}{1.71} \% \\ &= 52.05\% \end{aligned}$$

Key point

The coefficient of variation is the ratio of the standard deviation to the mean expressed as a percentage.

This provides similar information to the standard deviation, but people often understand percentages better.

Interquartile range

The interquartile range is the set of the limits within which the middle 50% of an ordered set of observations falls. It is the difference between the value of the upper quartile (the value that cuts off the highest 25% of ordered scores) and lower quartile (the value that cuts off the lowest 25% of the data).

Standard error

The **standard error** is the standard deviation of the **sampling distribution** of a statistic. For a given statistic (such as the mean) it tells us how much variability there is in this statistic across samples from the same population. A large value for standard error indicates that a statistic from a given sample may not be an accurate reflection of the population from which the sample came.

Think of sampling distribution as follows: if you take a sample from a population and calculate a statistic (such as the mean), the value will depend on the sample you took—it will vary slightly from sample to sample. If you took many samples from the population and calculated the statistic (such as the mean), you could create a frequency distribution of the values. The result is what the sampling distribution represents.

Uncertainties

When analysing data, a level of uncertainty will arise. Methods are used to account for and manage the various sources of uncertainty. **Uncertainties** can arise from random variations in experimental conditions, measurement errors and sampling bias. Common methods used to manage uncertainties in statistics include calculating confidence intervals, using standard errors and applying statistical tests for significance. These methods can provide more accurate and reliable estimates of the true values of the quantities being measured and analysed.

Using *t*-tests

Means, standard deviations and coefficients of variation can be useful when comparing differences in performance between individuals and groups or by the same individual or group but at different times.

Table 2 shows the distances covered in 60 seconds by a group of 12 soccer players. Each player did a running-with-the-ball test following rest, and then again after 20 minutes' exercise at 70% of their individual maximum volume of oxygen uptake ($\dot{V}O_2\text{max}$).

▼ **Table 2** Distances (metres) covered in 60 seconds by soccer players following rest and after exercise at 70% $\dot{V}O_2\text{max}$

Participant	After rest	After 20 minutes at 70% $\dot{V}O_2\text{max}$
1	450	390
2	345	455
3	389	378
4	327	405
5	401	366
6	387	388
7	397	400
8	400	405
9	359	401
10	395	432
11	333	411
12	412	399
Mean	382.92	402.5
SD	35.66	23.42
V	9.31%	5.82%
t_{11}	1.194	
<i>p</i>	0.205	

Note: SD = standard deviation; V = coefficient of variation

The key question is whether the difference in mean distances is due to exercise or chance. To test whether or not there is a *real* difference, you can carry out an inferential statistical test called a **t-test**. This can be calculated using a graphic display or scientific calculator, or a computer program.

Using a graphic display calculator, you can find that $t_{11} = 1.194$. This does not mean much by itself. However, you can use it to calculate the probability (p) of finding this difference between the times. A graphic display calculator does this; it shows that $p = 0.205$. The p -value can also be found using probability tables for t -tests; these can be found in most statistics texts.

In order to use the tables, you need to know the **degrees of freedom**. These are represented by the number 11 in our example. This number is normally written in subscript but sometimes in brackets, for example $t(11)$.

To understand degrees of freedom think of the following example. You are the coach of a soccer team. You have a team sheet with 11 blank spaces relating to the positions on the soccer team. When the first player arrives for the match you have a choice of 11 positions in which to place this player. You give him a position (for example, goalkeeper), and this means that one position on your team sheet is now occupied. When the next player arrives, you have a choice of 10 positions but you still have the freedom to choose which position this player is allocated. As more players arrive you will reach the point when the final player arrives and 10 positions have been filled. With this player you have no freedom to choose their position because there is only one position left. Therefore, for 10 of the players you had some degree of choice over the position they played, but for one player you had no choice. The degree of freedom is one less than the number of players.

The important thing to note in the previous example (the distances covered in 60 seconds by a group of 12 soccer players) is that the p -value is greater than 0.05. This means that there is more than a 5% possibility that the results are by chance rather than caused by the exercise. These results are “non-significant”. For a result to be significant, $p < 0.05$.

TOK

Scientists use r as a measure of the strength of the relationship between two variables. They use $p < 0.05$ to denote a significant difference or correlation when determining r .

By using an objective value you can guard against, for example, drug manufacturers that claim their product has significant effects when in fact it does not.

You must be careful when describing results that fail to show $p < 0.05$. They are not statistically significant—but they should not be described as *insignificant*. They are non-significant. Non-significant results can be significant scientifically. For example, if a pharmacologist finds that using a particular drug has a non-significant effect on patients, it tells him that this drug does not work—which is not insignificant; it is an important finding.

The t -test described above is a **paired t -test**. It is called this because it was the same people tested following rest and exercise. For a test to be paired, it does not need to be the same people; it can be people who are paired for reasons such as height, weight or experience.

Another type of t -test is the independent t -test or **unpaired t -test**. McMorris and Beazeley (1997) compared the speed of decision-making of 10 experienced and 10 inexperienced soccer players on a soccer-specific test. The experienced group had a mean decision time of 1.242 s, $SD = 0.01$, while the inexperienced had a mean time of 1.599 s, $SD = 0.02$. This was significantly different ($t_{18} = 9.50$, $p < 0.001$). The p -value shows that there was only a 0.1% possibility of this result being by chance.

Note also that the degrees of freedom for this test were 18 when the total number of participants was 20. In the paired t -test the degrees of freedom were 11 when the total was 12. One of the differences between the calculation of paired and unpaired t -tests is the degrees of freedom. Therefore, it is important to choose the correct test.

The experiment of McMorris and Beazeley is one of many that have shown that experience affects decision-making in team sports and is a type of cause and effect experiment. The next section, *Inquiry process*, will examine the design of cause and effect experiments more fully.

Correlation

You may want to know if there is a *relationship* between two things. For example, is there a correlation between athletes' ages and times for a 5,000 m race? You can do this by calculating the r - and R^2 -values.

The **correlation coefficient** r is a measure of how strong the relationship between two variables is. When you calculate r , you get a number between 0 and 1, which can be positive or negative:

- If r is close to 0, there is weak or no correlation between the two variables.
- If r is close to 1, there is strong correlation between the two variables.
- If r is positive, the correlation is positive (as one variable increases, so does the other variable).
- If r is negative, the correlation is negative (as one variable increases, so does the other variable).

A common criterion for interpreting the meaningfulness of the correlation is R^2 . This is called the **coefficient of determination** (R^2) and is simply the square of the correlation. Usually the coefficient of determination is expressed as a percentage. For example, for a correlation of 0.70 between standing long jump and vertical jump score, only 49% of the variance (or influence) in one test is associated with the other.

If you multiply R^2 by 100 you get the percentage of overlap between the two measures. Even if this is high it does not mean that age *causes* the athlete to run the 5,000 m faster. It simply means that age and speed are related. There is correlation, but not causation.

ATL Research skills

How do you overcome the problem of dependence on the measurement scale? For example, if you wanted to measure the relationship between attitude to climbing every 1,000 metres during a climb of Mount Everest, it is important to note that attitude cannot be measured in metres!

Key point

Probability tells us the likelihood of the differences between two sets of data being statistically significant.

Summary

- The standard deviation is calculated from the spread of scores around the mean.
- The terms s , SD and the Greek letter σ (sigma) are often used for standard deviation.
- When the data are normally distributed, about 68% of all values will lie within ± 1 standard deviation, while 95% will be within ± 2 standard deviations.
- The coefficient of variation is the ratio of the standard deviation to the mean expressed as a percentage.
- Interquartile range is the set of limits within which the middle 50% of an ordered set of observations falls.
- Standard error is the standard deviation of the sampling distribution of a statistic.
- Whether difference between group means is due to the exercise or is simply due to chance can be examined by a t -test.
- If the probability (p) is less than 0.05 or 5%, the results are significant.
- Paired t -tests are carried out if scores by the same people are being compared or the individuals have been paired for height or weight, or for experience. If participants are not paired, you use an independent or unpaired t -test.
- If you wish to know whether there is a relationship between two things, calculate their correlation. Do this by calculating the r - and R^2 -values.
- If you multiply R^2 by 100 you get the percentage of overlap between the two measures.

Check your understanding

After reading this chapter, you should be able to:

- calculate standard deviation
- understand what the standard deviation, coefficient of variation, standard error and interquartile range tell us about the distribution of the data
- understand the significance of uncertainties in data
- understand what a correlation is
- understand what the t -test tells us about differences between two sets of data.

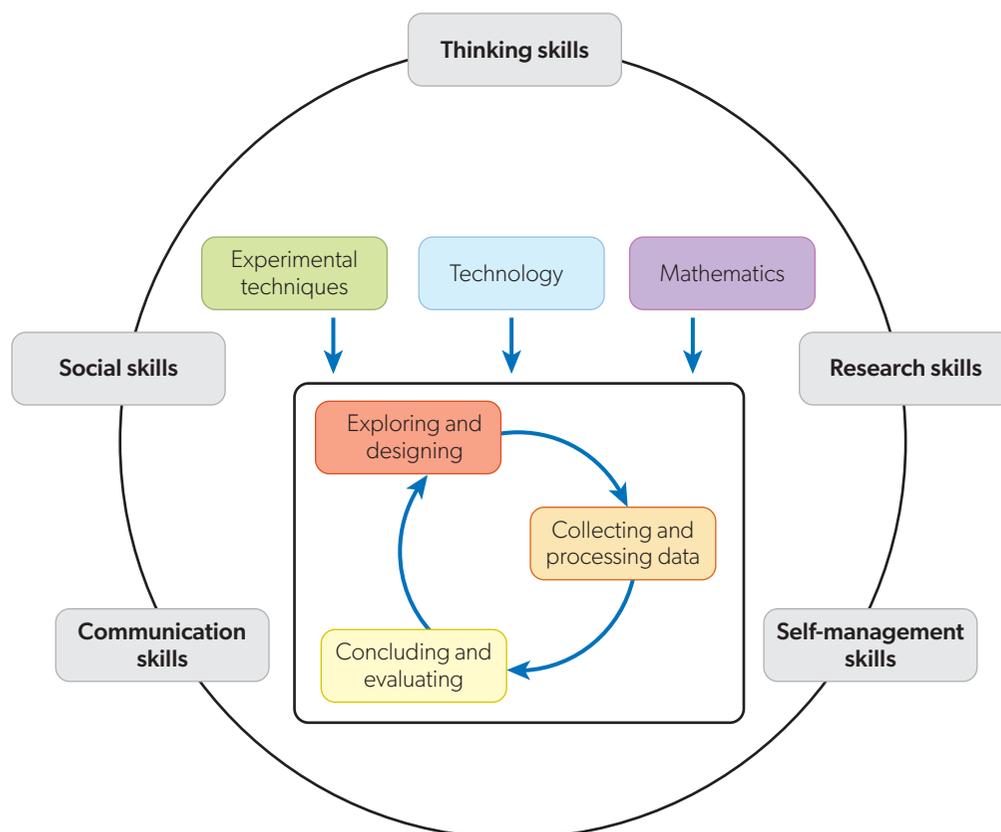
Inquiry process

Introduction

The inquiry process is central to the study of sports, exercise and health science. The process has three stages:

- exploring and designing
- collecting and processing data
- concluding and evaluating.

Your skills in experimental techniques, technology and mathematics, together with your ATL skills, will help you to understand and apply the inquiry process.

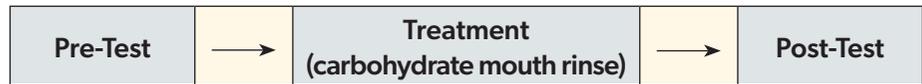


▲ Figure 1 Skills for sports, exercise and health science

Designing sports, exercise and health science experiments

This section examines the factors that you need to take into account when designing sports, exercise and health science experiments.

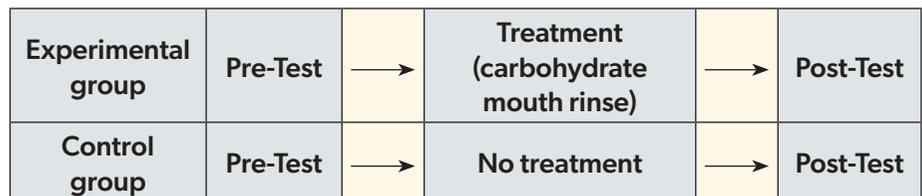
One type of experiment is the cause and effect experiment. You might want to know if, for example, taking a carbohydrate mouth rinse (without ingestion) has an effect on repeated sprint performance. Figure 2 shows an experimental design that might be used in such an experiment.



▲ Figure 2 A weak experimental design

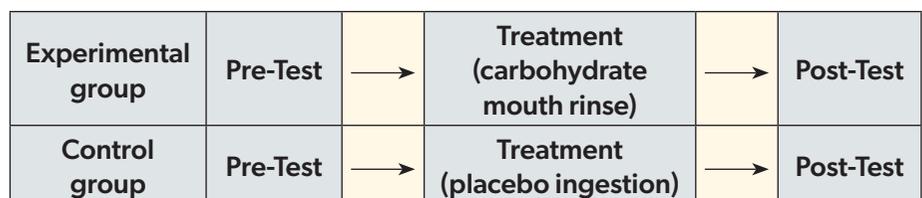
What is wrong with the design in Figure 2? Can you be sure that any changes in repeat sprint performance are due to the carbohydrate mouth rinse? Could it simply be that there has been a learning or habituation effect? What could you do to solve this problem?

Figure 3 shows the most common way of overcoming the learning/habituation problem—the use of a **control group**.



▲ Figure 3 An experimental design using a control group

The control group, in itself, does not ensure that the experiment is well-designed. The experimental group was given a carbohydrate mouth rinse, so they might expect an effect on their performance. The control group got nothing and, therefore, might expect to see no improvement in their performance. So, the results could be due to the *expectations* of the participants (those doing the experiment) rather than the carbohydrate mouth rinse. What could you do to overcome this? Figure 4 shows a possible method—the use of a **placebo**.



▲ Figure 4 An experimental design using a control group with a placebo

Key term

Double-blind experiment An experiment in which neither the participants nor the experimenters know who has been given the placebo.

The placebo will taste like the real thing but is, in fact, a harmless substance that will not affect performance. If you tell the participants which group they are in, then you are defeating the object, so all participants have to think that they *may* be getting the carbohydrate mouth rinse. This is called “blinding” the participants. Often, an experiment is called a **double-blind** experiment. In double-blind experiments, both the participants and the experimenters are blind to which treatment is given (another person issues the treatment). This is to make sure that the experimenters do not accidentally influence the participants.

In the carbohydrate mouth rinse study you must also be careful not to bias the results by, for example, choosing all the conscientious individuals in the carbohydrate mouth rinse group and those less likely to try hard in the control group. To guard against this, you can use a process called **randomization**—randomly allocate individuals to the groups.

In some studies, you may want to ensure that at the start the groups are fairly evenly matched. To do this, pair them based on results from the pre-test. In other studies, participants may be placed into groups based on their experience.

TOK

The **placebo effect**, with its central role in clinical trials, is acknowledged as a factor in sports medicine. Placebo effects of varying magnitudes are reported in studies addressing sports from weightlifting to endurance cycling. Findings suggest that psychological variables, such as motivation, expectancy and conditioning, and the interaction of these variables with physiological variables, might be significant factors in driving both positive and negative outcomes. Research involving the triangulation of data, and investigation of contextual and personality factors in the mediation of placebo responses may help to advance knowledge in this area.

Source: Beedie, Foad (2009).

- Explain how motivation might be a significant factor in driving both positive and negative outcomes of a placebo.
- Discuss whether placebo responsiveness is a generalized trait.
- If placebo responsiveness were a generalized trait, does this represent a desirable or undesirable characteristic in terms of athletic personality?

Activity 1

Choose a research question that you would like answered and design a study that will allow you to answer the question.

Experiments

Selecting control groups in sports, exercise and health sciences research constitutes a critical consideration for study design. If control groups are inappropriately selected, this can result in the misinterpretation of results and, in turn, lead to suboptimal recommendations for applied practice. There are several available comparison and control group designs for research in sport and health, such as no treatment and placebo.

Why might researchers prefer to use a placebo control group compared with a no treatment control group?

Accuracy, precision, reliability and validity

There are four important factors to take into account when designing an experimental methodology: accuracy, precision, reliability and validity.

Accuracy

The degree to which a measurement or observation closely matches the true or accepted value of a quantity, indicating how correct the data are. You must make sure that any measuring instruments are accurate. For example, if you are measuring weight, you must look after your weighing machines properly or they may provide inaccurate information.

Precision

The degree of consistency and reproducibility in repeated measurements or observations of the same quantity, regardless of whether they are close to the true value. Precision measures the proportion of true positives among all positive predictions. For example, in a medical test for disease, a true positive would be a case in which the test correctly identifies a patient as having the disease when they actually do have it. The related factor of specificity measures the proportion of true negatives among all negative predictions. For example, in a medical test for a disease, a true negative would be a case in which the test correctly identifies a patient as not having the disease when they actually do not have it.

Reliability

The ability of a measurement or experiment to produce consistent and dependable results when repeated under similar conditions, indicating the stability and consistency of a method. For example, if you want to know whether someone has become fitter, you need to be sure that any improvement shown from the testing is due to fitness and not because there is something wrong with the reliability of the test. Tests can be unreliable when there is a learning or habituation effect. If there are such effects, you might need to have a series of practice sessions to allow the participants to learn the task fully—that is, reach a point where they can get no better. McMorris et al. (2005) found that it took their participants 160 trials on a non-compatible choice reaction time test before they had fully learned the task. So, they had participants undertake 160 practice trials before carrying out their experiment.

Validity

The extent to which a measurement or experiment accurately measures or assesses what it intends to measure, ensuring that it reflects the concept or phenomenon of interest accurately. For example, having soccer players run 100 m will not tell you how quick they are in a soccer game, where sprints are much shorter and are repeated many times.

Activity 2

Choose a sport or a physical activity and devise a precise, accurate and valid test of either overall performance or of one aspect of performance.

How would you test reliability?

Null hypothesis and alternative hypothesis

The hypothesis is the expected result or outcome of a study or experiment. The study must be designed to ensure the hypothesis can either be supported or refuted—it must be testable. Hypotheses are deduced from theory or induced from other empirical studies and real world observations.

A research hypothesis is based upon logical reasoning and predicts the outcome of the study—if the hypothesis or prediction that comes from your theory is saying that an effect will be present, this hypothesis is called the **alternative hypothesis** (sometimes called the experimental hypothesis).

In contrast, the **null hypothesis** is used mainly in the statistical test for the reliability of the results. The null hypothesis states that there are no differences between treatments (or no relationships between variables). The purpose of the statistical test is to evaluate the null hypothesis at a specific level of probability (such as $p < 0.05$). All that the statistical test can do is either reject or fail to reject the null hypothesis.

Measuring fitness

Physical fitness is a complex and challenging term to define, but essentially it relates to an individual's physical ability to perform a specific activity. It is also important to acknowledge that the term fitness can be used in a range of contexts, such as "fit for purpose" or "mental fitness".

This section will focus on measuring physical fitness, emphasizing that there are many different components and ways to assess an individual's fitness.

Why is fitness assessed?

Testing fitness is important for both health and performance reasons. Health-related fitness assessment is primarily used to evaluate health and identify any weaknesses, relative to healthy "norms". This can assist with diagnosis, assessment of severity and, in some cases, prognosis.

However, testing is also used to:

- monitor progress as a result of interventions (for example, exercise training or medication)
- assist with education of participants/patients
- design individual exercise training programs.

These same reasons also apply in the performance sport context, with a few additional purposes, such as:

- to provide feedback to athletes
- to try and predict performance potential
- to establish goals for athletes to work towards.

How is fitness assessed?

Accuracy, precision, reliability and validity are important principles when deciding what fitness tests to use.

The value of the test will be determined by these important principles together with other considerations, often of a practical nature. These include, but are not limited to:

- the safety of the participants
- ethical considerations
- the number of participants to be tested
- the resources and facilities available
- the accuracy that is required
- the order of tests.



Global impact of science

When assessing an individual's physical fitness, there is often a comparison made between a recorded or estimated score and reference normative data. Take care to ensure that this comparison is fair and that the normative data are applicable to the individual being tested, as differences in fitness are not the only factors to contribute to individual differences. An interesting example of this is what is "normal" for acceptable or healthy body composition, which may vary according to regional and cultural factors. This is not restricted to only physiological factors, but also includes perceptions and acceptance as well.

Therefore, the practitioner must decide on the appropriateness of a fitness test based on the balance between the optimum—often called the gold-standard test—and what is actually practical. This means there will be limitations that must be considered when interpreting and applying the results.

Components of fitness

Given the wide range of physical activities performed in both the health and sport domains, it is not surprising that there are many different components of physical fitness. Many of these are inter-related in terms of mechanisms and outcomes.

Aerobic capacity

Aerobic capacity refers to the ability to take in, deliver and use oxygen for use by the aerobic or oxidative energy system (chapter A.2.3). It is most commonly characterized by an individual's maximal oxygen uptake ($\dot{V}O_2\text{max}$)—the maximal rate at which oxygen can be used during maximal exercise. It is also referred to as aerobic capacity, although you should recognize that there are other functional markers of aerobic performance. Aerobic capacity is underpinned by the limits of the cardiovascular and ventilatory systems to extract oxygen from the atmosphere, deliver it to respiring tissues and use it. The following examples illustrate why aerobic capacity fitness is important for health and sport.

- In conditions where cardiovascular or ventilatory function is impaired (such as heart disease or chronic lung disease) aerobic capacity is reduced. This means an individual can only tolerate very low intensities of physical activity before relying on anaerobic energy systems, which are less sustainable. Even simple physical tasks become unachievable, which worsens the physical deconditioning.
- In contrast, endurance-trained athletes have very high levels of aerobic capacity, enabling them to tolerate much higher intensities and durations of physical activity.

Power

Power is defined as the rate of doing work. It represents the combination of force and velocity, or strength and speed. Therefore, it is underpinned by the same factors as strength and speed—and the relative importance of these factors depends on the activity. Where high forces are required, the emphasis will be on strength. Where lower forces are required, the emphasis will be on speed. Muscular power is often seen as one of the most important determinants of sporting performance.

Strength

Strength is defined as the ability to generate force by a muscle or muscle group (chapter B.2.1). Strength is underpinned by the muscle mass that is available (volume and muscle fibre-type), the ability to activate that muscle mass and the coordination of this muscle activity. It is, therefore, dependent on the neural and muscular systems and their interaction.

Muscular endurance

Muscular endurance is the ability of a muscle or muscle group to maintain force or power (chapter B.1.3). It is sometimes described as fatigue-resistance at a local muscular level. Typically, local muscular endurance is mostly related to the availability of substrates, enzyme activity and build-up of metabolites, although the nervous system also has an important role.

Balance

Balance refers to the stability of the body. To maintain balance, the centre of gravity needs to be above the supporting base of the body. This is achieved through coordinated contraction and relaxation of postural muscles in response to positional changes. Positional changes are detected by visual, vestibular and proprioceptive processes. This stimulates the coordinated muscular responses in order to maintain balance. Therefore, successful balance depends on the ability to sense position and respond to the sensory information in a coordinated fashion, with integration of neuromuscular systems.

Body composition

Body composition relates to the proportion of an individual's total body mass that is made up of fat and fat-free mass (FFM). Although total body mass itself is easy to assess—and is often measured and interpreted in relation to health and sports performance—the makeup of total body mass is more important. Body fat mass (FM) includes essential fat found in the tissues and organs and stored fat, which is essentially an energy reserve. In contrast, FFM refers to what makes up the rest of the total body mass, including muscle, water and bone.

The following examples illustrate why body composition may be important for health and sport.

- High levels of body fat are associated with many pathological disorders. Attaining and maintaining low body FM is important for health-related physical fitness. However, if body mass is too low, the individual will typically have a FM that is too low (such as *anorexia*) and/or muscle mass that is too low (such as *sarcopenia*).
- There are many sporting activities where total body mass and body composition are important. In almost all of these the body fat is kept low (Sumo wrestling being an extreme opposite example). Instead, FFM is more important, whether it be an advantage to have a large FFM (for example, in collision sports such as American football or rugby union) or a low FFM (for example, in weight-restricted sports such as boxing, or more aesthetic sports such as gymnastics).
- Bone density is important. A low bone density underpins osteoporosis, and exercise can play an important role in maintaining bone density.

It is clear that body composition has a functional role in both health-related and performance-related physical fitness.

Flexibility

Flexibility refers to the ability to move through the full range of movement around a joint (chapters B1.1 and B1.2). Flexibility is underpinned by a range of factors, such as:

- the capacity of muscles and tendons to stretch
- ligament condition
- joint mechanics
- size and shape of bones.

There is a range of flexibility observed across populations. Joints may have impaired range of movement yet, for some individuals, some movement of joints can go beyond the accepted normal range of motion (called hypermobility). Therefore, flexibility can be both advantageous and possibly detrimental in the extreme.

Reaction time

Reaction time is described as the duration between the presentation of a stimulus and the associated response. Therefore, similar to balance, this depends on the integration of neuromuscular systems. The reaction time reflects the combination of detecting sensory information, processing this information, sending a response and effecting this response. The reaction time is very dependent on the interaction of the stimulus type and environment. For example, there may be a single stimulus and single response in the simplest tasks, compared with highly complex tasks with multiple stimuli and multiple responses with distracting information.

Coordination

Movements are often the result of several skeletal muscles (prime mover/agonist and antagonist, synergists, and fixators) acting as a group rather than acting alone. Coordination is the ability to perform smooth and accurate motor tasks. It often involves using the senses and a series of correlated muscular contractions that affect a range of joints and, therefore, relative limb and body positions. Try juggling three tennis balls for as long as you can. In young people in the early stages of strength training, some of the observable strength increases are from improved motor skill coordination. So, coordination is the ability of an individual to execute a sequence of movements correctly and with precision, and when playing sports or exercising this often involves coordinating the simultaneous movements of different body parts while involved in whole body action. For example, dribbling a basketball to go past a defender and progress toward the basket to shoot. There is a range of tests to assess coordination, such as the wall-toss test, and sport specific tests, such as basketball-specific coordination tests.

Speed

Speed is defined as the rate of change of distance (refer to chapters B.2.1 and B.2.2). This could refer to whole-body speed or speed of a particular joint or muscle group, depending on the context in sport and exercise. Speed is determined by the complex interaction of biomechanics and physiology, although maximum speed performance is also dependent on psychology. Physiologically, speed depends on similar factors to strength. However, the rate at which force is applied and the coordination of the subsequent movement are key to the outcome.

- In many sports, the time it takes to complete an activity is what determines the outcome. For example, in a 100 m sprint, strength is important—especially at the start when ground contacts are longer—but the ability to apply that strength quickly is more important in determining running speed.
- Explosive sporting activities, such as jumping and throwing, rely on the speed of movement.

Speed has more relevance for performance-related fitness than health-related fitness, where the speed at which actions are completed is of less importance.

Agility

Agility can be defined as the ability to rapidly change direction or speed. This may or may not be in response to a stimulus. It can be separated into the

physical ability to change direction or speed and the perceptual and decision-making component of responding to a stimulus (refer to *Reaction time*). The underpinning factors are many and complex. Briefly, they include similar factors of strength (both to decelerate the body and accelerate the body), power, speed, flexibility, balance, peripheral vision, anticipation and experience.

Activity 3

Does each of the following have a functional role for both health-related and performance-related fitness? Provide examples for each that illustrate why.

- Strength
- Power
- Muscle endurance
- Flexibility
- Agility
- Balance
- Reaction time



▲ Figure 5 Some components of fitness

Physical Activity Readiness Questionnaire (PAR-Q)

Tests to measure fitness require the individual to undertake (often strenuous) physical activity. Before asking someone to take part in a physical test you must make sure that taking part will not put their health at risk. Before asking someone to undertake physical activity, ask them to complete the Physical Activity Readiness Questionnaire (PAR-Q).

People should also complete this form when asking for training advice or joining a sports and/or exercise club.

▼ Table 1 Physical Activity Readiness Questionnaire (PAR-Q)

		YES	NO
1	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?		
2	Do you feel pain in your chest when you do physical activity?		
3	In the past month, have you had chest pain when you were not doing physical activity?		
4	Do you lose your balance because of dizziness or do you ever lose consciousness?		
5	Do you have a bone or joint problem that could be made worse by a change in your physical activity?		
6	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?		
7	Do you know of any other reason why you should not do physical activity?		

Key point

Before assessing an individual's physical fitness, ensure they have medical/health clearance and have signed an informed consent form.

If the person answers "No" to all questions then there should be no problem with them undertaking physical activity. However, if the person answers "Yes" to one or more questions they must see their doctor before undertaking any physical tests, training programmes or playing sport.

Field tests versus laboratory tests

Once the PAR-Q is successfully completed, you have to decide which test (or tests) of fitness to use. Remember the criteria outlined earlier: are the tests precise, accurate, reliable and valid?

First, decide what you want to test. For example, suppose you want to measure someone's $\dot{V}O_2$ max. You could do this accurately using a laboratory test. But if you do not have access to a laboratory, you could use a field test such as the Bleep test or Cooper's 12-minute run test. These are not as accurate or reliable, but they may be all that is available.

Maximal tests versus sub-maximal tests

If you want to know the maximum amount a person can do, such as $\dot{V}O_2$ max or the maximal weight they can lift, then carrying out a maximal test meets all of the criteria (accuracy, precision, reliability and validity). However, if someone is not used to undertaking maximal exercise, they are likely to stop before actually reaching their maximum because they become anxious about causing themselves injury.

As a result, some sub-maximal tests have been devised. You can use these to calculate what the person's maximum would be. These tests are particularly useful with groups such as children who are not used to working to their maximum, or the elderly who may feel concerned about going to the maximum.

ATL Research skills

Use the internet to find examples of field and laboratory tests that claim to test the same thing. Can you find sub-maximal and maximal tests that claim to measure the same things? Which do you prefer?

In many situations it is not possible to directly assess a fitness component. This does not necessarily preclude fitness assessment, but may require either an indirect assessment of fitness or prediction of fitness using a field or laboratory test. In such circumstances, the tester needs to consider the suitability and accuracy of the prediction. For example, what data are the prediction equations based on? This might mean that one equation is suitable for one population, but not for another. Another suitable question may relate to how accurate and valid the prediction is, relative to whatever the criterion measure is. Such questions enable the tester to evaluate how much bias may have been introduced due to the known limitations.

Testing aerobic capacity

As discussed in chapter A.2.3, the gold-standard assessment of cardio-respiratory fitness is the direct assessment of $\dot{V}O_2$ max. This requires a progressive (gradually increasing exercise intensity) maximal test to exhaustion, including measurement of gas exchange. While this is routinely carried out in sport and medical laboratories around the world, it is unfeasible in many sport and health situations due to:

- the requirement for expertise and equipment to run the test
- the maximal nature of the test
- only being able to test one participant at a time.

Therefore, there are many field-based tests that have been designed to enable estimation of $\dot{V}O_2$ max. The following three examples are only some of the more commonly-used tests.

Multistage Fitness Test

The Multistage Fitness Test (MSFT), also known as the Beep or Bleep Test, was originally devised by Leger and Lambert (1982) and was then validated and commercialized by the National Coaching Foundation (Ramsbottom et al., 1988). The test requires participants to perform repeated 20 m shuttles at progressively increasing speeds until exhaustion is reached. The running speed is indicated by an audio-sound (the “beep”) that indicates that the next shuttle should start at this point (that is, the turn at each end of the 20 m course should coincide with the sound). The first level of the test is of low intensity (fast walk or light jog) and then approximately each minute the frequency of the sounds increases to the next level, causing an increase in running speed for that level. Performance in the test is described as the level reached and the number of completed shuttles in that level before the participant either voluntarily stops or fails to keep pace with the sound and was disqualified from continuing. For example, a score of Level 10-6 would imply six shuttles were completed in level 10. This score is then compared against a reference table where an estimate of $\dot{V}O_2$ max can be obtained based on the number of shuttles. An increased score corresponds to a higher $\dot{V}O_2$ max.

The evaluation of this test requires consideration of advantages and limitations compared with the gold-standard test.

Advantages include:

- limited expertise and equipment needed
- maximal test (not a sub-maximal prediction), so similar to gold-standard
- easy to score
- large numbers can be tested at once in a short time.

Key point

Physical fitness testing can play an important role in health and sport. However, for the assessment to be meaningful the appropriateness of a test must be assessed relative to a wide range of factors. Where a gold-standard test is not possible, the tester must assess the relative value against the associated limitations of the test, in the specific context of the participant and environment.

Limitations include:

- prediction based on performance and not direct measurement
- maximal test (safety and ethical considerations, as well as importance of motivation)
- environmental factors influence performance as not in a laboratory
- score is known by participants and previous scores or target scores may impact on performance.

The protocol is stop-start in nature, compared with continuous in the gold-standard test.

This test is widely used with healthy adults in sports teams as it has been shown to be reliable, provided the test is carefully standardised, and it is reasonably accurate for the estimation of $\dot{V}O_2$ max. It is also sensitive to training improvements, so although the value of $\dot{V}O_2$ max obtained will not be fully accurate, improvements in score will still indicate improvements in aerobic fitness. However, for other populations, alternative data are required to improve the accuracy of the estimation. For example, as the tables have been developed with adults free of disease, it is not possible to use the same tables to estimate $\dot{V}O_2$ max in children. Therefore, alternative equations have been developed for use with children. Note that due to the maximal nature of the test, it will not be suitable for people with pre-existing medical conditions who are not permitted to take part in maximal exercise.

Cooper's 12-minute run

There are several field-based tests where performance is assessed by the distance covered in a fixed period of time, or the time to complete a fixed distance. One such example was developed by Dr Ken Cooper (Dallas, Texas). This test simply requires participants to run/walk as far as they can in a period of 12 minutes, and the total distance is then entered into an equation to estimate $\dot{V}O_2$ max.

Advantages include:

- limited expertise and equipment needed
- maximal test (not a sub-maximal prediction) with continuous exercise
- easy to score
- large numbers can be tested at once in a short time.

Limitations include:

- prediction based on performance and not direct measurement
- maximal test (safety and ethical considerations, as well as importance of motivation)
- environmental factors influence performance as not in a laboratory
- the protocol is not progressive in nature and therefore pacing will be a key factor.

Similar to the MSFT, the test is widely used in non-clinical populations, and the same limitations do apply. As the protocol is continuous and self-paced, many performers are more comfortable with the test and may perform better than in the MSFT.

Harvard step test

Many tests used to estimate $\dot{V}O_2\text{max}$ do not involve maximal exercise. One of the oldest such tests is known as the Harvard step test, developed in the 1940s. Other commonly-used step tests include the Queens or McArdle step test.

The outcome measure for the Harvard step test is not performance, but the recovery of heart rate after performing a fixed amount of work. Participants are required to step on and off a 45 cm high step at a rate of 30 steps each minute for five minutes (a total of 150 steps). The participant's heart rate is measured at the end of the first, second and third minutes of recovery after the test. An equation is used to calculate the total of these three heart rate values to estimate $\dot{V}O_2\text{max}$, based on the association of a lower heart rate (and faster recovery) at a fixed intensity with higher $\dot{V}O_2\text{max}$.

Advantages include:

- limited expertise and equipment needed
- sub-maximal test (suitable for more participants) with continuous exercise
- the test is based on physiological findings and not performance (pacing and motivation will not affect the results).

Limitations include:

- prediction based on heart rate values
- does not account for individual variation in heart rate (not training-related)
- heart rate needs to be measured accurately, as small differences will impact on the result.

The main advantage of such a test is clearly that it does not require participants to exercise maximally, making it safer to conduct on a wide variety of participants. However, the test is less accurate unless alternative equations are used for differing populations. This test is more suitable for assessment of health-related fitness than sport-related fitness.

Key point

There are various tests available for estimating $\dot{V}O_2\text{max}$. Any estimation will introduce some error compared with direct assessment. However, field-based tests and sub-maximal predictions offer a range of advantages for the practitioner. The appropriateness of the test must be assessed against the relative strengths and limitations for use in specific contexts.

Activity 4

The above examples illustrate how to evaluate the suitability of fitness tests for use in assessing performance- and health-related fitness. For the following fitness tests related to the components of fitness, research what the test involves and evaluate the strengths and limitations of the test. Deduce the contexts in which you would (or would not) use each test.

- Body composition: body mass index (BMI), anthropometry and underwater weighing.
- Flexibility: the sit-and-reach test.
- Muscle endurance: maximum sit-ups, maximum push-ups, flexed arm hang.
- Agility: the Illinois agility test.
- Strength: the handgrip test using a handgrip dynamometer.
- Speed: the 40 m sprint.
- Balance: the standing stork test.
- Reaction time: the ruler drop test and also look at computer-based tests of reaction time.
- Power: vertical jump and standing broad jump.

Intensity

Intensity refers to the level of stress achieved during an exercise session, and intensity and duration of exercise are indirectly related. Exercise intensity can be expressed in many different ways, such as a percentage of maximal aerobic capacity ($\dot{V}O_2\text{max}$) or peak oxygen consumption, or by calculating the percentage $\dot{V}O_2$ reserve (the difference between $\dot{V}O_2\text{max}$ and resting oxygen consumption). These and similar gas analysis methods require graded exercise testing and the use of fairly expensive laboratory equipment (such as metabolic carts) to determine $\dot{V}O_2\text{max}$. Other indirect methods of quantifying exercise intensity that are easier to administer “in the field” as well as having additional benefits, such as being relatively inexpensive, include:

- the training heart rate concept
- the Karvonen method
- the training heart rate zone
- ratings of perceived exertion.

ATL Research skills

Distinguish between absolute and relative exercise intensity.

Training heart rate

The training heart rate (THR) is based on the linear relationship between heart rate and $\dot{V}O_2$ with increasing rates of work. The THR is calculated by using the heart rate that is equivalent to a set percentage of your $\dot{V}O_2\text{max}$. There can be various classifications of exercise intensity using per cent heart rate maximum ($\%HR_{\text{max}}$), for example:

- “light” exercise is 35%–54% HR_{max}
- “moderate” exercise is 55%–69% HR_{max}
- “heavy” exercise is 70%–89% HR_{max} .

The Karvonen or per cent heart rate reserve method (HRR) takes into account the difference between resting heart rate (HR_{rest}) and maximal heart rate (HR_{max}). The training heart rate is calculated by taking a percentage of HRR and adding it to the HR_{rest} . It is important to select an exercise intensity appropriate to the health needs and fitness status of the individual. For example, a sedentary individual about to begin an aerobic exercise programme might be well advised to target a “light” (say 35% HR_{max}) THR for the first few sessions (and gradually increase intensity over time) as follows:

$$THR_{35\%} = HR_{\text{rest}} + 0.35(HR_{\text{max}} - HR_{\text{rest}})$$

Technological advances allow heart rate monitors to measure exercise intensity as well as time in a target heart rate zone. The Karvonen method can also be used to establish a THR zone rather than a single THR value. For example, a recent study investigated time spent in the target heart rate zone and cognitive performance of nine-year-old children as part of the Fitness Improves Thinking (FIT) kids programme. The FIT programme is designed to improve the physical fitness of children and enhance their cognitive performance. The THR zone for the children was set to 55%–80% HR_{max} . This study also used the children’s OMNI scale to collect the children’s ratings of perceived exertion (RPE). This involved using the range of numbers 1–10 and child-like pictures to quantify how tired the child was during exercise testing.

ATL Research skills

1. Distinguish between the following RPE scales:
 - a. Borg
 - b. OMNI
 - c. CERT
2. Outline **two** reasons as to why it may be a more sensible approach to establish an exercise intensity THR zone rather than a single THR value.

Summary

- The inquiry process involves exploring and designing, collecting and processing data, and concluding and evaluating.
- Factors that must be taken into account when collecting data are accuracy, precision, reliability and validity.
- Reliability is the “degree to which a measure would produce the same result from one occasion to another”.
- Validity simply means that the test actually measures what it claims to measure.
- Experimental designs can be improved by the inclusion of a control group. Where appropriate the control group can take a placebo.
- Major components of physical fitness include body composition, aerobic capacity, strength, speed, power, muscular endurance, flexibility, agility, balance, reaction time and coordination.
- The Multistage Fitness Test (MSFT) and the Cooper 12-minute run are field-based tests designed to estimate $\dot{V}O_2\text{max}$.
- Monitoring exercise intensity can be quantified on the basis of the training heart rate or the rating of perceived exertion.

Check your understanding

After reading this chapter, you should be able to:

- understand the three stages of the scientific inquiry process
- discuss the importance of good study design in experiments
- outline the importance of accuracy, precision, reliability and validity in data collection
- describe the components of fitness
- outline why and how fitness is assessed
- discuss the advantages and disadvantages of field, laboratory, sub-maximal and maximal tests when examining human performance
- suggest ways of monitoring exercise intensity.

Internal assessment (IA) and practical work

Key point

Experimental programme

There are 40 teaching hours (SL) or 60 teaching hours (HL) of the SEHS course dedicated to the experimental programme. This includes:

- 1. Practical work:** 20 hours (SL) and 40 hours (HL).
- 2. Scientific investigation:** 10 hours. An assessed written report (3,200 words maximum) of a scientific investigation. Worth a total of 24 marks with a weighting of 24% of the SEHS final assessment.
- 3. Collaborative sciences project:** 10 hours; a non-assessed interdisciplinary collaborative piece of work. You are required to write a 100-word reflection.

Introduction

The experimental programme for IB Diploma Programme in sports, exercise and health science (SEHS) includes hands-on work both in the laboratory and in the field. The experimental work is a chance for you to gain and develop new practical and investigative skills and techniques. You should find this stimulating and challenging! When carrying out your experimental work, keep calm and remember that you are not penalized for seeking guidance. You should initiate discussions with your teacher to obtain advice and information. However, if you cannot complete this work without substantial support, you will not be able to gain full marks. As part of the learning process, your teacher can provide feedback on your first draft of the written report for your scientific investigation.

Aims of the SEHS experimental programme

The experimental work has several aims.

- It provides you with experience of methods and techniques used in sports, exercise and health investigations.
- It develops your ability to analyse, evaluate and synthesize scientific information.
- It strengthens your experimental and investigative scientific skills.
- It engenders your awareness of the need for, and the value of, effective collaboration and communication during scientific activities.
- It develops information and communication technology skills for the study of sports, exercise and health science.

Planning the scientific investigation

You will investigate and answer a research question that is of interest to you and is your own. For both SL and HL this assessed written report (3,200 words maximum) is compulsory and is worth 24% of your final assessment. The following are not included in the word count: charts and diagrams; data tables; equations, formulae and calculations; citations/references; bibliography; and headers. The investigation of the research question **must** involve the collection and analysis of quantitative data.

The techniques for data gathering and analysis that could be used in isolation or in conjunction with each other, are as follows: hands-on practical laboratory work, fieldwork, use of a spreadsheet for analysis and modelling, extraction and analysis of data from a database, and use of simulation.

Developing your research question and methodology

Your teacher will give you an open-ended problem to investigate and you must generate your own focused problem or specific research question. Make sure you choose an area you are interested in. Consider exploring an issue that you genuinely wonder about.

Some examples of some topics with teacher prompts for specific research questions relating to them appear in Table 1.

▼ **Table 1** Examples of topics for research questions

Topic	Teacher prompt
starting strategies	Which starting strategies optimise acceleration in sprinting?
sensory deprivation	What are the effects of sensory deprivation on performance?
practice	Does practice make perfect?
feedback	What is the effect of feedback on performance?
physical performance	How does your chronotype impact your physical performance?
fitness	What is the range of fitness levels in children with the same chronological age?
muscle fatigue	Compare the recovery-stress state of children 24-h and 48-h after a training session/competition.
cardiovascular response	Design an investigation to characterise the cardiovascular response to various stimuli.
joint movement	Compare the range of movements of joints of participants in different sports.
predicting future success	Investigate whether the results of physical or mental testing are strong predictors of future athletic success.
centre of mass	Investigate how the position of the centre of mass can affect athletic performance.
trajectories	Investigate the optimal range of initial projection angles for a basketball free throw.
body responses	Investigate the rate of sweat production in individuals with different fitness levels and/or different body mass.
assessment of physical activity	Compare rates of physical activity to sporting success or to the incidence of specific health conditions.
anthropometry	Investigate whether certain body dimensions affect the performance of sports skills, or correlate to specific health conditions.
models of motor learning	Investigate whether the rate of skill learning is related to methodology suggested by different models of motor learning.
response time	Investigate the effect of external or internal noise on response time.
motivation	Investigate if motivation levels affect learning rate.
psychological skills	Investigate if the implementation of a psychological skills program can influence performance.

Methodology for individual work

If you are working individually, you will investigate your research question by either:

- manipulating an independent variable,
- selecting variables during fieldwork, or
- selecting different data from an external database.

You may seek support from peers when collecting data.

Methodology for collaborative work

If you are working in a collaborative group, the methodology developed to answer your individual research question may be in part the outcome of collaborative activity. You will investigate your individual research question by manipulating either:

- a different independent variable to those selected by other group members,
- the same independent variable with a different dependent variable to those selected by other group members, or
- different data to that selected by other group members from within a larger communally acquired data set.

The final report must be your own work. A report by the group is not permitted. All authoring, including the description of the methodology, must be done individually.

Methodology using a school database

A school may take part in a large-scale activity collecting data to generate a database using standardized protocols. If you decide to use such a database to answer your research question, then the investigation must be treated as a database investigation. In such a case, the methodology should be focused on the way the data is filtered and sampled from the whole database in the same way as if the data was wholly acquired from an external source.

Assessing the scientific investigation

Your work for the scientific investigation is marked against four IA assessment criteria (research design, data analysis, conclusion, evaluation), with each criterion having a maximum mark of six. The marks for each of the criteria are added together to determine the final mark out of 24. This is the contribution the IA and practical work makes to your final mark for the course.

Your assessed written work for the scientific investigation may be externally moderated by the IB. External moderation aims to ensure that the practical component of the course has been carried out and that the standard of marking is standardized across all schools in the world doing the course.

Internal assessment criteria for both SL and HL

There are four IA criteria for the scientific investigation. The marks and weightings are shown in Table 2.

▼ Table 2

Criterion	Maximum number of marks available	Weighting (%)
research design	6	25
data analysis	6	25
conclusion	6	25
evaluation	6	25
Total	24	100

Research design

This criterion assesses the extent to which you effectively communicate the methodology (purpose and practice) used to address the research question.

▼ Table 3

Marks	Level descriptor
0	The report does not reach the standard described by the descriptors below.
1–2	The research question is stated without context.
	Methodological considerations associated with collecting data relevant to the research question are stated.
	The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	The research question is outlined within a broad context.
	Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described.
	The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	The research question is described within a specific and appropriate context.
	Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained.
	The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

Checklist for research design

- In the research question, are the independent and dependent variables fully described, with units and the correct unit of uncertainty, where applicable?
- Does the research question fully describe the system in which it is embedded?
- While referencing relevant scholarly works, does the background information discuss both the independent and dependent variables, and discuss why there might be a link between the two that is worth investigating?
- Does the background information help justify the chosen methodology?
- Have the choices of the conditions of the independent variable and the method of measuring the dependent variable been justified?
- Have all of the important variables been controlled and the reason for control justified?
- Will the method collect sufficient, relevant data?
- Have the confounding variables been discussed and mitigated where possible?
- Have your decisions regarding the subject selection and basic design been explained?
- Have you included a risk assessment that correctly identifies the risks to the subjects, and includes information on how the risks were mitigated?
- When using human subjects, have ethical issues such as informed consent, subject confidentiality and the right to withdraw been addressed?
- Is the method clear and repeatable?
- Have non-generic materials been listed?
- Have you added clarity to the method by including diagrams or images?
- If secondary data were used, have the data been verified by a second source, and is the process used to extract the data clear?
- If secondary data were used, was the confidentiality of the original subjects maintained?

Data analysis

This criterion assesses the extent to which your report provides evidence that you have recorded, processed and presented the data in ways that are relevant to the research question.

▼ Table 4

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	The recording and processing of the data is communicated but is neither clear nor precise.
	The recording and processing of data shows limited evidence of the consideration of uncertainties.
	Some processing of data relevant to addressing the research question is carried out but with major omissions, inaccuracies or inconsistencies.

3–4	The communication of the recording and processing of the data is either clear or precise.
	The recording and processing of data shows evidence of a consideration of uncertainties but with some significant omissions or inaccuracies.
	The processing of data relevant to addressing the research question is carried out but with some significant omissions, inaccuracies or inconsistencies.
5–6	The communication of the recording and processing of the data is both clear and precise.
	The recording and processing of data shows evidence of an appropriate consideration of uncertainties.
	The processing of data relevant to addressing the research question is carried out appropriately and accurately.

Checklist for data analysis

- Is the method of processing clear?
- Does the paper include sample calculations or a clear description of what spreadsheet formulae were used?
- Has/have the correct graph(s) been chosen, and are the data presented in a way that is clear to the reader?
- Have the data tables and graphs been correctly presented, and are there few to no errors in the use of SEHS-specific conventions?
- Where mathematically sound, have standard deviation, coefficient of variability or other measures of variability, such as standard error, been calculated?
- Are the unit uncertainties correct and justified?
- Has the variability of the data been discussed?
- Are the error bars on the graph(s) correct and have they been explained?
- Has the effect of the uncertainty and/or reliability of the data been discussed?
- Have outlying data been correctly determined, and correctly included or excluded?
- Has the correct inferential test been chosen, executed and interpreted properly?
- Will the processing allow a valid and detailed answer to the research question?

Conclusion

This criterion assesses the extent to which you successfully answer your research question with regard to your analysis and the accepted scientific context.

▼ Table 5

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	A conclusion is stated that is relevant to the research question but is not supported by the analysis presented.
	The conclusion makes superficial comparison to the accepted scientific context.
	Practical implications of the findings are stated.
3–4	A conclusion is described that is relevant to the research question but is not fully consistent with the analysis presented.
	A conclusion is described that makes some relevant comparison to the accepted scientific context.
	Practical implications of the findings are outlined.
5–6	A conclusion is justified that is relevant to the research question and fully consistent with the analysis presented.
	A conclusion is justified through relevant comparison to the accepted scientific context.
	Practical implications of the findings are explained.

Checklist for conclusion

- Does the conclusion answer the research question correctly and directly?
- Has the conclusion been justified by referring to the data and to the results of the inferential testing?
- Have you considered the strength of conclusion and its validity, considering uncertainty?
- Is the conclusion described in detail, and does it consider the system in which the research is embedded?
- Have you provided a scientific explanation for the conclusion, using scholarly sources not previously discussed?
- Do other, similar published studies justify the conclusion, or do they show that the result is not supported by other research?
- Are the implications presented practical, and are they explained with reference to a valid extension?

Evaluation

This criterion assesses the extent to which your report provides evidence of evaluation of the investigation methodology and has suggested improvements.

▼ Table 6

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	The report states generic methodological weaknesses or limitations.
	Realistic improvements to the investigation are stated.

3–4	The report describes specific methodological weaknesses or limitations.
	Realistic improvements to the investigation, which are relevant to the identified weaknesses or limitations, are described.
5–6	The report explains the relative impact of specific methodological weaknesses or limitations.
	Realistic improvements to the investigation, which are relevant to the identified weaknesses or limitations, are explained.

Checklist for evaluation

- Are multiple methodological weaknesses and/or limitations identified?
- Is there a description of the weaknesses or limitations?
- Is there a correct explanation of why and to what extent the weaknesses and/or limitations affected or limited the strength of the conclusion?
- Are the improvements suggested realistic and relevant to the stated weakness or limitations?
- Is there an explanation of why the suggested improvements would work?

The collaborative sciences project

The collaborative sciences project is a compulsory interdisciplinary sciences project, providing a worthwhile challenge to Diploma Programme and Career Programme students, addressing real-world problems that can be explored through the sciences. The nature of the challenge should allow you to integrate factual, procedural and conceptual knowledge developed through the study of your discipline.

Aims of the collaborative sciences project in SEHS, biology, chemistry, physics and computer science include:

- making connections between different disciplines
- developing the ability to approach unfamiliar situations with creativity and resilience
- designing or modelling solutions to local and global problems in a scientific context
- developing the ability to communicate and collaborate effectively
- developing awareness of the ethical, environmental, economic, cultural and social impact of science.

Additionally, the collaborative sciences project supports the development of your ATL skills, including team building, negotiation and leadership. It facilitates an appreciation of the environment and the social and ethical implications of science and technology.

The 100-word reflection

It is compulsory to write an individual 100-word reflection on completion of the project. The most authentic and valuable reflections are written as genuine commentaries on the experience—how you felt about it and benefited from it—rather than as lists of what was done. A copy of your reflection must be saved (on paper or electronically) as evidence of completing the collaborative sciences project.

Preparing for your exams

Format of the syllabus

The syllabus format (Figure 1) provides a lot of information that can help your study.

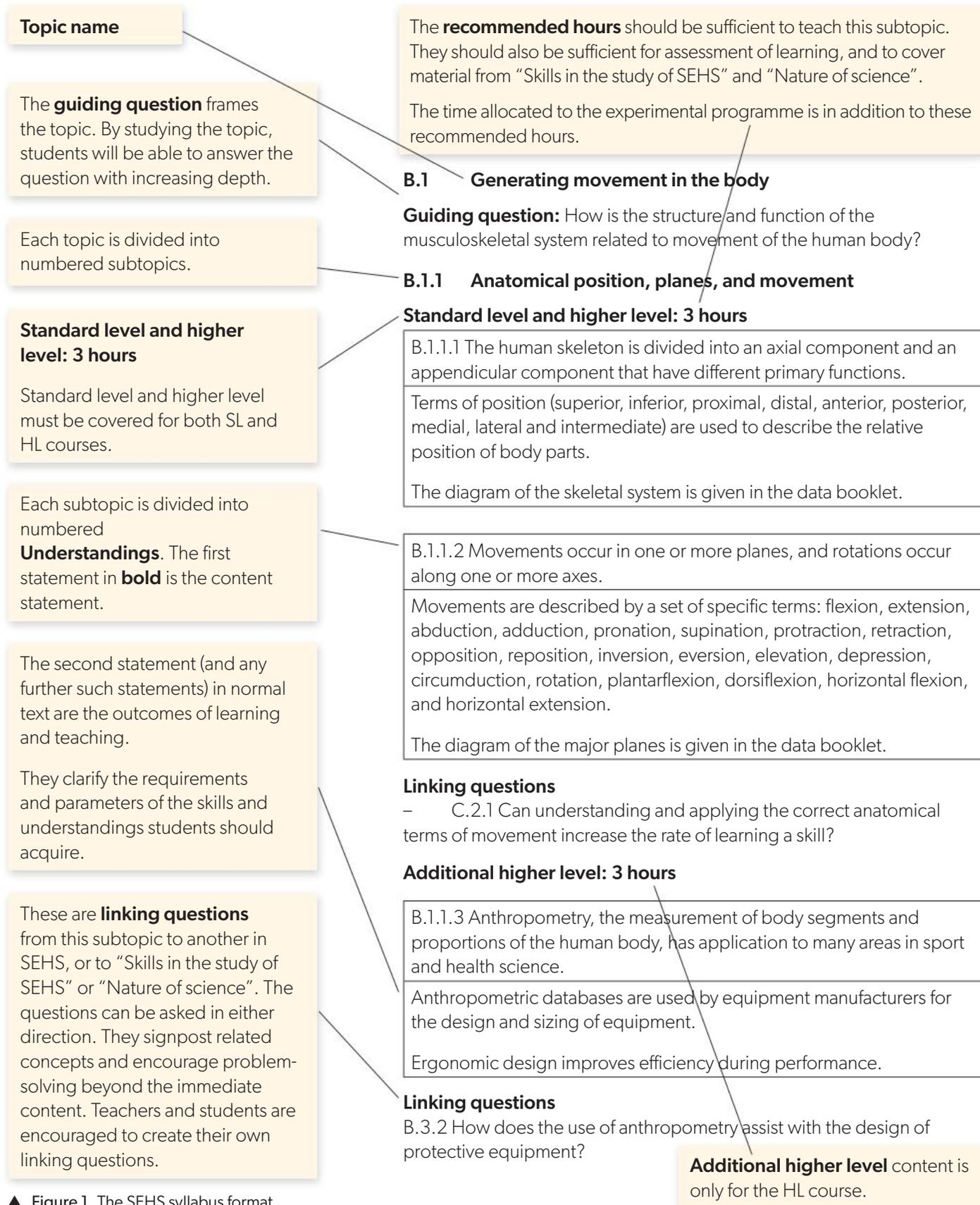
- The **guiding question** frames the topic.
- Each topic is divided into numbered **subtopics**.
- Each subtopic is divided into numbered **understandings**. The first statement is the content statement, and the second statement (and any further such statements) are the outcomes of learning and teaching.
- **Linking questions** signpost related concepts and encourage problem-solving beyond the immediate SEHS content, including links:
 - from one subtopic to another within SEHS
 - to “skills in the study of SEHS” (such as Tool 1: Experimental techniques)
 - to the overarching theme of the nature of science.

This course companion follows the same structure.

You need to be prepared to handle all aspects of the syllabus content for the level you are taking. This means that you need to put in significant time and effort to ensure that you know and understand the many different topics in the course.

Much of the information that you study is linked in some way. For example, your knowledge of anatomy will support your understanding of the regulation of body temperature.

Syllabus format



▲ Figure 1 The SEHS syllabus format

External assessment outline

A significant amount of your overall grade will come from the external examination.

- Marks from internal assessment = 24%
- Marks from external assessment (examination) = 76%

For both Standard Level (SL) and Higher Level (HL) the examination is made up of two papers, completed over two days: Paper 1 on day one and Paper 2 on the day after.

For all of the papers:

- the use of calculators is permitted
- you will have access to a clean copy of the *SEHS data booklet* during the examination
- the questions test assessment objectives 1, 2 and 3.

External assessment at Standard Level

Paper 1 is 1 hour and 30 minutes, has a weighting of 36% and a possible 55 marks. The paper is presented in two separate parts (Paper 1A and Paper 1B). You complete both parts together without interruption.

- Paper 1A (30 marks): 30 multiple-choice questions on SL material only; no marks are deducted for incorrect answers.
- Paper 1B (25 marks): data-based questions and questions on experimental work.

Paper 2 is 1 hour and 30 minutes, has a weighting of 40% and a possible 50 marks. There will be short-answer and extended-response questions on SL material only. All the questions are compulsory.

External assessment at Higher Level

Paper 1 is 1 hour and 45 minutes, has a weighting of 36% and a possible 65 marks. The paper is presented in two separate parts (Paper 1A and Paper 1B). You complete both parts together without interruption.

- **Paper 1A** (40 marks): 40 multiple-choice questions on SL and additional higher level material; no marks are deducted for incorrect answers.
- **Paper 1B** (25 marks): data-based questions and questions on experimental work.

Paper 2 is 1 hour and 30 minutes, has a weighting of 40% and a possible 80 marks. There will be short-answer and extended-response questions on SL and additional higher level material.

Command terms used in examination questions

Table 1 shows the command terms that may be used in exam questions. Each command term gives information about how to answer the question. Therefore, your ability to understand what the command terms mean is important. It will help you to answer the question in the way that has been asked. Spend time becoming familiar with these command terms.

▼ Table 1 Command terms

Objective 1	
Label	Add labels to a diagram.
List	Give a sequence of brief answers with no explanation.
State	Give a specific name, value or other brief answer without explanation or calculation.
Objective 2	
Annotate	Add brief notes to a diagram or graph.
Apply	Use an idea, equation, principle, theory or law in relation to a given problem or issue.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Outline	Give a brief account or summary.
Objective 3	
Analyse	Break down in order to bring out the essential elements or structure.
Compare	Give an account of similarities between two (or more) items or situations, referring to both (all) of them throughout.
Contrast	Give an account of the differences between two (or more) items or situations, referring to both (all) of them throughout.
Deduce	Reach a conclusion from the information given.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons or causes.
Interpret	Use knowledge and understanding to recognize trends and draw conclusions from given information.
Predict	Give an expected result.
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Suggest	Propose a solution, hypothesis or other possible answer.

Taking control of your own learning

In this course companion you will find plenty of relevant self-study questions to help you study.

You can condense, organise and refine your study notes by using techniques such as:

- bullet points
- condensing paragraphs into shorter sentences or keywords
- diagrams to summarise large amounts of information
- cue cards.

Your new, condensed notes are what you then read over. Reading aloud is a good thing to do. It should get to a point where you are not reading any more, but simply saying the content to yourself with your notes beside you (to remind you when needed). You need to engage with the material so that the level of your understanding is high. As your understanding grows, you will discover connections between the different aspects of the SEHS syllabus and beyond—all of this will assist you in remembering the information.

You will remember best if:

- you pay attention
- you are deeply engaged
- the information has meaning for you and it makes sense
- the information has connections.

There is no getting away from it: you have to put in a lot of time to ensure that you understand the material in this course. Those who develop good memory often do some of the following.

- Organise time well and set goals. This can be done with the aid of the Study plan chart, as shown on the next page. You must look at studying as you would at any training programme.
- Build up your brain endurance slowly (progressive overload) so you will be able to cope with the high demands. Start early.
- Provide plenty of rewards, treats or breaks. Exercise is a great reward as it will give you balance and works your heart and lungs to help you cope with stress. When it is really bad weather or time for just a short break, try juggling! Add the breaks to your chart.
- Insert your exam times so you are aware when they are. This can also help you decide where to put your subjects to ensure you have given balance to your plan.
- Study for periods of about 40–50 minutes with at least a 10 minute break between.
- Remember to hydrate yourself.
- Minimise distractions.
- Create a glossary of terms and ideas you have difficulty remembering or understanding. This can be done each week as you move through the topics. Sometimes you may feel like you are learning another language. It is important that you give yourself some time to understand these new terms.

- Create and complete a chart like the one in Figure 2. Each day has eight time slots to use. Adjust it to suit your needs. Put all of your commitments on the chart so you can plan around everything you do.

Study plan								
Date	Time slot	Mon	Tue	Wed	Thu	Fri	Sat	Sun
insert date								

▲ Figure 2

Useful resources

Resources that will help you with your studies include:

- the SEHS course guide: this has detailed information about the syllabus for the course and the skills you will develop
- this course companion and any other study resource booklets
- the internet (for example, you could search for “sliding filament theory” and look for an animated version)
- podcasts (for example, the Pacey Performance podcast) for interesting discussions on varied topics about high performance athletes.

Examination strategies

It is important that you have checked and double checked your examination time and place. You should also ask someone else to check this with you. It would be a tragedy to have put in many hours of study to then have this wasted because you had the wrong day or time written down.

Paper 1: The purpose of Paper 1A is to assess the breadth of common material at SL and additional higher level material at HL. At HL there will be a minimum of 15 questions common to the SL paper, and 20 questions on additional HL material.

You will have 1 hour and 30 minutes (SL) **or** 1 hour 45 minutes (HL) for this paper, which will be presented as two separate booklets.

Paper 1A

- Remember this is a multiple-choice (four possible answers; A–D) paper with 30 questions (SL) **or** 40 questions (HL).

- All questions are compulsory.
- There will be questions testing assessment objectives 1, 2 and 3, with a roughly equal split between assessment objectives (1 + 2) and assessment objective 3.
- Calculators are permitted, but the aim is not to test calculator skills (simple mental arithmetic should be enough to solve any calculations).
- When you are working through the questions it is critical that you take your time with each one by reading the question carefully and then looking at each of the possible answers. This will allow you to identify the best possible answer. If you rush yourself you may misinterpret the question.
- Consider using a highlighter to identify key phrases and terms. For example:
What is the **term** given to the **volume of air** comprising **vital capacity and residual volume**?
- Try to answer the question before you look at the answer options.
- Eliminate incorrect answers.
- Do not second guess yourself. Examiners do not write questions to trick you. Trust your instincts. Often your first response is the correct one.
- If you come across a difficult question that you are unsure of, skip it and move to the next one. This will give your brain time to process it, and you may be assisted by any one of the questions that follow it.
- At the end check your answer sheet for gaps and work on these first, then go back over each question again and check what you have put down. If there is still time, check again.

Paper 1B

The purpose of Paper 1B is to assess the experimental and fieldwork-based knowledge and understandings outlined in the SEHS skills and techniques. This paper is **not** used to assess syllabus-specific content. However, understanding of the nature of science (NOS) should also be assessed when appropriate.

- Remember, the questions are data-based as well as questions on experimental work.
- Questions will begin with some form of stimulus, such as a table of data or a graph. The initial questions will get you to draw information from this.
- There will be questions on experimental work/techniques. For example:
 - “Outline how the placebo effect could account for the change in performance shown on the graph.”
 - “Evaluate the use of the *t*-test to determine the significance of the results in Table 1.”
- Check the number of marks that the question is offering—this will indicate the number of points you need to make.
- The questions on this paper will test assessment objectives 1, 2 and 3. There should be a roughly equal split between assessment objectives (1 + 2) and assessment objective 3. However, there may be a slightly higher proportion of assessment objective 3 marks in Paper 1B to balance if there is a slightly lower proportion in Paper 1A.

- All questions are compulsory.
- Read the questions carefully to make sure you know what is being asked for.
- Check diagrams and tables carefully. Highlight units and look for a key to assist in interpreting the graph or table.
- Separate your ideas. Do not bundle all your answers into one long sentence.
- Check your spelling and use of terms. For example, *glycogenolysis*, *glucose*, *glucagon* and *glycogen* can be easily confused.
- In this paper, your understanding of the command terms is important.
- Graphic display calculators are permitted.

Paper 2

The purpose of Paper 2 is to assess the syllabus-specific content. Understanding of the NOS will also be assessed.

Paper 2 will be completed the next day and you will have 1 hour and 30 minutes (SL) **or** 2 hours and 30 minutes (HL) to complete this.

- At SL there will be short-answer and extended-response questions **on SL material only**.
- At HL there will be short-answer and extended-response questions on SL (common questions) **and** additional HL material.
- All questions are compulsory.
- Small items of stimulus material can be used for questions, but the aim of this paper is **neither** to assess specific experimental skills and techniques, **nor** to read information in a database.
- The questions will assess objectives 1, 2 and 3, with a roughly equal split between assessment objectives (1 + 2) and assessment objective 3.
- Check the number of marks that the question is worth as this will guide you as to how many points you need to make if this is not already stated in the question.
- Read the questions carefully so you are sure that you know what is being asked for.
- In this paper your understanding of the command terms is important.
- **No definition** questions will be asked.
- Graphic display calculators are permitted.
- Include units when answering a question.
- Separate your ideas. Do not bundle all your answers into one long sentence.
- Check your spelling and use of terms. For example, *glycogenolysis*, *glucose*, *glucagon* and *glycogen* can be easily confused.

Sample exam questions

These questions are taken from specimen papers, © IB Organization 2023.

Paper 1A

1. What is measured by the baroreceptor?
 - A. Blood pressure
 - B. Heart rate
 - C. pH of the blood
 - D. Carbon dioxide levels of the blood

2. A coach considers movement as a complex interaction between the body, the task and the environment. Which approach to motor learning is this?
 - A. Ecological theory
 - B. Schema theory
 - C. Open loop theory
 - D. Closed loop theory

3. Which factors contribute to the total force produced at a motor unit?
 - I. The number of muscle fibres
 - II. The muscle fibre type (type I or type II)
 - III. The size of the motor unit
 - A. I and II only
 - B. I and III only
 - C. II and III only
 - D. I, II and III

4. How will a surfer increase their stability to maintain balance on a surfboard?



◀ Figure 3

	Base of support	Centre of gravity
A.	high	low
B.	low	low
C.	low	high
D.	high	high

5. Which training set is likely to increase the energy available in the short term from the phosphagen system?
- Maximal intensity intervals lasting between 5 and 10 s with 60 s rest
 - High-intensity intervals lasting between 30 and 60 s with 10 s rest intervals
 - A long continuous bout of exercise lasting at least 25 min
 - A set of 10–12 repetitions of resistance exercise at 60%–70% of 1 maximum repetition
6. An elite sprinter runs the 100 m. They reach 50 m in 6.47 s and their velocity at this point is 11.5 m s^{-1} . They reach the finish in a time of 11.98 s, crossing the finish line with a velocity of 11.5 m s^{-1} .

What can be deduced from these data?

- The runner moves at constant speed during the race
- The runner reaches peak acceleration in the last 50 m of the race
- The runner moves at constant speed in the last 50 m
- The runner decelerates in the last 50 m

Paper 1B

1. In 2016, carbon fibre plate (CFP) shoes were introduced. The makers claimed that the shoes would improve times in long-distance running events.
- (a) The effectiveness of the CFP shoe was investigated by recording the running times of a female athlete. She competed in six 10 km races over a 10-week period, alternating between her usual shoes and a pair of CFP shoes.

▼ Table 2

	Mean 10 km time
Usual shoes	40 min 03 s (40.05 minutes)
CFP shoes	38 min 59 s (38.98 minutes)

- Calculate the percentage reduction in 10 km running time. [1]
 - Explain why the study selected only races taking place at sea level. [2]
 - Explain two weaknesses of a study design based on one athlete. [2]
2. An investigation compared the running economy of athletes on a treadmill wearing traditional or CFP shoes. Table 3 summarizes the athlete characteristics and Table 4 the rate of oxygen uptake ($\dot{V}O_2$).

▼ Table 3 Athlete characteristics

	Mean age (years)	Mean body mass (kg)	Mean 5 km personal best (min)
Male ($n=12$)	24.3 ± 4.5	66.5 ± 8.5	14.35 ± 0.38
Female ($n=12$)	23.0 ± 3.1	53.6 ± 4.4	16.64 ± 0.51

▼ Table 4 The rate of oxygen uptake, $\dot{V}O_2$, measured at two running speeds

Speed (km hr^{-1})	Athletes	Mean $\dot{V}O_2 \pm \text{SD}^*$ ($\text{ml kg}^{-1} \text{min}^{-1}$)	
		Traditional shoe	CFP shoe
14.0	male	44.72 ± 2.24	43.38 ± 2.21
	female	43.96 ± 2.70	42.55 ± 2.58
15.0	male	52.44 ± 2.14	51.26 ± 2.23
	female	52.32 ± 2.39	51.26 ± 2.27

*SD: standard deviation

- (a) **Interpret** the data in relation to the shoes. [3]
- (b) For the same shoe size, a traditional shoe had a mass of 118 g, and the CFP shoe had a mass of 205 g. **Explain** how this impacts the data. [2]
- (c) **Evaluate** the use of a *t*-test to determine the significance of the results in Table 4. [2]

Paper 2

1. In bobsled (or bobsleigh), a team aims to get the sled to the bottom of an ice track as quickly as possible. Figure 4 shows the push-off phase at the start, when two bobsled athletes push the sled to accelerate it down the ice track.



◀ Figure 4 Bobsled at the start of a race

- (a) **Explain** why the bobsled athletes wear spiked shoes. [2]
- (b) **Calculate** the average acceleration, in m s^{-2} , during the push-off phase. Use section 15 in the data booklet. [1]

Weight of the empty sled	1,700 N
Maximum weight of sled with two bobsled athletes	3,900 N (or mass of 390 kg)
Length of push-off course	50 m
Time for push off	6 s
Speed at end of push off	12 m s^{-1}

- (c) **Outline**, with reference to Newton's laws of motion, why the bobsled athlete's helmet has a foam core liner. [2]
- (d) **Distinguish** between outcome and performance goals for an elite bobsled team. [2]
- (e) **Explain** how strength training influences power output during the push-off phase at the start. [3]

Glossary

- A band** the middle part of the sarcomere that extends the length of the thick filaments; towards each end of the A band is a zone of overlap (both thick and thin filaments)
- abduction** opening of the joint angle around the sagittal axis at the joint
- ability** an inherited perceptual or motor attribute that enables performance of skills
- acceleration** change in velocity divided by the time taken for the change to take place
- acclimation** acclimatization in an artificial environment (for example, an environmental chamber)
- acclimatization** a natural adaptation, for example, to improve exercise performance and heat tolerance in a hot climate
- achievement motivation** a personality trait relating to an individual's desire to succeed in relation to their fear of failure
- active recovery** submaximal activity after fatiguing exercise, training or competition, with the aim of preserving performance level by enhancing recovery between exercise bouts
- acute injury** injury that occurs immediately or suddenly due to an excessive application of force
- adaptation** the body's attempts to counteract stressors, such as heat, humidity and cold
- adaptation (in the ecological model)** the continuous reorganization of components (that is, degrees of freedom) to satisfy the ecological constraints of competition
- adduction** closing of the joint angle around the sagittal axis at the joint
- adenosine triphosphate (ATP)** a molecule that provides energy for muscle contraction when it is split
- affordances (in the ecological model)** opportunities or possibilities for action offered by the environment
- agonist (mover)** a muscle that contracts concentrically to move the bone relative to the joint; a muscle whose contraction is responsible for producing a movement
- "all-or-none" principle** the rule that all of the muscle fibres attached to one motor neuron are either relaxed or contracted
- alternative hypothesis** the hypothesis or prediction that comes from your theory, saying that an effect will be present
- altitude** height above sea level
- amotivation** a state of lacking motivation or having a diminished sense of drive, interest or enthusiasm towards engaging in activities or pursuing goals
- anabolism** the constructive phase of metabolism where smaller molecules are converted to larger molecules
- angular displacement** the difference between start and end positions when a body moves around an axis with angular motion
- angular kinematics** the study of motion around an axis
- angular momentum** a measure of the amount of (or potential for) rotation
- angular velocity** the change of angular displacement divided by the time taken
- antagonist** a muscle that acts in the opposite direction to its usual concentric function, and gets longer even though it is contracting; a muscle that opposes the action of an agonist
- anterior** in front of or nearer to the front
- anteriorly concave** curves inwards at the front
- anteriorly convex** curves outwards at the front
- anthropometric data** data that measure human body dimensions, proportions and physical characteristics
- anti-diuretic hormone (ADH)** a hormone that causes the kidneys to retain fluids and reduce urine production
- anxiety** a temporary, ever-changing emotional state of subjective, consciously perceived feelings of apprehension and tension associated with activation of the autonomic nervous system
- appendicular component of the skeleton** has 126 bones and includes the pectoral (shoulder) girdle, the pelvic (hip) girdle and the bones of the upper and lower extremities
- appraisal** the process of evaluating a particular encounter with the environment
- arousal** the response to a stressor by the sympathetic nervous system
- associative phase** the phase of motor learning during which practice is required to perfect the skill and develop consistent, coordinative movement
- atrioventricular (AV) node** a specialist group of cells in the heart that cause the muscles in the walls of the atria to contract simultaneously
- atrophy** the loss of size, or mass, of body tissue, such as muscle atrophy with disuse
- attentional narrowing** the tendency of individuals to focus their attention on a limited set of cues or stimuli, while excluding other irrelevant information
- attribution theory** a theory that focuses on reasons used to explain successes and failures
- autonomic nervous system** a division of the peripheral nervous system that regulates involuntary bodily functions, such as heart rate, digestion and breathing
- autonomous phase** the phase of motor learning when the individual can perform consistently and with little overt cognitive activity
- autonomy-supportive coaching style** an approach that enhances decision-making and athlete's choice
- avoidance coping strategies** coping strategies that involve attempting to disengage from a stressful situation
- axial component of the skeleton** contains 80 bones and includes the skull, ribs, sternum and vertebral column
- balanced diet** a diet that provides all nutrients in the right amount to maintain health and prevent nutrient excess or deficiency diseases
- ball and socket joint** a class of synovial joint that can move in all directions and therefore has the greatest amount of movement
- barometric pressure (Pb)** the total pressure exerted on the human body by all the gases that make up the atmosphere
- baroreceptors** specialized nerve cells that detect higher or lower blood pressure
- basic psychological needs theory** a mini-theory of self-determination concerned with the three basic psychological needs (autonomy, competence and relatedness)
- Bernoulli principle** the rule that when fluid is moving (or a body or object is moving through it), the pressure it exerts reduces as its velocity increases
- "big five" personality traits** a model that presents five dimensions as the most important personality characteristics: openness, conscientiousness, extraversion, agreeableness and neuroticism
- blood pressure** the pressure in the arteries
- body mass index (BMI)** a measurement of body fat, calculated by dividing weight in kilograms by height in metres squared
- bone mineral density (BMD)** the main determinant of bone strength
- boundary layer** layer of fluid that experiences a change in velocity due to its proximity to a moving object
- brain stem** the part of the brain that connects the brain and the spinal cord
- broad attentional focus** perceiving several occurrences simultaneously
- bundle of His** a part of the conduction system of the heart
- buoyancy** a force acting vertically on objects immersed or partially immersed in a fluid
- burnout** a plateau in performance as a result of overtraining accompanied by a decrease in motivation to train
- cardiac output** the amount of blood ejected from the heart per minute
- cardiovascular disease (CVD)** a group of disorders of the heart and blood vessels
- cardiovascular drift** a phenomenon characterized by a rise in heart rate and a fall in stroke volume over time
- cartilage** a connective tissue that consists of a dense network of collagen fibres and elastic fibres
- cartilaginous joint** a type of joint in which the bones can be separated by a fibrocartilage disc or by a thick layer of hyaline cartilage
- catabolism** the destructive phase of metabolism where larger molecules are converted to smaller molecules
- catastrophe theory** a model to describe the combined effects of physiological arousal and cognitive anxiety on performance levels
- causality orientations theory** a mini-theory of self-determination concerned with the extent to which people are exposed to three types of causal orientations or environments
- cell respiration** the controlled release of energy in the form of ATP
- central fatigue** fatigue caused by factors that reside within the central nervous system (brain, spinal cord and motor neurons)
- central nervous system (CNS)** a division of the nervous system consisting of the brain and spinal cord
- centre of mass** the mathematical point around which the mass of a body or object is evenly distributed
- cerebellum** the part of the brain that governs balance and coordinates skilled movements
- cerebrum** the part of the brain that allows you to think, be aware of sensory stimuli and voluntarily control your movements
- chemoreceptors** specialized cells that detect chemicals in the mouth (taste), nose (smell) and body fluids
- chronic (overuse) injury** injury that occurs due to repeated application of force over time
- chronotype** characteristic that describes an individual's predisposition towards morning or evening alertness
- circadian rhythm** sleep-wakefulness cycle linked with responses of the pineal gland to cues from the environment (for example, daylight/darkness)

- circumduction** the “circling of a body segment at a joint, for example, moving the arm in a circle around the shoulder, such as in cricket bowling
- closed-loop control** when a movement can be altered during its execution, using feeling or feedback
- clutch state** a performance increment that happens under pressure
- coefficient of determination** a common criterion for interpreting the meaningfulness of a correlation
- coefficient of dynamic friction** a scalar quantity that reflects the characteristics of the surfaces in contact that are moving relative to each other
- coefficient of restitution** the variable that quantifies how much energy is conserved in a collision, mainly dependent on what materials the objects colliding are made of
- coefficient of static friction** a scalar quantity that reflects the characteristics of the surfaces in contact that are not moving relative to each other
- cognitive evaluation theory** a mini-theory of self-determination concerned with intrinsic motivation
- cognitive phase** the phase of motor learning during which the individual tries to make sense of instructions
- cognitive skill** a skill that emphasizes thinking rather than execution of movement
- collision** when two or more objects come into contact with (exert forces on) each other during a short period of time
- commitment** the ability to carry out tasks successfully, despite problems or obstacles
- concussion** injury that occurs due to force being applied to the head
- condyloid joint** a class of synovial joint in which an oval or egg-shaped convex surface fits into a reciprocally shaped concave surface
- confidence** maintaining self-belief despite setbacks
- congenital** present at the time of birth
- constraints-led approach** the mind, body and environment continuously influencing each other to shape the emergent behaviours of each individual
- continuous skills** tasks and activities that have no clearly defined beginning and end and a longer duration
- contractility** the ability of muscle to contract and generate force when it is stimulated by a nerve
- controlled distraction** methods that enable a performer to increase awareness of distractors and enhance their understanding of the task-relevant information
- controlling coaching style** an approach that involves giving directives, exerting pressure or controlling the athletes’ behaviour
- contusion** injury that occurs when a compressive force is applied to the muscle, bone or joint
- coping** cognitive and behavioural efforts to manage stressors
- correlation coefficient** a measure of how strong the relationship between two variables is
- critical power** a measure of the maximum power output that a person can sustain for a prolonged period of time without becoming fatigued
- cross-bridge cycle** the repeating sequence of molecular events that occur between the myosin heads (cross-bridges) and the actin filaments during muscle contraction
- cytokines** proteins that regulate the process of inflammation, which is common in all forms of tissue damage and is an important part of the healing process for damaged tissue
- “do-your-best” goals** a form of non-specific goal that challenges an athlete to perform as well as possible
- degrees of freedom (ecological dynamics theory)** the interacting components in the human body, as described in ecological dynamics theory
- degrees of freedom (statistics)** an input to the t-test based on the number of independent values
- depression** dropping or moving downwards (movement); also a common mental disorder with symptoms including low mood
- diabetes** a disease characterized by elevated blood glucose concentrations
- diencephalon** the part of the brain containing the thalamus and the hypothalamus
- dietary guidelines** recommended amounts of foods, food groups or meals
- dietary recommendations** recommended amounts of essential nutrients in the diet
- discrete skills** tasks and activities with a fixed beginning and end and short duration
- displacement** a change in position from one place to another
- distal** further away from where a limb attaches to the body
- distance** size of linear displacement
- diuretic** a substance that increases the rate at which urine is produced
- dorsiflexion** flexion of the ankle joint
- double-blind experiment** an experiment in which neither the participants nor the experimenters know who has been given the placebo
- drag** the force experienced when a body or object moves through a fluid, acting in the direction opposite to the motion of the body
- drive theory** the view that there is a direct and linear relationship between arousal and performance
- dynamic friction** the frictional force between surfaces that are moving relative to each other
- dynamical systems theory** an explanation of how complex systems with many interacting components, known as degrees of freedom, self-organize
- eccentric force** the force applied to create torque
- ecological dynamics theory** a model that describes how individuals continually reorganize the human movement system in response to perceived events
- effect size** an objective and standardized measure of the magnitude of observed effect. We can compare effect sizes across different studies that have measured different variables, or have used different scales of measurement
- effort arm** the distance at which the effort acts from the fulcrum
- ego (performance) climate** an environment in which comparison with others is the most important source of information for self-evaluation
- ego orientation** a perception of success focused on demonstrating superior ability compared with others and on winning in competitions with less effort than others
- elasticity** a muscle’s ability to return to its original resting length after the stretch is removed
- elevation** lifting or moving upwards
- emotion-focused coping strategies** coping strategies that attempt to manage the emotional consequences of the stressor (emotion)
- endocrine system** part of the body, consisting of all tissues or glands that secrete hormones, that works with the nervous system to regulate the human body and control the responses to physiological challenges
- energy systems** a set of catabolic reactions occurring within all cells whose principal function is generating ATP
- epidemiology** a branch of science that studies the occurrence, transmission and control of epidemic (widespread) diseases
- epinephrine** a hormone involved in regulating blood pressure, heart rate and blood sugar levels
- ergonomic design** design that takes into account the human body’s biomechanics (and physiology) to create equipment and environments that minimize discomfort and fatigue
- eversion** medial rotation of the ankle joint
- excess post-exercise oxygen consumption (EPOC)** period of recovery from exercise during which oxygen utilization continues at a rate greater than that needed at rest
- extensibility** the ability of muscle to be stretched beyond its normal resting length
- extension** opening of the joint angle around the frontal axis at the joint
- external** located on or near the surface
- external attentional focus** directing attention outwards
- external distractors** auditory or visual factors coming from outside an individual that affect concentration
- external risk factors** risks relating to outside the exercising person, for example, the environmental conditions or the playing surface
- extracellular fluid (ECF)** the fluid of the body outside of cells
- extrinsic feedback** information resulting from an action that is provided for us by someone or something else
- extrinsic motivation** results from external rewards such as money, trophies and prizes, and less tangible rewards such as praise and status
- extrinsic regulation** participation driven by external forces rather than our own desire
- fascia** a connective tissue that is located in between and surrounding other tissues of the body such as muscles and bones
- fast-twitch (type II) muscle fibres** muscle fibres that are better suited for anaerobic activity and play a major role in high-intensity activity
- fatigue** a disabling symptom in which physical and cognitive function is limited by interactions between performance fatigability and perceived fatigability
- feedback mechanism** a system for regulating an environment involving a receptor, a control centre and an effector
- fibrous joint** a type of joint that has a thin layer of fibrous tissue connecting the edges of two bones
- first-class lever** a lever with the effort force and the load force on opposite sides of the fulcrum
- fixator (stabilizer)** a muscle that contracts to prevent a body segment from moving so that the agonist may move the desired segment; a muscle that assists an agonist by preventing or reducing movement at another joint
- flexion** closing of the joint angle around the frontal axis at the joint
- flow state** a state characterized by focus and absorption in a specific activity
- follicular phase** the phase of the menstrual cycle between the last day of menstruation and ovulation
- force** the mechanical interaction that goes on between two objects or bodies
- form drag** drag caused by the shape of a body or object
- frontal axis** an axis of rotation of the human body, going from left to right
- frontal plane** a plane of movement of the human body, cuts the body from front to back
- frostbite** the continued cooling and freezing of cells
- frostnip** the initial freezing of the superficial skin tissue

- fulcrum** the fixed point about which a lever rotates
- galvanic skin response** measure of the continuous variations in the electrical characteristics (conductance) of the skin caused by the variation of the sweating activity of the human body
- gas exchange** the transfer of oxygen and carbon dioxide between the cardiovascular and respiratory systems, and body tissues
- generalized motor pattern** fundamental movement patterns that serve as the building blocks for more complex motor skills
- genes** sections of DNA that determine characteristics
- gliding joint** a class of synovial joint in which the surfaces of the bones are flat or slightly curved and they glide back and forth and from side to side across each other
- glucagon** a hormone involved in blood sugar regulation
- gluconeogenesis** the conversion of protein or fat into glucose
- glycaemic index** a measure of the ability of a food to raise blood glucose levels
- glycogen** the storage form of glucose
- glycogenesis** a process by which many glucose molecules are linked together to form glycogen
- glycogenolysis** the conversion of glycogen to glucose
- glycolysis** the breakdown of glucose to pyruvate
- glycolytic system** an anaerobic method of generating ATP
- goal contents theory** a mini-theory of self-determination that distinguishes between intrinsic and extrinsic goals
- goal orientation theory** the view that in achievement settings, such as sport and exercise, an individual's main concern is to demonstrate high ability and to avoid demonstrating low ability
- goal-setting paradox** the observation that athletes often feel less satisfied when a higher goal is achieved than an easier goal
- gravity** the force that acts between all objects with mass
- H zone** part of a sarcomere that contains thick but not thin filaments
- heart rate** the number of heart beats per minute
- high responder** individual who shows exceptionally large responses following a standardized training intervention
- hinge joint** a class of synovial joint that can bend (flex) or straighten (extend) in one direction only, for example the elbow joint
- homeostasis** the condition in which the body's internal environment remains relatively constant, within physiological limits
- horizontal extension** opening of the joint angle around the transverse plane when the body segment has already been flexed to 90 degrees
- horizontal flexion** closing of the joint angle around the transverse plane when the body segment has already been flexed to 90 degrees
- hormones** chemicals released by glands or tissues, to control and regulate the activity of other cells around the body
- hyponatremia** a condition in which the concentration of sodium in body fluid is too high
- hypertension** a long-term condition of high blood pressure
- hyperthermia** an elevated body temperature, usually above 39°C (102°F)
- hypertrophy** an increase in the size or mass of an organ or body tissue
- hypokinetic disease** a disease associated with a sedentary or inactive lifestyle
- hyponatremia** a condition in which the concentration of sodium in body fluid is too low
- hypothalamus** the part of the brain responsible for maintaining homeostasis
- hypothermia** low body temperature that has different clinical categories depending on the severity
- hypoxia** low partial pressure of oxygen in the air
- I band** part of a sarcomere that contains thin filaments but no thick filaments; a Z disc passes through the centre of each I band
- identified regulation** participation because we value the activity
- individual zone of optimal functioning (IZOF) model** a model centred on the view that elite athletes have a zone of optimal state anxiety in which their best performance occurs
- inferior (position)** below or further away from the head
- information processing model** a model to describe the processes of the CNS
- injury** a reduction or loss of bodily function or structure
- insertion** the end of a skeletal muscle that attaches to the bone being pulled
- insulin** a hormone involved in blood sugar regulation
- integrated regulation** participation because we feel the activity is a key part of ourselves
- interactionism** a view that personality is developed through a constant interaction between the person and their environment
- intermediate** between two structures, one of which is medial and one of which is lateral
- internal** located inside or further away from the surface
- internal attentional focus** directing attention inwards to thoughts and feelings
- internal distractors** feelings or sensations that are negative or unrelated to an individual's goal that affect concentration
- internal risk factors** risks relating to the person exercising or participating in physical activity
- interstitial fluid** extracellular fluid found in the spaces between the cells of tissues
- intracellular fluid (ICF)** the fluid of the body inside cells
- intrinsic feedback** information resulting from an action that is available to the performer without outside help
- intrinsic motivation** comes from within the person and is associated with doing an activity for itself and for the pleasure and satisfaction derived from participation
- introjected regulation** participation to avoid disapproval or feelings of guilt
- inversion** lateral rotation of the ankle joint
- inverted-U theory** the view that for complex tasks there is an optimal level of arousal above and below which performance levels will decrease
- isokinetic motion** when a muscle contracts so that the body segment to which it is attached moves at a constant speed around the joint
- isometric contraction** type of muscle contraction when the muscle contracts, but the rotational effect of the muscle force (muscle torque or moment) is exactly equal to that provided by the resistance
- isotonic concentric contraction** type of muscle contraction when muscles are actually drawn together
- isotonic eccentric contraction** type of muscle contraction when the muscle is contracting but the rotational effect of the muscle force (muscle torque or moment) is less than that of the resistance, so the ends of the muscles actually get further apart, even though the muscle is still contracting
- jet lag** a loss of synchrony between the internal circadian rhythms and the new destination time when multiple time zones are rapidly crossed
- joule (J)** a unit of energy; in nutrition, joules measure the energy obtained from food that is available through cell respiration
- kinematics** the study of motion
- kinetics** the study of the forces involved in the movement of an object or body
- Krebs cycle** a series of chemical reactions that occurs in the mitochondria which involves the oxidation of acetyl CoA to produce a large quantity of ATP
- laceration** injury that occurs when the skin or even muscle is cut by an external object
- lactate inflection point** the point at which blood lactate begins to accumulate substantially above resting concentrations during exercise of increasing intensity
- laminar flow** when the boundary layer has all the molecules moving in the same direction
- lateral** further away from the midline of the body
- lateral (outward) rotation** the anterior surface of the moving bone moves towards the lateral (outside) aspect of the body
- learned helplessness** an acquired condition in which an individual perceives that their actions have no effect on the desired outcome of the task or skill
- learning** a relatively permanent change in performance resulting from practice or past experience
- learning-focused goals** prioritize the acquisition of knowledge, skills and understanding rather than solely emphasizing the outcome or end result; includes both performance goals and process goals
- leukocytes** white blood cells
- level of arousal** the level of physical and psychological activation, from low arousal to high arousal
- lift force** a force acting perpendicular (at right angles) to the direction of motion of an object when travelling through a fluid
- ligament** a strong, flexible connective tissue that connects bone to bone
- linear impulse** force multiplied by the time that the force acts for
- linear kinematics** the study of motion in a straight line
- linear momentum** the property an object has due to its movement
- linear pedagogy** a view of skills learning that considers learning as a separate process that precedes performing
- lipolysis** the process of releasing triglycerides from the body's fat stores; excess fat is stored in adipose tissue and muscles
- load arm** the distance at which the load acts from the fulcrum
- longitudinal axis** an axis of rotation of the human body, going from top to bottom
- low energy availability (LEA)** a state in which the body has insufficient energy intake to meet energy needs
- luteal phase** the phase of the menstrual cycle between ovulation and the start of menstruation
- M line** part of a sarcomere consisting of proteins that hold the thick filaments together at the centre of the H zone
- macrocycle** an athlete's training programme for an entire year or season
- macronutrients** nutrients that our body needs in larger amounts to maintain health
- Magnus force** the lift force caused by a pressure difference due to rotation
- malleable** able to be changed
- mass** the amount of material in a body or object
- mastery (task) climate** an environment in which success is evaluated in terms of personal mastery and improvement and not in comparison with others

- maximal oxygen uptake ($\dot{V}O_{2\max}$)** an individual's maximal rate of oxygen uptake, which represents maximal aerobic capacity
- mechanical advantage of a lever** a measure of the efficiency of a lever in terms of the amount of effort required to move a particular resistance
- medial** closer to the midline of the body
- medial (inward) rotation** the anterior surface of the moving bone moves towards the medial (inside) aspect of the body
- menopause** the permanent cessation of menstruation, in most cases occurring naturally between the ages of 45 and 55 years
- mental fatigue (MF)** a state caused by prolonged periods of demanding cognitive activity that negatively affects physical and cognitive performance
- mental imagery** a psychological skill that involves using all the senses to recreate or create an experience in the mind
- mental toughness** an aspect of personality that partly explains how individuals manage challenging and pressurized situations
- mesocycle** a block of training composed of several week-long microcycles
- metabolic acidosis** a reduction in the normal pH of a fluid or tissue caused by the production of acidic substances
- metabolic equivalent of task (MET)** a measure of the energy expenditure of physical activity
- metabolism** all chemical processes in living organisms required for the maintenance of life
- microbiome** the collection of genomes from all the microorganisms in an environment
- microcycle** a weekly training programme
- micronutrients** nutrients that our body needs in smaller amounts to maintain health
- mindfulness** an approach centred around paying attention to the present moment in a non-judgemental way
- minute ventilation (VE)** the volume of air being exhaled per minute
- moment of inertia** how difficult a body or object is to rotate about an axis
- motivational climate** the environmental factors that lead individuals to view competence in different ways and pursue different goals
- motor nerves** nerves that send information from the CNS to tissues, organs and systems of the body
- motor skill** a skill that emphasizes movement and does not require much thinking
- motor unit** a single motor neuron and the muscle fibres that it innervates
- myofibrils** the contractile elements of skeletal muscle
- narrow attentional focus** focusing attention on a limited set of stimuli
- need achievement theory** the view that motivation is a balance between the motive to achieve success and the motive to avoid failure
- nervous system** part of the body that senses internal and external conditions and allows communication, coordination and interaction of tissues and systems
- Newton's first law** bodies or objects stay where they are or keep moving unless acted on by an unbalanced force (law of inertia)
- Newton's second law** force is equal to mass multiplied by acceleration (law of acceleration)
- Newton's third law** for every action there is an equal and opposite reaction (law of reaction)
- non-exercise activity thermogenesis (NEAT)** expenditure of energy during daily activities such as sitting, standing, walking and talking
- non-linear pedagogy** a view of skills learning in which learning activities are situated in performance settings
- non-responder** individual who shows exceptionally small or unchanged responses following a standardized training intervention
- non-shivering thermogenesis** a process by which the body generates heat in response to cold temperature exposure without shivering
- non-steroidal anti-inflammatory drugs (NSAIDs)** medication used both to alleviate pain and to reduce inflammation
- norepinephrine** a hormone involved in regulating blood pressure, heart rate and blood sugar levels
- null hypothesis** the hypothesis that states that there are no differences between treatments (or no relationships between variables)
- obesity** an excess of body fat that endangers health
- oestrogen** a reproductive hormone that has effects on sparing glycogen and joint stiffness
- open goals** a form of non-specific goal with an open-ended, exploratory nature
- open-loop control** when a movement is performed without alteration during its execution
- opposition** movement of the thumb across the palm to touch fingertips on the same hand
- organismic integration theory** a mini-theory of self-determination concerned with the four types of extrinsic motivation
- origin** the end of the muscle attached to a fixed bone
- osteoporosis** a condition characterized by low bone density
- outcome goals** relate to the outcome of an event, and usually involve a comparison with others
- overjustification effect** the observation that controlling events, such as monetary incentives, can make people feel controlled by others, which in turn decreases intrinsic motivation
- overreaching** pushing the body beyond its limits for a short period of time to stimulate a training response
- overtraining** training too often or at too high an intensity over a prolonged period of time
- oxidative system** the aerobic method of generating ATP, which is dominant during rest and periods of submaximal intensity
- parasympathetic nervous system** a division of the autonomic nervous system which has a major role in carrying out processes such as digestion, urination, glandular secretion and conservation of energy
- partial pressure of oxygen (PO_2)** the part of barometric pressure exerted only by the oxygen molecules in the air
- pathogens** microorganisms known to cause disease within our bodies
- perceived control** a tendency to feel and act as if one is influential
- perception-action coupling** the relationship between an athlete's actions and information from the environment in which those actions take place
- perceptual skill** a skill involving interpretation of environmental stimuli
- perceptual-motor skill** a skill involving interpretation of environmental stimuli and the motor response to this sensory information
- performance** a temporary occurrence, fluctuating over time
- performance goals** relate to a specific product of performance, which is normally relatively independent of others, that is, self-referenced
- periodization** the systematic process of changing one or more variables in a training programme over time to ensure the training stimulus remains challenging and effective
- peripheral fatigue** fatigue caused by factors that reside outside of the central nervous system, distal to the neuromuscular junction
- peripheral nervous system (PNS)** a division of the nervous system consisting of all the nerves outside of the CNS
- personality** an individual's characteristic patterns of thinking, feeling and behaving
- PETTLEP model of imagery** a model that provides a way of incorporating all the relevant senses into an imagery intervention (Physical, Environment, Task, Timing, Learning, Emotion, Perspective)
- phases of movement approach** an approach that categorizes movement into different stages: preparatory phase, force production phase, critical instant and follow-through/recovery
- phosphagen system** an anaerobic method of generating ATP involving creatine phosphate
- pivot joint** a class of synovial joint in which one bone forms a ring in which the other bone rolls or pivots allowing rotation of the joint
- placebo** a harmless treatment given to a control group that will not affect performance, used to reduce bias in study design
- placebo effect** an observed response to taking a placebo due to psychological variables
- plantarflexion** extension of the ankle joint
- polyphenols** a family of naturally occurring chemical compounds associated with health benefits
- posterior** behind or nearer to the back
- postpartum** following childbirth
- power** the rate at which work is performed, usually represented by the letter *P*
- power stroke** the tilting of the myosin head during the cross-bridge cycle
- prehabilitation** interventions that aim to reduce the likelihood of a muscle strain occurring via flexibility training, warm-up programmes or exercises completed to lower the risk of injury
- probiotics** live microorganisms that are considered to be health promoting
- problem-focused coping strategies** coping strategies that attempt to influence the person-situation relationship (problem)
- process goals** relate to the processes during the performance, that is, they are self-referenced and focus on technique or strategy
- progesterone** a reproductive hormone involved in the menstrual cycle
- projectile** the motion of an object that has been projected into the air or dropped and where the only forces acting on it are gravity and air resistance
- pronation** medial rotation of the radioulnar joint (not the wrist joint)
- proprioceptors** specialized cells located in muscles, tendons, joints and the inner ear which provide information about body position, muscle length and tension, position and movement of joints, and help maintain balance
- protraction** anterior movement of a body part in the transverse plane
- proximal** nearer to where a limb attaches to the body
- psychological refractory period** the increase in reaction time for a second stimulus when two stimuli are presented close together
- psychological skills** tangible steps that can be taken by an athlete to improve their psychological state
- psychological skills training (PST)** a change-based approach to improving performance using techniques such as imagery, goal setting, self-talk and arousal regulation
- Purkinje fibres** fast conducting fibres in the heart that spread impulses along the ventricle walls

- randomization** a process to randomly allocate individuals to groups in a study
- reciprocal inhibition** the reflex that when an agonist contracts to move a body segment, it is usual for the antagonist to relax
- recovery** a multilevel (for example, psychological, physiological, social) process that includes a broad range of physiological processes like sleep, motivated behavior (for example, eating and drinking) and goal-oriented components (for example, relaxation or meeting friends)
- relationships motivation theory** a mini-theory of self-determination concerned with relatedness as the third basic need
- relative energy deficiency in sport (RED-S)** a condition due to low energy availability (LEA) leading to impaired physiological function
- reposition** returning the thumb to its anatomical position next to the index finger
- resilience** the ability to rebound after failures
- resistance training** a general term used to describe exercises that cause the muscles to contract against an external resistance (for example, body mass, elastic bands or dumbbells)
- respiration rate** the number of breaths per minute
- resultant motion** the sum of the forces acting on an object
- retraction** a movement of a protracted part of the body back to the anatomical position
- running economy (RE)** steady-state oxygen consumption ($\dot{V}O_{2,max}$) at a given running velocity
- saddle joint** a class of synovial joint in which the bones are shaped like a saddle and a rider sitting in the saddle
- sagittal axis** an axis of rotation of the human body, going from front to back
- sagittal plane** a plane of movement of the human body, cuts the body from left to right
- sarcomeres** functional units that contain bands of contractile proteins called actin and myosin and are very important for muscle contraction
- sarcopenia** a decline in muscle mass and strength that often occurs along with the menopause
- scalar** a measurement that only has size
- schema theory** an explanation of motor programmes that includes both open- and closed-loop control
- second-class lever** a lever with the effort force and load force on the same side of the fulcrum, but with the effort arm longer than the load arm
- self-compassion training** a balanced, non-judgemental approach to relating to oneself when experiencing pain, inadequacy, suffering and failure
- self-efficacy** the expectation that people hold regarding their own capabilities for performance
- self-fulfilling prophecy** a concept that suggests our beliefs and expectations about ourselves or others can actually influence the outcomes we experience
- self-myofascial release (SMR)** self-massage techniques, such as the use of foam balls and rollers, which may assist recovery
- self-organization** the spontaneous adaptation of movement patterns based on perceived environmental changes or circumstances
- self-talk** the internal communication we have with ourselves
- sensory nerves** nerves that inform the CNS about what is going on within the body and outside the body
- shivering** involuntary contractions of skeletal muscle that produce heat
- sinoatrial (SA) node** a specialist group of cells found in the right atrium of the heart that generate electrical impulses causing the heart to contract and pump blood
- skill** a specific action (or the level of performance of an action) that has been learned through practice and which has a predetermined outcome or goal
- sleep disturbances** not only fewer hours spent sleeping but also increased movement during sleep that reduces the quality of sleep
- sleep hygiene** strategies, such as regular going to bed and wake-up times, a routine prior to going to bed, and a cool, quiet and dark bedroom environment, that appear to promote good sleep (efficiency, latency, onset and total sleep time)
- sliding filament theory** the sliding of many thousands of actin and myosin molecules, which makes the muscle contract
- slow-twitch (type I) muscle fibres** muscle fibres with higher aerobic endurance that are well-suited to low-intensity endurance activities
- social learning theory (SLT)** the process through which individuals acquire new behaviours, attitudes and skills by observing and imitating others
- somatic nervous system** a division of the peripheral nervous system that controls voluntary movements of the skeletal muscles
- speed** size of linear velocity
- standard error** the standard deviation of the sampling distribution of a statistic
- static friction** the force acting between two surfaces that are not moving relative to each other
- strain** injury that occurs when muscle fibres are stretched beyond their normal limit
- stress** a response of the body to a demand made upon it (a stressor) resulting in arousal of the sympathetic nervous system
- stressor** something that causes psychological strain
- stroke volume** the amount of blood being ejected from the heart with each contraction
- subordinate motor pattern** specific variations or refinements of generalized motor patterns
- superior** above or nearer to the head
- supination** lateral rotation of the radioulnar joint (not the wrist joint)
- surface drag** drag caused by the interaction between the surface of a body or object and fluid molecules
- sweat response** the main way for the body to lose heat during exercise
- sympathetic nervous system** a division of the autonomic nervous system that activates the “fight or flight” response
- synergist (neutralizer)** a muscle that contracts to prevent unwanted actions of the agonists or antagonists; a muscle whose contraction helps an agonist in an action
- synovial joint** the most commonly occurring type of joint in the body, providing mobility
- t-test** a statistical test to examine whether differences between group means is due to the exercise or is simply due to chance
- task orientation** a perception of success focused on mastery of the task, the learning of skills, exerting effort and self-improvement
- tendon** a tough, flexible band of fibrous connective tissue that connects muscle to bone
- testosterone** predominant male reproductive hormone which helps with bone formation, aids in muscle growth and repair, and also helps in the production of erythropoietin
- thalamus** part of the brain that is important for motor control
- thermoregulation** regulation of body temperature
- thick filaments (myosin)** type of filament contained in a myofibril
- thin filaments (actin)** type of filament contained in a myofibril, actually composed of three different protein molecules: actin, tropomyosin and troponin
- third-class lever** a lever with the effort and load forces on the same side of the fulcrum, but the effort arm is smaller than the load arm
- tidal volume (V_T)** the size of each breath
- to articulate** to form a joint
- torque** created when a force is applied to an object that is free to rotate around an axis, as long as the force is applied so that it does not act through the axis
- training** the systematic, repeated performance of structured exercise sessions over a period of time, with the achievement of a specific goal in mind
- trait-based approach** a view of personality that assumes that the constituent components of personality are relatively stable over time
- transverse plane** a plane of movement of the human body, cuts the body from top to bottom
- trauma** the sensation of pain, discomfort or loss of function
- travel fatigue** tiredness or exhaustion associated with a long journey
- tropomyosin** a protein that covers the myosin-binding sites on actin, preventing the binding of myosin heads and muscle contraction
- troponin** a protein to which calcium ions bind to initiate muscle contraction by moving tropomyosin off the myosin-binding sites (on actin)
- turbulent flow** when the molecules of the boundary layers get mixed up
- type I motor units** motor units consisting of mainly type I (slow-twitch) muscle fibres, which have fairly slow nerve transmission speeds and small muscle forces
- type IIa motor units** motor units consisting of mainly type IIa (fast twitch) muscle fibres, which have fast neural transmission times and stronger contraction forces and are also resistant to fatigue
- type IIx motor units** motor units that generate the fastest contraction times and largest forces, consisting mainly of type IIa (fast-twitch) muscle fibres
- uncertainties** variability in data that arises from random variations in experimental conditions, measurement errors and sampling bias
- undertraining** not providing the body with enough stimulation for performance to improve, by training too infrequently or at too low an intensity
- vasoconstriction** the narrowing of blood vessels (caused by contraction of the smooth muscle in the wall of the blood vessel)
- vasodilation** the widening of blood vessels (caused by relaxation of the smooth muscle in the wall of the blood vessel)
- vector** a measurement that has both size and direction
- velocity** change in displacement divided by the time taken for the change to take place
- wave drag** the opposing force caused by an object making waves in a fluid
- weight** the effect of the force of gravity on mass
- weightlifting** a competitive sport in which the athletes use barbells in competition to perform two competitive lifts: the “snatch” and the “clean and jerk”. In training, weightlifters may use both dumbbells and barbells as well as a variety of benches and racks. Weightlifting is governed internationally by the International Weightlifting Federation
- work done** the result of the application of a force over a distance, when energy is transformed from one form to another
- Z discs** separate one sarcomere from the next
- β-oxidation** the process of releasing energy from fatty acids

Index

- ability, skills relationship 447
acceleration 311, 131–16
acclimation in environmental chambers 33, 47, 52–4
acclimatization to environments 33–4, 40, 47, 52–4
accuracy in experimental data 607
achievement motivation 492–503
 goal orientation theory 497–500
 goal setting 580–1
 need achievement theory 497–8
Achilles tendon 288
acidosis 10, 209–11, 222–3
actin in muscles 101, 128, 211, 223, 289, 293–6
active lifestyle, health benefits 176–205
active recovery 233–4
adaptation, dynamical systems theory 463–4
adaptation to environments 33, 40, 53
adenosine triphosphate (ATP) 27, 28, 80, 127–9, 131–2, 134–5, 144–5
ADH *see* antidiuretic hormone
adolescents
 aerobic capacity 138
 developmental pathways 467–8
 growth rates 371
 injury risks 371, 372
 physical activity 176, 194, 196–7
 resistance training 370, 372
adrenalin *see* epinephrine
aerobic capacity *see* maximal oxygen uptake
aerobic fitness, thermoregulation 31, 34, 35
aerobic oxidative energy system 126, 130–2
aerodynamic resistance 354
 see also streamlining
affordances in environment inviting responses 465–6
age considerations
 maximal oxygen consumption 138–9
 recommended activity levels 197
 risk of injury 371, 372
 training programme considerations 159
agility 382, 389, 612
agonist muscle role 289–92
air density 340–3
air humidity 31, 48, 50, 342
air resistance 47, 335, 339–40
air temperature
 altitude effects 48
 see also cold environments; hot environments
alcohol 42, 117, 118, 236, 247
altitude
 acclimatization and acclimation 52–4
 effects on exercise and performance 47, 50–2
 responses 46–50
 training methods 54–5
anaerobic energy systems 132
anatomical body (starting) position 254
anatomy 61, 253–7, 263–6, 276
angular movement 311–13, 321–3
antagonist muscle role 289–92
anthropometry 263–4
antidiuretic hormone (ADH) 13, 16, 17, 80–2, 86
anxiety 537–44
 beneficial to performance 537
 caffeine effects 111
 cognitive 481, 538–41
 cognitive versus somatic 481, 538–41
 definitions 532, 537
 exercise relationship 139, 194–6, 198
 gut microbiome effects 122
 health anxiety 417
 hyperventilating 64–5
 immune system effects 179
 mental fatigue relationship 246
 nutrition relationship 189
 personality relationship 417
 sleep relationship 242
 somatic 538–41
 zone of optimal functioning 537
appendicular skeleton 254–5, 257
appetite
 altitude effects 50, 53
 overtraining syndrome 172
 regulation 16, 23, 117, 188, 189
appraisal, stressful situations 459
arousal 484–5, 525, 529–32
arterial-mixed venous oxygen difference 74–5
association and dissociation 488–9
associative phase of learning 456
ATP *see* adenosine triphosphate
ATP depletion, fatigue 220
attention control 476–91
 see also focus
attribution theory 439–40
autonomic nervous system 4–7, 25–6, 525, 529, 542
autonomous phase of learning 456
autonomy, motivation 508, 510–13
(AV)O₂ *see* arterial-mixed venous oxygen difference
average kinematics 313–14
avoidance strategies, coping 552, 561, 563
axes of rotation, joints 258–9
axial skeleton 254–6
balance *see* body stability; homeostasis
balanced diet 101–5
ball sports, coefficient of restitution 327
barometric pressure, altitude 46–8, 51
baroreceptors 11, 24, 26
basic psychological needs theory, motivation 509
bias in research 416, 434, 567, 606
“big five” personality traits 400–5, 417
biological sex differences
 athletic advantage 19
 body mass 31
 injury risks 159, 372–3
 maximal oxygen consumption 137–8, 139
 metabolic rate 101
 skeleton 257
 thermoregulation 31–2
 training programme considerations 159
biomechanical maladaptation, injuries 382–3
blood
 circulation 67–9
 flow distribution 71–2
 functions 66
 glucose regulation 12–13, 15, 16, 26–7, 133–5
 pH regulation 24
blood pressure 7, 11, 24, 69–72, 85, 87, 88, 184, 542
BMD *see* bone mineral density
body composition, fitness measurement 611
body composition and size, cold environments 39–40
body heat 27–31
body mass
 exercise effects 188
 heat/cold tolerance 35, 39
 monitoring dehydration 82, 84
 sex differences 31
body stability (balance) 318, 338, 611
body temperature
 core temperature versus skin temperature 218
 environmental effects 33–46
 hyperthermia 29, 31, 35, 36, 38, 214–15, 217–18
 hypothermia 23, 37, 40, 42
 normal core temperature 28–9
 thermoregulation 27–32, 38–9
bone mineral density (BMD) 191–4
bones 269–73
 dynamic tissue 271–2
 functions 270
 health 191–4, 272
 skeletal structure 254–7
 structure of bone 270–2
 types 269
 see also osteoarthritis; osteopenia; osteoporosis
brain 4–6
 acidosis impaired haemoglobin effects 222–3
 blood supply increased with exercise 195
 cardiovascular centre 26
 heat effects 36
 homeostasis 23–4, 26, 48
 hormone regulation 16
 hypoxia effects 50
 sensory and motor systems 9–11
 structure and function 4, 5–6, 9
breathing 60–4
buoyancy 342–3
burnout 227, 404, 438, 466
caffeine 111, 236, 247
calcium
 bones 191, 255
 fatigue 209, 211
 from diet 101, 119, 191, 272
 muscle contraction 211, 295, 296
carbohydrates 93–5, 105–10, 129–31
carbon dioxide 64–5
cardiorespiratory systems
 acute response to exercise 72–5
 functional capacity 74–5
 integration importance 58–9
 see also heart; respiratory system
cardiovascular disease (CVD) 183–7
cardiovascular drift 87, 88
cardiovascular responses to high altitude 49–50
cardiovascular system 66–73
cartilage 273–4, 275
causality orientations theory of motivation 509
cell respiration 127
central nervous system (CNS) 4, 9, 208, 283, 450–1
 see also brain; spinal cord
centre of mass 318, 322–3, 337–9
cheating in sport 327, 519
 see also unfair advantage
chemoreceptors 10, 24, 26, 48
children
 cardiovascular capacity 73, 74–5, 138–9
 developmental pathways 467–8
 injury risks 371
 learner-centred approach 471
 metabolic rate 29
 physical maturation and skill learning 448
 recommended activity levels 197
 scaling equipment and playing area 390
 thermoregulation 40
 variety in sport versus specialization 466
 see also adolescents
chloride 82, 101
“choking”, poor performance under stress 525, 533–4, 537, 540, 574
cholesterol 118, 131, 185, 186
circadian system 243–4
circulation 67–72
circumduction movements 261–2
climates *see* cold environments; global warming; hot environments; motivational climate
closed-loop control, motor skills 459
CNS *see* central nervous system
coaching styles 507, 510–12
coefficient of restitution 326–7
coefficient of variation 600
cognitive evaluation theory, motivation 508–9
cognitive phase of learning 456
cognitive skills 446
cold applications to aid recovery 232, 238–9, 392
cold environments 37–46
 see also frostbite/frostnip; hypothermia
collaborative sciences project 628
collisions, laws of motion 326–7
commitment, mental toughness 424–5
competencies
 perception 500, 508, 509, 512
 personality 406, 408
compression, acute injury 392
compression garments, recovery 237–8
concentration 476, 479–81, 483
 see also effortful awareness; focus

- concussion 373, 376–7, 379, 381, 388, 393–4
 conduction of heat 29–30, 41, 43, 217
 confidence *see* self-belief/self-confidence
 congenital factors, injury risk 374
 connective tissues 269–80
 constraints-led approach to skills acquisition 466–8
 continuous skills, movement analysis 361
 contractility of muscles 282, 283, 287
 contraction cycle in muscles 295
 controllable stressors, coping 565
 controlled distraction 480–1
 controlling behaviours/events/rewards, not motivating 495, 509–12
 contusion or compression injuries 379
 convection 29, 30, 38, 41, 217
 Cooper's 12-minute run test 616
 coordination, fitness measurement 612
 coping 548–71
 - appraisal process 549–51
 - avoidance strategies 552, 561, 563
 - categorization 551–3
 - controllability of stressors 565
 - definition 548–9
 - effectiveness of strategies 560–4
 - endurance activities 488–9
 - mental toughness 422–4, 426, 427, 432, 434
 - problem-focused versus emotion focused 551–3, 561–2
 - response 551
 - skills and strategies 554–60
- correlation in data 603
 cortisol 21, 133, 178, 228, 535, 542–3
 countdown to major event, stress 535
 CP *see* critical power
 creatine 111, 135, 220, 230–1
 creatine kinase 121, 132, 220, 288, 289
 creatine phosphate system 132
 - see also* phosphocreatine depletion
- critical power (CP) 142
 cross-bridges in muscle contraction 101, 295
 cryogenic chambers (cryo-chambers) 42, 232
 cryotherapy 232, 238–9, 392
 cultural biases in research 567
 cultural differences
 - body norms 617
 - diet 94, 102, 103
 - views of menstruation 164
- CVD *see* cardiovascular disease
- daily analysis of life demands for athletes (DALDA) questionnaire 181, 182
 dancers' health 272, 280
 data analysis, mathematical skills 598–604
 data collection and analysis, internal assessment 621–7
 data generation, measurement 465
 degrees of freedom 461–3, 602
 dehydration
 - in athletes 82–5
 - cold environments 38, 42, 43
 - definition 80
 - fatigue 214–16
 - high altitude 48, 50, 54
 - hormonal response 81
 - hot environments 31, 35, 36
 - monitoring status in athletes 82–5
 - rehydration after exercise 236
 - see also* thirst
- delayed onset muscle soreness (DOMS) 289
 depressive symptoms
 - exercise effects 196, 198
 - mental toughness 437–8
 - non-clinical versus clinical depression 194
- determination *see* mental toughness; self-determination theory
 developmental pathways 467–8
 diabetes 26, 134, 190–1, 201
 dialectic aspect of motivation 507
 diet *see* nutrition; supplements
 direction motivation 493
 disabilities, recommended activity levels 198
 discrete skills, movement analysis 359–60
 disengagement, coping 563
 displacement, kinematics 310, 312
 dissociation 488–9
 distraction
 - concentration disruption 479–81, 483
 - coping 563
 - diuretics 80, 111, 118, 216
 - DOMS *see* delayed onset muscle soreness
 - double-blind experiments 238, 416, 434, 606
 - do-your-best goals versus specific goals 579, 585
 - drag forces 343–50
 - drive theory of arousal 531
 - dynamical systems theory 460–3
 - dynamic friction 328
- eccentric contraction of muscles 287, 289
 eccentric forces 321
 - see also* torque
- ECF *see* extracellular fluid
 ecological dynamics theory 460–71
 ecological model of motor learning 449, 460–8
 efficiency of movement patterns 359, 361
 effortful awareness 415
 ego challenges, self-worth and identity threats 501
 ego-oriented individuals 497–501, 518, 581
 ego (performance) motivation climates 517, 519, 581–2
 elasticity of muscles 282, 283, 287
 electrolytes in body fluids 13, 17, 33, 79–82, 85–7, 101, 212–13
 electrolytes in drinks 87, 125, 236
 emotional stability 402, 421, 432, 439, 440
 emotion-focused coping strategies 551–3, 562
 emotions, imagery 591, 593
 endocrine system 3–4, 12–19, 27
 - see also* hormones
- energy balance 188
 energy deficiency in sport 113–16
 energy form interconversion 28
 energy status of body, measurement 224
 energy systems 126–47
 enteric nervous system 120
 environment
 - dialectic aspect of motivation 507
 - imagery 593
 - personality interaction 406
 - practising in similar environment to competition 467
 - projectile motion in different conditions 340–2
- environmental chambers for acclimation 33, 52–4
 environmental responses and adaptations 33–55
 - altitude 46–55
 - cold environments 37–46
 - hot environments 33–7
- epinephrine (adrenalin) 12, 14–16, 25, 133, 178, 525, 535, 542
 EPOC *see* excess post-exercise oxygen consumption
 equipment *see* protective equipment; sporting equipment
 design
 essential amino acids 98–9
 essential fatty acids 96, 97
 ethical issues 166–7, 173, 186, 225, 276, 531, 539, 578
 - see also* unfair advantage in sport
- evaporation 29, 30–1
 exam preparation 629–39
 excess post-exercise oxygen consumption (EPOC) 144–5
 executive motor programmes 458
 exercise benefits, mood states 176, 194–5, 198
 exercise intensity 135, 196, 618
 exhaustion, fatigue comparison 208
 experimental design 605–9
 experimental programme for internal assessment 621–8
 extensibility of muscles 282, 283, 287
 extracellular fluid (ECF) 79–81, 86, 101
 extrinsic motivation 494–5
 - see also* self-determination theory
- fairness *see* unfair advantage in sport
 fascia 274
 fatigue 206–25
 - causes 209–24
 - definitions 207–8
 - hot environments 36
 - impact on muscle contractions 224
 - mental fatigue 246–7
 - motivation relationship 224
 - overtraining 171–2
 - travelling 245–7
 - types 208
- fat mass and fat free mass in body 611
 fat oxidation 131–2
 fatty acids 12, 96–7, 103, 119, 120, 131–2, 135, 220
 fear 529–30
 feedback mechanisms 16, 17, 23–4, 80–1, 223, 450–1
 feedback (on performance) 362, 437, 460, 488, 494, 495, 509, 579–80
 Fick equation 74–5
 fixator muscle role 289, 291
 fixed mindset, goal setting 581, 582
 flexibility, fitness measurement 611–12
 flow, enhanced by imagery 590
 fluid mechanics 334–58
 focus
 - concentration relationship 476, 479
 - mental toughness 424
 - psychological state 415
 - shifting attention 478–9
 - strategies for perseverance 483
 - types of attentional focus 481
 - see also* concentration
- food *see* fuelling; nutrition
 foot movements 260, 261
 forces 314–15, 319, 321
 form drag 344–7, 348
 friction 327–9
 frostbite/frostnip 41–4
 fuel availability 219–22, 224
 fuelling 92–125
 fuel utilization 18, 39, 134–5
 gas exchange in lungs 63
 gastrointestinal system 112–13, 116–23
 gender reassignment 19
 gender, *see also* biological sex differences
 generalized motor patterns 459
 genetic factors
 - mental toughness 422
 - obesity 189
 - responses to training 165–7
 - role in performance 75
- GI *see* glycaemic index
 global warming 37
 glucagon 133
 gluconeogenesis 16, 26, 129–30
 glucose
 - blood testing 134
 - from food/drink 94–5, 108
 - hormonal regulation 12–13, 15, 16, 26–7, 133–5
 - metabolism 129–32
- glycaemic index (GI) 108–10, 229
 glycogen
 - depletion 221–2, 229
 - glucagon role in breakdown 13, 26
 - insulin role in synthesis 16, 27
 - muscle use in hot environments 33, 34
 - shivering effects 39
 - synthesis for storage 129
- glycogenesis 129–30
 glycogenolysis 13, 26, 129–30
 glycogen sparing 18, 19, 160, 161
 glycolysis 129–31
 glycolysis rate 222
 glycolytic system 132
 goal contents theory, motivation 510
 goal orientation theory 497–500, 581, 582
 goal-oriented imagery 591
 goal setting 409, 413, 573–89
 - achievability and adjustment of goals 583–4
 - achievement motivation theory 580–1
 - difficulty level 579, 583
 - effectiveness 578–9, 582–3
 - growth or fixed mindset 581, 582
 - motivation climate effects 581–2
 - recovery from injury 582, 583
 - SMARTER approach 413, 578, 580
 - specific versus non-specific 579, 585–6
 - types of goals 576–80
- goal-setting paradox 583
 gravity 314–15, 318
 growth hormones 15, 17, 133
 growth mindset, goal setting 578, 581, 582
 gut microbiome 116–23

Index

- habituation to cold environments 40
 Harvard step test 617
 health benefits of active lifestyle 176–205
 health effects of personality type 416–17
 health and safety *see* injuries
 heart
 cardiac cycle 67–8
 cardiac output 74–5
 intrinsic/extrinsic excitation 25–6
 regulation 24–6
 structure and function 67–9
 heart rate
 at high altitude 49–50
 CNS control 6–8, 10, 11, 25–6
 cold environments 39
 coping 559–60
 during exercise 10, 26
 hot environments 33, 34
 measurement 70, 618–19
 resting heart rate increase 169
 stress/arousal 530–1
 heat
 conduction 29–30, 41, 43, 217
 local thermal applications to aid recovery 238
 production in body 27–9
 transfer 29–31, 38, 41, 43, 217
 heat illness (heat stroke/heat exhaustion) 35
 see also hyperthermia
 heat stress 29, 33–5, 43
 high ego orientation, motivation 499–501
 high responders to training 164
 homeostasis 22–57, 58
 blood glucose regulation 26–7
 blood pH regulation 24
 body's adaptation to stressors 22–3
 body temperature regulation 27–32
 disturbed by exercise 208, 226
 feedback mechanisms 16, 17, 23–4, 80–1
 heart regulation 24–6
 water balance 80–1
 hormones 12–19
 appetite effects 118–19, 188
 energy metabolism 133–4
 impact on health and performance 17–19
 regulation 16–17
 types 14
 see also endocrine system; female reproductive hormones; male reproductive hormones
 hot environments 33–7, 143
 human research ethics 531, 578
 humidity 31, 48, 50, 342
 hydration
 recovery 235–6
 see also water balance
 hydration status, monitoring in athletes 82–5
 hydrogenated fats 97
 hydrogen ions (H⁺) 10, 24, 131, 209–10, 220
 see also acidosis; pH
 hypermobility 263, 273, 280, 374, 611–12
 hypernatremia 87
 hypertension 184
 hyperthermia 29, 31, 35, 36, 38, 214–15, 217–18
 hypertrophy 286
 hyperventilation 64–5
 hypohydration 217
 see also dehydration
 hypokinetic disease 182–3
 hyponatremia 86–87, 212–213
 hypothalamus 6, 16–17, 23
 hypothermia 23, 37, 40, 42
 hypoxia at altitude 46–53
 hypoxic chambers 52–4
 ICF *see* intracellular fluid
 identified regulation, motivation 505, 509, 512
 identity perception, ego challenges 501
 imagery 555, 590–7
 immune system
 exercise effects 177–82
 long-lasting arduous exercise effects 178
 maintaining health in athletes 181
 overtraining effects 170–1, 180–1
 stress effects 178–9
 impulse–momentum relationship 320
 impulse principles 319–20
 inactive lifestyle risks 182–94
 individual zone of optimal function (IZOF) 537
 inertia 315, 321–3
 inflammation
 biochemical regulation 13, 170, 231
 cold/heat therapies 283
 injuries/tissue damage 13, 170, 280, 289, 391–3
 joint stiffness 18
 polyphenol-rich foods 231
 information processing model, motor learning 449–60
 injuries
 acute versus chronic 380–1
 age effects 371, 372
 biomechanical maladaptation 382–3
 causes 367–85
 external risk factors 370–1, 374–8
 inflammation 13, 170, 280, 289, 391–3
 initial treatment 390–1
 internal risk factors 370–4
 interventions 386–97
 movement analysis to avoid 361, 362
 musculoskeletal types 378–80
 personal protective equipment 375–7, 387
 prehabilitation to reduce 158, 386–9
 recovery 391, 394, 582, 583
 recurrence 372, 375
 rehabilitation 287, 372, 391, 393, 562
 resistance training risks 370, 372
 risk assessment 367–70
 risk reduction strategies 386–90
 risks in pregnancy 373–4
 rules to reduce risk 265, 387, 388
 sex differences 159, 372–3
 training effects 372
 inquiry process 605–20
 inspiration, self-efficacy 414
 instantaneous kinematics 313
 insulin 13, 15, 16, 26–7, 133–5, 201
 see also diabetes
 integrated regulation, motivation 505, 509, 513
 intensity motivation 493
 interactionism, personality 406–7, 415
 interdisciplinary approach to learning 471–2
 internal assessment 621–8
 interquartile range 600
 inter-system communication 2–21
 intracellular fluid (ICF) 79, 80, 101
 intrinsic motivation 494–5
 see also self-determination theory
 introjected regulation, motivation 505, 509, 511, 512
 inverted-U theory of arousal 532
 iron in diet 49, 101
 isokinetic motion 287
 isometric muscle contraction 287, 288
 isotonic muscle contraction 287, 288
 IZOF *see* individual zone of optimal function
 jet lag 245, 246
 joints 273
 anatomical sex differences 138
 cartilage 270, 273–4
 connective tissues 273–5
 hypermobility 263, 273, 280, 374, 611–12
 movement 258–63, 273, 278
 muscular contractions 287–8
 oestrogen effects 18, 160
 range of motion 263
 role of muscles 289–92
 skeletal anatomy 257
 stability 273, 275, 278
 structure 275–6
 types 273, 275–7
 kidneys 17, 49, 80–3, 85, 230
 kinematics 309–14
 kinetics 314–31
 laboratory tests versus field tests 614
 lactate inflection point 126, 141–3
 lactate system 111, 129, 130
 lactate threshold 34, 54
 lactic acid versus lactate production 141–2, 209–10
 lamina flow 348
 LEA *see* low energy availability
 learned helplessness 436–7, 579
 learning
 coping skills 556, 558
 exam preparation 633–4
 imagery 593
 phases 456–7
 psychological skills training 574–6
 transfer to performance 466
 versus performance 447–8
 see also motor learning
 learning curves 457
 learning-focused goals 577–9, 585
 levers 300–7, 321
 lift forces 350–3
 ligaments 273, 275
 linear impulse principle 319
 linear kinematics 310–11
 linear momentum principle 319
 linear pedagogy 449–60, 469–70
 lipids and fats 96–7, 131–2
 long-term memory (LTM) 452, 453
 low energy availability (LEA) 113–16
 lung volumes 62
 macronutrients 93–9
 Magnus force 352–3
 malnutrition 92, 98–9
 mass and weight 315
 mastery (task) motivation climates 517–19, 581
 mathematical skills 598–604
 maximal oxygen uptake/consumption ($\dot{V}O_{2\max}$)
 absolute and relative 137
 aerobic fitness measure 74, 610, 615–18
 aerobic training effects 139–40
 age and sex effects 137–9
 at high altitude 50–3
 cold environments 43
 endurance 137–43
 hot environments 32
 pregnancy 374
 training effects 139–42
 maximal tests versus sub-maximal tests 614
 measurement
 data generations 465
 fitness assessment 609–19
 kinematics 310, 313
 mechanics
 fluids 334–58
 forces and motion 309–33
 kinematics 309–14
 kinetics 314–31
 levers 300–7
 work and power 329–31
 memory, motor learning 452–4
 menopause 18, 191, 192, 201–2
 menstrual cycle 17–19, 31–2, 102, 107, 114, 159–64
 mental fatigue (MF) 246–7
 mental health
 exercise effects 194–6
 see also anxiety; depressive symptoms
 mental practice, attention control 482
 mental toughness 421–43
 aerobic fitness relationship 139
 attention narrowing prevention 485
 attributes 422–5
 depressive symptoms/burnout/sleep 437–8
 development/improvement 426–32
 environmental conditions 45
 measuring 432–3
 mindfulness 426–8
 overreaching 489
 overriding fatigue 225
 psychological skills training 426–7
 recovery from injury 394
 self-compassion 429–32
 see also resilience
 metabolic acidosis, role in fatigue 209–10, 222–3
 metabolic equivalent of task (MET) 45, 183, 184
 metabolic rate
 at high altitude 50, 53

- energy balance 188
sex differences 101
thermoregulation 29, 30, 34, 39
- metabolic syndrome 186–7, 201, 202
- metabolism 126–34
- MF *see* mental fatigue
- micronutrients 93, 99–101
- mindfulness, mental toughness 426–8
- minerals in diet 100–1
- minute ventilation (V_e) 63–4
- mitochondria 126–7, 129, 131, 215, 231
- modelling (vicarious experiences) 413–14
- moments of inertia 312, 321–3
- momentum
angular 322–3
principles 319–20
- mood states
exercise benefits 176, 194–5, 198
see also anxiety; depressive symptoms
- motion
drag forces 343–50
Newton's laws 309, 315–31
projectiles 334–42
study of (kinematics) 309–14
see also movement
- motivation 492–523
achievement motivation 492–503
definitions 493–4
goal orientation theory 497–500
goal setting 576, 577, 579–82, 585
intrinsic and extrinsic 494–5
intrinsic–extrinsic continuum 504–5
need achievement theory 495–7
organismic-dialectic approach 507–8
reward types 494, 495
self-determination theory 504–15
skill learning 448
- motivational climates 395, 516–23, 581–2
- motor learning 444–91
attentional focus 485–9
curves 457
linear pedagogy 449–60, 469–70
linear versus non-linear approaches 449–50, 469–70
non-linear pedagogy 449, 460–70
phases 456–7
processes 445–75
rate variations 448
transfer between tasks 448
- motor patterns 459–60
- motor programmes 458–9
- motor units of muscles 284–6
- movement
analysis 359–65
axes of rotation and planes of movement 258–9
laws of motion 309–33
levers 300–7
through air and water 334–58
types of joint movements 258–63
variability for coordination skills 468
- Multistage Fitness Test (MSFT) 615–16
- muscles
atrophy 286
chronic soreness 170
contraction mechanics 293–6
contraction types 287
control of forces 296
energy needs 128–9, 135, 144–5
fascia 274
fibre types 284–5
filaments 293–6
functions 281–2
hypertrophy 286
internal structure 293–6
motor units 284–6
properties 282–3
reciprocal inhibition 291–2
relaxation 287, 291–2
sarcopenia 201
types 281
- muscular endurance, fitness measurement 610
- muscular system 281–99
- musculoskeletal injury types 378–80
- myofascial release *see* self-myofascial release
- myofibrils 293–6
- myosin in muscles 101, 128, 211, 223, 289, 293–6
- need achievement theory of motivation 495–7
- needs, *see also* psychological needs
- negative feedback, physiological processes 16, 24, 80–1
- nervous system 3–11
control of heart rate 8
coordination of sensory and motor systems 8–10
gastrointestinal system relationship 120
organisation 5
structure and function 4–7
- neuromuscular function 283–6
- neurons, structure 283–4
- Newton, Sir Isaac 314, 315
- non-linear pedagogy 449, 460–71, 488–9
- non-responders to training 165, 167
- non-steroidal anti-inflammatory drugs (NSAIDs) 113, 289, 393
- norepinephrine (noradrenalin) 12, 25, 178, 196
- normative data, regional and cultural factors 618
- NSAIDs *see* non-steroidal anti-inflammatory drugs
- null hypothesis and alternative hypothesis 608–9
- nutrition 92–125
appetite suppression through overtraining 172
at high altitude 50
balanced diet 101–5
ballet dancers 272
bone health 272
elements of diet 92–101
macronutrients 93–110
metabolisable energy 126
micronutrients 93, 99–101
recovery relationship 229
for sports people 104–15
see also supplements
- nutritional ergonomic aids 111–12
- nutritional status 92
- obesity 92, 187–9, 201
- oestrogen 13, 14, 17–19, 93, 159–62, 191, 201
- older adults, exercise 197, 200–3
- open-loop control, motor programmes 458–9
- open (non-specific) goals 586
- open window model of overtraining 179–81
- orderly recruitment principle, muscle fibres 286
- organismic-dialectic approach to motivation 507–8
- organismic integration theory 509
- osteoarthritis 187, 275, 278
- osteopenia 201, 217
- osteoporosis 183, 191–3, 201, 202, 271
- OTS *see* overtraining syndrome
- outcome goals 577, 579, 585
- over-justification effect 509
- overreaching 150, 169, 171, 180, 226, 489
- overtraining 150, 151, 167–73, 180–1, 226–7, 379, 437, 595
see also burnout
- overtraining syndrome (OTS) 168–73, 226
- overuse (chronic) injuries 381
- oxygen deficit 144–5
- oxygen uptake ($\dot{V}O_2$)
physiological function marker 59
see also maximal oxygen uptake
- pacers in races 349–50
- parasympathetic nervous system 5, 7, 8, 11, 24–6, 529, 541
- PAR-Q *see* Physical Activity Readiness Questionnaire
- partial pressure of oxygen at altitude 46–53
- pedagogy, linear versus non-linear approaches 449–71
- perceived ability, ego orientation 500–1
- perceived control 424, 426, 566
- perception–action coupling 464–5
- perception of competence, motivation 508, 509, 512
- perceptual-motor skills 447
- perceptual skills 446
- perceptual trace, skill learning 459
- perfectionism 404, 405
- performance
learning transfer 466
overtraining syndrome 169
stress/arousal effects 531–2
versus learning a skill 447–8
- performance (ego) motivation climates 517, 519
- performance goals 481, 577–80, 585
- performance profiling 412–13
- periodized training programmes 153–7
- peripheral nervous system (PNS) 4–5
- personality 339–420
athletic success contribution 403–5, 412, 573
definition 400
health relationship 416–17
interactionist approach 406–7
malleability 432
measurement 403
motivation/need achievement 407, 493, 496
placebo effect 607
potential for change 404–5, 409, 415–16
self-efficacy 410–15
social-cognitive theory 406, 410–15
social learning theory 407–9
stress responses 402, 416, 560
trait-based approach 400–5, 416–17
type A and type B 416–17
see also mental toughness
- persuasion, self-efficacy 414–15
- PETTLEP model of imagery 592–3
- phases of movement, movement analysis 359–61
- pH imbalance
fatigue 209–11
see also acidosis
- phosphagen system 132
- phosphate accumulation, fatigue 223–4
- phosphocreatine depletion, fatigue 220–1
- Physical Activity Readiness Questionnaire (PAR-Q) 613–14
- physical literacy 471
- physical testing, fitness 609–19
- physiological testing, responses to exercise 58–9
- physiotherapists 386, 390–1, 562, 583
- pituitary gland 16
- placebos 238, 299, 606, 607
- planes of movement 258–9
- PNS *see* peripheral nervous system
- polyphenols 117, 231–2
- polyunsaturated fatty acids 97, 102
- postpartum period 199–200, 373–4
- potassium 80, 101, 212–14
- power
fitness measurement 610
output in sport 330–1
work relationship 329–31
- practical work, internal assessment 621–8
- precision in experimental data 608
- pregnancy 198–200, 373–4
- prehabilitation/warm-ups 158, 386–9
- problem-focused coping strategies 551–4, 557, 561–2
- process goals 577–80, 585
- progesterone 13, 14, 17–19, 31–2, 93, 159–62, 201
- progression of exercise intensity 196
- progressive overload, training principle 151–2
- projectile motion 334–42
- projecting objects, levers 303
- proprioceptors 10, 26
- protective equipment 375–7, 387
- proteins in diet 98–9, 110, 229
- PST *see* psychological skills training
- psychological differences 398–443
- psychological factors in injury risk 374
- psychological needs theories 505–6, 509
- psychological refractory period 455–6
- psychological skills 572–97
definitions 573
effectiveness 574
goal setting 573–89
imagery 590–7
mental toughness 426–7
- psychological skills training (PST) 426–7, 574–6
- psychological state, self-efficacy 415
- psychological theories and constructs 592
- qualities of training 149–75
- questionnaires 182, 228–9, 432–3, 517, 520–1, 523, 538, 553, 613–14
see also self-reported data
- radiation of heat 29, 30, 38, 43, 217
- range of motion (ROM), at a joint 263, 264, 287
- RE *see* running economy

Index

- reaction, Newton's third law 316
 reaction time 454–6, 612
 rebreathing 64–5
 receptors
 hormones 14, 26
 sensory 10–11, 24, 26, 48
 reciprocal inhibition 291–2
 recovery 206, 226–44
 assessment and monitoring 228–9
 inadequacy leading to immunosuppression 180–1
 mental fatigue 246–7
 sleep 239–46
 techniques 232–9
 in training 150, 152
 recovery from injury *see* injuries
 RED-S *see* relative energy deficiency in sport
 rehabilitation after injury 287, 372, 391, 393, 562
 relationships motivation theory 510
 relative energy deficiency in sport (RED-S) 114–16, 121, 164, 168, 193, 272, 374
 relaxation of muscles 287, 291–2
 relaxation skills, coping 555, 559–60, 562–3
 reliability in experimental data 608
 repetitive drills, linear approach to skills learning 469
 research design, internal assessment 624–5
 resilience 422–3, 425, 563, 576
 see also mental toughness
 resistance (weight) training, injury risk 370, 372
 respiration *see* breathing; cell respiration
 respiratory responses, cold air 43
 respiratory system 60–5
 anatomy 61
 breathing 60–4
 chemoreceptors 10, 24
 cold air responses 43
 high altitude responses 48–9
 integration with cardiovascular system 58–9, 74–5
 role in heat exchange 30, 31
 response time 454–5
 response to training 148–251
 rest *see* recovery; sleep
 resting heart rate 88, 169, 618
 resultant motion, sum of acting forces 314
 reversibility, training principle 151
 reward types, motivation 494, 495, 512
 risk assessment, injuries 367–70
 ROM *see* range of motion
 routines, attention control 481
 running economy (RE) 140–1

 sarcopenia 201
 saturated fatty acids 97, 102
 schema theory, motor learning 449, 459
 scientific studies
 inquiry process 605–20
 mathematical skills for data analysis 598–604
 SD *see* standard deviation
 SDT *see* self-determination theory
 selective attention 453–4, 476, 477
 self-belief/self-confidence
 attribution theory 440
 feedback from others 460, 561
 imagery 592, 594
 mental toughness 422, 423, 425, 426, 434–6
 perceived ability/competence 500, 508, 509, 512
 self-fulfilling prophecies 434–7
 self-compassion 429–32
 self-determination theory (SDT) 504–15
 application 510–13
 intrinsic–extrinsic motivation continuum 504–5
 mini-theories 507–10
 psychological needs 505–6
 self-efficacy, personality 410–15
 self-myofascial release (SMR) 236–7
 self-organization of complex systems 461–3
 self-regulation skills, recovery 248
 self-reported data 403, 404, 417, 432–3, 489, 538, 543–4, 549, 564
 see also questionnaires
 self-talk, coping 555, 557–8, 564
 self-worth, ego challenges 501
 senses, imagery using all 590, 591
 sensory function of nervous system 3, 8–10

 sensory information store (SIS) 452
 sensory input, motor learning 451
 sensory receptors 10–11, 24, 26, 48
 sesamoid bones 269
 sex differences *see* biological sex differences
 shifting attentional focus 476, 478–9, 481
 shivering 24, 30, 37–9, 40, 162, 282
 short-term memory (STM) 452–3
 signal detection, motor learning 451–2
 single channel theory of selective attention 453, 455
 situation awareness 476, 478
 skeletal system
 anatomy 254–7
 anthropometry and ergonomic design 263–6
 appendicular skeleton 254–5, 257
 axial skeleton 254–7
 bones 269–73
 joints and movement 257–63
 skills, characteristics and classification 445–7
 skills-oriented imagery 591
 sleep 239–46
 benefits of active lifestyle 176, 195
 circadian system 243–4
 disturbance in athletes 170, 171, 240–2
 hormonal effects 15, 19
 mental toughness 438
 quality 118
 SLT *see* social learning theory
 SMARTER approach to goal setting 413, 578, 580, 582
 SMR *see* self-myofascial release
 social-cognitive theory 406, 410–15
 social learning theory (SLT) 407–9, 516
 social support importance 554, 561, 580
 sodium 80, 82, 86–8, 101, 103, 212–13, 236
 somatic nervous system 4
 specificity, training principle 151
 specific versus non-specific goal setting 579, 585–6
 speed, fitness measurement 612
 spinal anatomy 256
 spinal cord 4–6, 9, 255, 283, 284
 sporting equipment design
 cycling 331, 354, 377–8
 ergonomic design 264–6
 friction 329
 optimizing power output 331
 scaling for children 390
 surface minimizing drag 344
 swimming 264, 331, 349
 stability of joints 273, 275, 278
 stability, *see also* body stability; emotional stability
 standard deviation (SD) 598–600
 standard error calculation 600–1
 static friction 328
 step tests for aerobic capacity 617
 STM *see* short-term memory
 strain type injuries 379
 streamlining 345–7
 see also aerodynamic resistance
 strength measurement 610
 stress 524–71
 anxiety 537–44
 arousal 525, 529–32, 538, 540–2
 badly managed goal setting 578
 burnout 438
 categories 526–7
 definitions 526, 528, 529
 hormones 21, 178, 535
 immune system effects 178–9
 physiological effects 529–31
 physiological origins 525
 transactional model 536
 see also burnout; mood states
 stressors
 controllability 565
 environmental 32, 33
 homeostasis 22–3, 33
 past and future 550, 551
 stretching 234–5
 stubborn responders 167
 subordinate motor patterns 459–60
 summing joint forces principle 319

 supplements 111–12, 120–2, 123, 230–2
 surface drag 343
 sweating 30–1
 sympathetic nervous system 5–8, 11, 24–6, 529, 541
 synergist muscle role 290–1
 synovial joints 258, 275–7

 TARGET approach 518–19
 Task and Ego Orientation in Sports Questionnaire (TEOSQ) 517, 520–1
 task-involved goals, achievement motivation 581–2
 task (mastery) motivation climates 517–19
 task-orientation 497–9, 581
 temperature *see* air temperature; body temperature
 tendons 274, 288
 TEOSQ *see* Task and Ego Orientation in Sports Questionnaire
 testosterone 14, 15, 18, 19, 114, 159
 thalamus 6
 thermoregulation 18, 27–33, 38–9, 73, 88, 161–2
 thirst 6, 23, 33, 81, 82, 89, 216, 236
 thought control, coping strategies 555
 THR *see* training heart rate
 torque 289, 291–2, 321–4
 tough-mindedness *see* mental toughness
 trace elements in diet 100–1
 training
 baseline values and progress measures 157
 definition 150
 effects on injury risk 372
 individual responses 164–7
 principles 151–3
 qualities 149–75
 undertraining 150
 see also overtraining
 training heart rate (THR) 618–19
 training status assessment 157, 159
 trait-based approach to personality 400–5
 transactional model of stress 536, 549
 trans fatty acids 97, 102
 transport of oxygen 58–77
 trauma, injuries 170, 367, 380–1
 travel fatigue 245–7
 trigger words, attention control 481
 troponin and tropomyosin in muscles 296
 t-tests 601–3
 turbulent flow 348
 type A and type B personalities 416–17

 ultra-endurance events/ultramarathons 32, 33, 86, 91, 422, 438
 unattainable goals 583–4
 uncertainties in data analysis 601
 uncontrollable stressors, coping 565–6
 undertraining 150
 unfair advantage in sport 13, 19, 225, 327, 331, 349, 354
 upper respiratory tract infections (URTIs) 121, 172, 179–80
 urine analysis 82–3

 validity in experimental data 608
 variety, training principle 152
 vasoconstriction/vasodilation 5
 V_e *see* minute ventilation
 velocity 310–14
 ventilation *see* breathing
 vicarious experience, self-efficacy 413–14
 vitamins 99–100
 $\dot{V}O_2$ *see* oxygen uptake
 $\dot{V}O_{2\max}$ *see* maximal oxygen uptake

 wake, objects moving through a fluid 344, 348, 349
 warm-up *see* prehabilitation
 water
 as a micronutrient 93
 see also dehydration; hydration
 water balance 49, 80–1
 water and electrolyte balance 79–91
 wave drag 347
 weight (resistance) training, injury risk 370, 372
 wind chill 41
 wind speed, effects on motion 340–2
 work and power 329–31

 zone of optimal functioning, anxiety 537

Oxford Resources for IB
Diploma Programme



2024 EDITION

SPORTS, EXERCISE AND HEALTH SCIENCE

COURSE COMPANION

Written by an expert and experienced practitioner, and developed in cooperation with the IB, this 2024 edition of the DP Sports, Exercise and Health Science course book provides:

- A comprehensive and accurate match to the latest IB DP Sports, Exercise and Health Science specification, delivering in-depth coverage of all topics for both SL and AHL
- Guidance for inquiry and support for developing deep conceptual understanding within the subject through case studies and linking questions
- A focus on both acquiring knowledge and mastering subject-specific skills, with a dedicated mathematical tools chapter and ample opportunities for practice
- Complete alignment with the IB philosophy, featuring ATL skills, Nature of Science and Theory of Knowledge support woven throughout
- Thorough preparation for IB assessment via self-study and data-based questions, plus dedicated sections for the inquiry process and the internal and external assessments.

To enhance your teaching and learning experience use this course book alongside the Kerboodle course. Kerboodle is a digital learning platform that works alongside your print textbooks to create a supportive learning environment and to enable success in DP and beyond.

Also available
in this series:



9781382042635



FOR FIRST ASSESSMENT IN 2026



www.oup.com

How to get in touch:

web www.oxfordsecondary.com/ib
email schools.enquiries.uk@oup.com
tel +44 (0)1536 452620

ISBN 978-1-382-04264-2



9 781382 042642