



NELSON

# PHYSICAL EDUCATION

Rob Malpeli, Rachael Whittle, Monique Sharp,  
Mark Corrie, Amanda Telford

Rob Malpeli *Coordinating Author*

VCE Units

3+4



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Nelson Physical Education VCE Units 3&4 Student Book

7th edition

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ISBN 9780170480994

Senior Product Manager: Caroline Williams

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Editor: Nick Tapp

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Series Designer: Nikita Bansal

Cover Design: Everyday Ambitions (Emilie Pfitzner)

Text Design: Alba Design (Rina Gargano)

Cover image: snaptitude/Adobe Stock

Permissions researcher: Lumina Datamatics

Content Manager: Jess Lovell

Typeset by: Lumina Datamatics

Any URLs contained in this publication were checked for currency during the production process. Note, however, that the publisher cannot vouch for the ongoing currency of URLs

#### Acknowledgments

Tables 10.10 and 10.11 were first created by Topend Sports, using as an initial guide the fitness ratings for  $VO_2$  max scores, combined with the formula for estimating  $VO_2$  max from Yo-Yo test results (as published by Bangsbo et al., 2008), as well as adjusting the norms based on test results from a range of athletes from the same paper and other known test results from a range of athletes of varying fitness levels. <https://www.theyoyotest.com/results.htm>. Selected VCE Examination questions and extracts from the VCE Study Designs are copyright Victorian Curriculum and Assessment Authority (VCAA), reproduced by permission. VCE® is a registered trademark of the VCAA. The VCAA does not endorse this product and makes no warranties regarding the correctness or accuracy of this study resource. To the extent permitted by law, the VCAA excludes all liability for any loss or damage suffered or incurred as a result of accessing, using or relying on the content. Current VCE Study Designs, past VCE exams and related content can be accessed directly at [www.vcaa.vic.edu.au](http://www.vcaa.vic.edu.au)

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#### National Library of Australia Cataloguing-in-Publication Data

A catalogue record for this book is available from the National Library of Australia.

#### Cengage Learning Australia

Level 5, 80 Dorcas Street  
Southbank VIC 3006 Australia

For learning solutions, visit [cengage.com.au](http://cengage.com.au)

Printed in China by 1010 Printing International Limited.  
1 2 3 4 5 6 7 27 26 25 24



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# HOW TO USE THIS BOOK

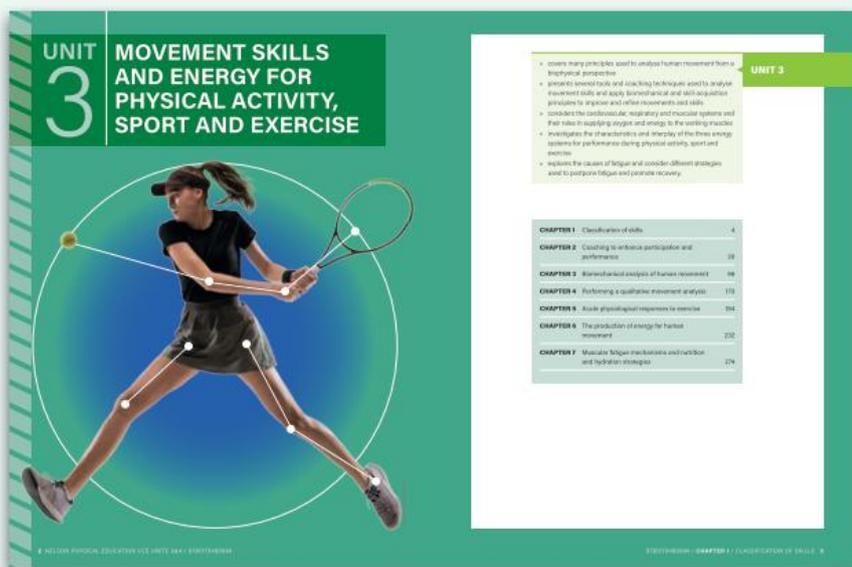
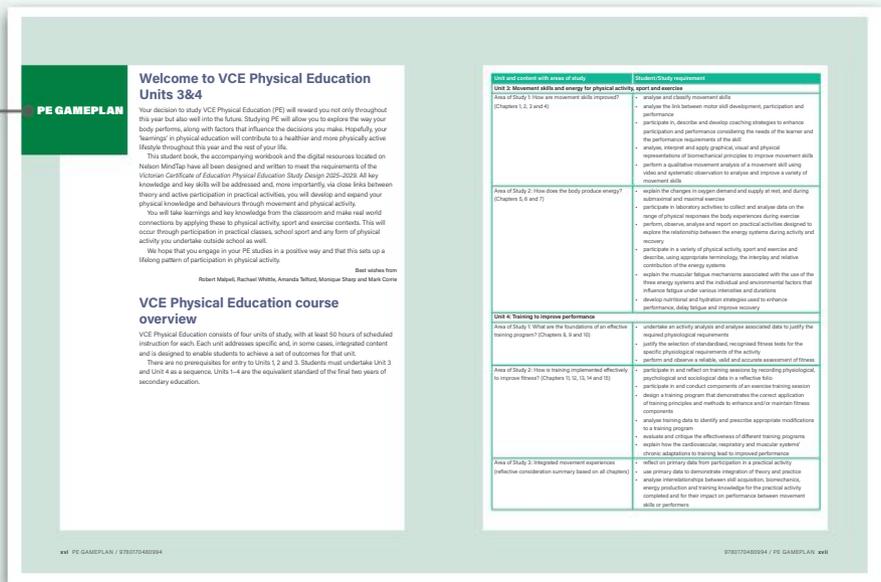
Nelson Physical Education VCE Units 3 & 4 provides a complete teaching and learning solution designed to engage and support VCE Physical Education students.

Written to comprehensively support the revised *Victorian Certificate of Education Physical Education Study Design (2025–2029)*, this edition has been informed by our highly experienced author team's deep expertise, up-to-date research and evidence-based pedagogical approaches to learning and assessment. The result is a fresh approach to this trusted series with a renewed focus on maximising opportunities for all students to actively engage, explore, practise and critically apply their key knowledge and skills.

Our expert author team have seamlessly interwoven explicitly aligned coverage of the content in the revised Study Design with preparation for both internal assessment and the end-of-Year 12 exam to help build students' confidence in their knowledge, equipping them for exam success and ultimate study score attainment.

## STUDENT BOOK FEATURES

The **PE Gameplan** section at the beginning of this student book provides students with a toolkit that they can refer to throughout the course. The PE Gameplan covers key concepts and skills, including unpacking data literacy, a glossary of command terms in a VCE Physical Education context, and in-depth advice on preparing for and tackling the end-of-year exam with valuable insights and useful tips.



**Unit opener** pages provide an overview of the content that will be covered across the chapters in this unit.

**CHAPTER 2**  
**COACHING TO ENHANCE PARTICIPATION AND PERFORMANCE**  
UNIT 3 - AREA OF STUDY 1



**KEY KNOWLEDGE**

- considerations when coaching to enhance participation and performance:
  - ecological factors that affect skill development
  - characteristics of the three stages of learning
  - types of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches
  - psychological skills (confidence, motivation, optimal arousal and concentration) and encouraging strategies
  - to receive and to provide feedback including type (open and closed), distribution (immediate and delayed) (and quality by feedback and receiver)
  - frequency and type of feedback including intrinsic and augmented knowledge of results and knowledge of performance

**KEY SKILLS**

- participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill

Source: Victorian Certificate of Education Physical Education Study Design (2023-2026)

**QUIZZES**

Chapter 2 Pre-test  
2.1 Check 3 questions  
2.2 Check 3 questions  
2.3 Check 3 questions  
2.4 Check 3 questions  
2.5 Check 3 questions  
Chapter 2 Review questions

**VISION**

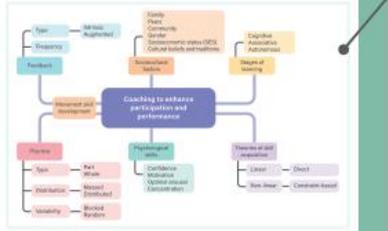
Masterplan Chapter 2  
Reflect on the Vision, Mission and Values of your school and the VCE Physical Education program

**RESOURCES**

2.6 To explore motor learning and skill acquisition  
Chapter 2 book-embedded QR code

Nelson MindTap  
To access resources online visit [ceegiga.com.au/nelsonmindtap](http://ceegiga.com.au/nelsonmindtap)

Concept maps at the beginning of each chapter clearly show the relationship between key concepts in the Study Design.



Study Design alignment is signposted throughout, including on the chapter opening page. Chapters are organised to explicitly follow the structure of the Study Design and are divided into modules to better support students.

Learning goals based on key knowledge and key skills from the Study Design are clearly described at the beginning of each module.

**CHAPTER 2**  
**UNIT 3**

Skill acquisition is an area that explores how we learn movement skills. It is influenced by the type of skills to be learnt, the developmental stage of the learner and the environmental context.

**PULSE CHECK**

You may have come across some of these concepts before while studying Physical Education. Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- List five examples of fine motor skills.
- Identify three characteristics of gross motor skills.
- Suggest an example of a closed motor skill.
- Describe what is meant by a closed motor skill.
- Explain the difference between an open and a closed motor skill.
- Discuss the link between motor skill development, participation and performance in activities.

**1.1 CLASSIFICATION OF MOVEMENT SKILLS**

In this module you will learn about:

- classification of movement skills, including fundamental movement skills, sport-specific skills, open and closed skills, gross and fine skills, and discrete, serial and continuous motor skills
- learn to:
  - analyse and classify movement skills.

When you throw a ball, walk, hit a tennis ball, play computer games, drive a car, dance, get dressed or play a musical instrument, you are performing a motor skill. As part of this study, you will be considering biomechanical and skill acquisition principles that can be applied when analysing and improving movement skills for participation and performance. As a starting point, it is important to gain an understanding of the broad categories that are used to classify motor skills. Skills can be classified based on their characteristics. Understanding the characteristics and demands of a skill enables coaches and teachers to assess performance, plan skill development and training sessions, and provide relevant, tailored and developmentally appropriate feedback.

**LOOKING FORWARD**

**Feedback**

Chapter 2

In Chapter 2, we will be taking a close look at the importance of frequency and type of feedback.

Pulse check quizzes at the start of each chapter are designed to activate and assess students' prior knowledge of the key concepts and topics to be covered in the chapter.

Check-in questions at the end of each module and Chapter review questions use VCAA command terms and model a wide range of different exam-style questions to boost students' exam preparation and readiness. Answers to all questions are available on Nelson MindTap.

**9.5 CHECK-IN QUESTIONS**

- Work-to-rest ratio data can be somewhat limited. Outline two reasons why simply expressing a work-to-rest ratio of 1:4 for a game of European football might not be all that useful when trying to plan a training program.
- Suggest two ways in which work-to-rest information can be improved in the above example to make it more useful when selecting fitness tests and training activities.

**TABLE: WORK-TO-REST RATIO DATA**

Work period	Work	Rest	Ratio	Work period	Rest period
1st	10:00-10:15	15:00-15:15	1:1	5th	15:45-16:00
2nd	10:15-10:30	15:15-15:30	1:1	6th	16:00-16:15
3rd	10:30-10:45	15:30-15:45	1:1	7th	16:15-16:30
4th	10:45-11:00	15:45-16:00	1:1	8th	16:30-16:45

Based on this data, the correct work-to-rest ratio (W:R) and the dominant energy system for this game are:

- 1:5 and ATP-PC system.
- 1:3 and anaerobic glycolysis.
- 3:1 and aerobic energy system.
- 3:1 and aerobic energy system.

**3** The following data was obtained by comparing work and rest efforts and distances in elite senior and under-18 Australian Rules footballers in three key positions.

**TABLE: WORK AND REST EFFORTS AND DISTANCES**

Position	Counted	Elite senior		Under-18	
		Work (m)	Rest (m)	Work (m)	Rest (m)
Midfield	Elite senior	1675	1152	1462	644
	U18 elite	1331	824	1261	54
	U18 elite	1525	1018	1275	447
Back	Elite senior	930	650	2073	187
	U18 elite	1278	946	1002	574
	U18 elite	1145	882	1242	182

Source: Wright et al. (2017) 'Work-rest patterns in elite and under-18 Australian Rules footballers: an exploratory study'. In Sports Sci Med 9(2), 254-60

- Calculate the work-to-rest ratio for an elite senior Australian Rules footballer.
- Based on your answer to part A, which energy system do you believe provides most of the energy for an Australian Rules footballer?
- Identify any other data that might suggest the energy system you have selected plays a significant role in the footballer's game.
- The small forwards have a different work-to-rest ratio from those in midfield and ruck positions. Discuss the effect this would have on preparing a much more specific training program for small forwards, rather than having them complete the same aerobic-based training the midfield and ruck players perform.

**Command term**  
**Calculate**  
Determine from given facts, figures or information.

**CHAPTER REVIEW**

- Which of the following tests would be the most appropriate for a state basketball coach to use to measure muscular power in her rebounding players?
  - standing broad jump
  - 1RM bench press
  - vertical jump
  - 30-metre sprint
- Which of the following testing sequences would produce the most reliable result?
  - sit and reach, 20-metre shuttle run, vertical jump, 50-metre sprint
  - 50-metre sprint, vertical jump, 20-metre shuttle run, sit and reach
  - vertical jump, 50-metre sprint, 20-metre shuttle run, sit and reach
  - vertical jump, 20-metre shuttle run, 50-metre sprint, sit and reach
- When completing the 20-metre shuttle run test, you will be disqualified if:
  - you fail to make the line.
  - you reach the end wall in advance of the beep.
  - you fail to make the line twice consecutively.
  - you power-walk the early stages instead of jogging.
- INTEGRATE** **CONCEPTS** **INTEGRATION**

Which one of the following is the most suitable to test anaerobic capacity for an under-18 basketball team?

  - vertical jump
  - 1RM bench press
  - 30-second Wingate test
  - multi-stage fitness test

**Command term**  
**Analyse**  
Provide characteristics, features or qualities of a given concept, topic, activity, event, process, effect, argument, practice, test, experiment, article, performance piece or other product in an accurate way.

**UNIT 3 REVIEW**

**INTEGRATED EXTENDED-RESPONSE QUESTIONS**

These questions have been developed to allow you to draw on the knowledge and skills that you have developed across both areas of study in Unit 3. These responses require you to integrate theoretical concepts found in each area of study, draw on practical examples and integrate theoretical and practical concepts.

**1. CHUKA: FOOTBALL STRIKE (10 marks)**

The soccer club's coaches are looking for ways to improve their players' shooting and passing skills on their club. While the aim is to try to provide as fast as possible, athletes do restricts slow down as they provide their soccer through the gates and making contact and knowing it is generally, because for the goal.

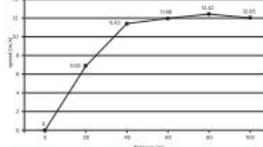
Explain how the relationship between the following factors would contribute to increase their successful performance in this soccer situation:

- Transfer of skill attention
- Kick



**2. CHUKA: FOOTBALL STRIKE (10 marks)**

The graph below shows the 20-metre split times for Usain Bolt's world record in the men's 100-metre sprint at the 2009 IAAF World Championships in Berlin in Berlin.



Source: H. Hampp et al., "Scientific research on sport: Biomechanical analysis of the Berlin 2009 IAAF World Championships in Berlin, Final Report, Berlin, German Commission on International Physical Education, February 2010, p. 6. IAAF, www.iaaf.org/WorldChamps2009

**DISCUSS** The relationship between ball use, leg and foot production with reference to acceleration and measure speed during Usain Bolt's 100-metre race performance. Ensure you reference data within your response.

The following javelin results were obtained from two experimental javelin throwers from a VCE PE class during the practical activity in Chapter 8. Javelin was given 2 minutes rest between attempts, whereas 10-minutes rest were given between sets. Both students performed a run-up before their throw and their results are displayed in the table below.

Run-up	John	Michelle
1	20.0 m	21.0 m
2	21.0 m	22.0 m
3	22.0 m	23.0 m
4	23.0 m	24.0 m

Use your own participant experience and understanding of skill classification (speed, transfer of momentum and speed of release to discuss the javelin system requirements of the skills and explain the difference between the results.

John and Brian are two VCE students who participated in a soccer session as part of their VCE PE class. They each tried to kick the ball as far as possible from a low-side kick. Brian is an experienced soccer player who has played in a junior academy for 5 years. Clear his skills experience with soccer and his more played complexity. The table below shows the results of their three attempts. The distance displayed was a measurement of the distance between when their foot struck the ball and the first bounce of the ball on the field. The performance conditions were identical.

Run-up	John	Brian
1	12.0 m	27.0 m
2	13.0 m	28.0 m
3	14.0 m	29.0 m

Use your understanding of the relationship between biomechanics, skill acquisition and acute responses to explain the difference between the results. Ensure you refer to:

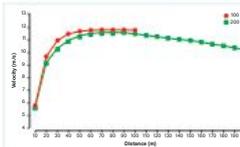
- Stages of learning
- Some summation
- Acute responses

**Unit reviews** feature exam-style extended-response questions. These questions have been developed to allow students to draw on the knowledge and skills that they have developed across the areas of study in each unit. Exemplar responses and advice on answering all questions are available on Nelson MindTap.

experiences a decline in power. The graph in Figure 1.6B looks at velocity decline over 100-metre and 200-metre sprint efforts. It clearly demonstrates a loss of power as the athlete sprints towards the 200-metre mark, showing the impact of CP depletion.

**DID YOU KNOW?**

The rate of CP depletion will be slower during exercise that is not performed at maximal intensity.



**FIGURE 1.6B** The performance impact of CP depletion is evident in a decrease in velocity between 100 and 200 metres.

Source: Grand, G. et al. (2015), 'Repeated sprint ability - Part 1: Sports Med', p. 573-584

**LOOKING BACK**  
Muscle fibre type

**Unit 1**

Muscle fibres can be classified either as fast-twitch or slow-twitch fibres. The ratio of fast-twitch and slow-twitch muscle a person possesses depends on their genetics and body composition. Fast-twitch fibres will produce more force and have the capacity to store more CP, but are quick to fatigue. Slow-twitch fibres take longer to fatigue but do not have the capacity to store as much CP.

**LOOKING FORWARD**  
Training methods

**Chapter 13**

When exploring different training methods, including resistance and plyometrics training, in Chapter 13, you will explore the preferential recruitment of muscle fibres based on the needs of the exercise. You will also explore the adaptations of each of the muscle fibres and how this enhances performance.

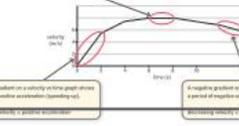
will need to stop the goal in each case (either in the goal or the ball) the speed of the ball and the speed of the ball as it approaches the goal. Once you are ready to stop the ball, speed plays an important role in many sports, and coaches and athletes analyze data and use the information to improve their performance skills to increase their speed or the speed of the ball, and improve their performance.

**WORKED EXAMPLE**

**ANALYSE: EXPLORING THE GOAL**

A student has an ability to stop the ball in the goal.

Constant velocity = slow acceleration



A participant on an ability to stop the ball in the goal shows a period of constant velocity (slow acceleration).

A participant on an ability to stop the ball in the goal shows a period of constant velocity (slow acceleration).

Based on the graph above, which one of the following statements best describes the student's sprint performance?

- The student ran at a constant velocity for 100 m.
- The student ran at their maximum velocity for 100 m.
- The student accelerated gradually until they reached their maximum velocity.
- The student accelerated gradually until they reached their maximum velocity.

**Feedback:** A velocity vs time graph can provide information about the athlete's performance. In this example we can see that the athlete:

- accelerated at the start of the race until they reached maximum velocity at 0 seconds;
- had a constant velocity between 0 and 0 seconds;
- decelerated down towards the end of the race (0 to 0 seconds).

We can also see that the total race time was 14 seconds.

**EXAM TIP:** In multiple-choice questions, if the answer is not obvious at first, look the information provided to approximate parts of the data. These points should allow you to determine options A, B and C, leaving the correct answer D.

**Worked examples** of exam-style questions demonstrate the steps required to complete a task or solve a problem, and include helpful annotations, exemplar responses and advice on avoiding potential pitfalls or common misconceptions.

Highlighting the cross-threading of concepts throughout the course with **Looking forward** and **Looking back** features.

**REAL WORLD APPLICATIONS**

**Confidence**

The 20-year-old was visibly engaged with his confidence in front of goal...

Player confidence is crucial to success, and yet it is incredibly fragile. Athletes can't just lean their confidence on and off. Fluctuates and can be the difference between an athlete's best performance and their worst. AFC player Harry McKay's confidence took a hit during the 2023 season, when his accuracy in front of goal all but disappeared.

When asked how one gets their confidence back, McKay answered:

**FIGURE 2.46** Harry McKay

**Motivation**

Motivation and confidence are closely connected. For movement skills to be learnt, the learner must be motivated - that is, they need to engage in, and put effort into, the learning process. Motivation to participate in physical activity, sport and exercise, and to learn movement skills will vary. We looked at some of the factors that influence participation and skill development in Module 2.1, and you may recall that children are often motivated to participate for fun, to be with their friends or part of a team, to improve or learn new skills, to gain for the challenge or achievement of competition and to have success (and win). Adults are also motivated by social interaction, competition, health benefits and a sense of achievement.

**Intrinsic motivation**

Intrinsic motivation is motivation that comes from participating in the activity itself and the enjoyment that comes from it. Individuals who are intrinsically trying to beat their personal best or an athlete who is motivated by playing well, are intrinsically motivated, and are more likely to produce long-term results and maintain their interest and participation in the activity.

**Extrinsic motivation**

Extrinsic motivation comes from an external source - for example, through rewards and recognition. Junior sporting clubs often use extrinsic rewards such as medals, trophies, certificates and trophies to encourage and reward players. Some athletes are motivated by fame and recognition, but at junior levels this form of extrinsic motivation can come from praise or social approval and/or acceptance.

**CASE STUDY**

**ANALYSE: EXPLORING THE GOAL**

Data on maximal lactate levels collected at the conclusion of three swim sprints demonstrated a significant difference depending on the duration of the effort. Table 2.6 shows the maximal blood lactate levels reached following 20-metre, 50-metre and 100-metre swims. This data demonstrates the accumulation of metabolic by-products (lactate H<sup>+</sup> ions) when the anaerobic glycolysis system has a large role in energy supply (Mansfield et al., 2022).

Swimmer (m)	Maximal lactate (mmol/L)
20	6.1 (2.2)
50	13.2 (2.6)
100	13.2 (2.6)

Source: Mansfield, M. et al. (2022), Blood lactate and maximal lactate accumulation rates at three sprint swimming distances in highly trained and elite swimmers. Sports Biomechanics, 21(1), 41-50.

**QUESTIONS**

- Identify if the maximal lactate levels have a greater contribution from the aerobic or the anaerobic energy systems.
- State the relationship between the duration of swim sprints and maximal blood lactate levels.
- Discuss why there is an accumulation of metabolic by-products during these maximal efforts.
- Explain the physiological impact of the accumulation of metabolic by-products (H<sup>+</sup>) during the swim sprints.

**Analyse:** Why there is an increase in blood lactate levels as the duration of the swim sprints increases. Predict what would happen to blood lactate levels for a 100-metre swim sprint and explain your prediction.



**FIGURE 2.6B** All three energy systems are working together, but one is producing most of the ATP.

**Real world applications** and **Case studies** are designed to provide students with multiple opportunities to encounter, engage with, and elaborate on new knowledge and skills.

**Command terms** are highlighted in all questions, with margin definitions to build awareness and exam readiness in students.

**COLLABORATIVE TASK**  
**Prac activity**  
**Investigating friction**

**AIM**  
 To investigate the effect of friction on sprint times

**EQUIPMENT**

- tape measure
- stopwatch

**METHOD**

1. In pairs, allocate a timer and a runner.
2. Select four different conditions to sprint 25 metres. These may include:
  - shoes on – indoor surface
  - shoes off – indoor surface
  - school shoes – grass
  - runners – grass
  - runners – running track
  - running spikes – running track.
3. On the timer's signal, the runner sprints as fast as they can over 25 metres.
4. Allow the runner to fully recover in between each sprint.
5. Repeat steps 2 and 4 for each of the four conditions selected.
6. Record the time for each sprint.

**OBSERVATIONS**  
 Timer to record anything they observe for each sprint (such as slipping/sliding).  
 Runner to record their thoughts after each sprint.

**DISCUSSION**  
 Discuss the role of friction in sprinting. Refer to the data collected (both the times recorded and the observations from both the timer and the runner). In your discussion, consider the shoe contact surfaces, and the impact of the friction present in each situation on the sprint time.

**Torque**  
 When a force causes an object to rotate or turn, this effect is called a torque.  
 Torques cause changes in **angular motion**. Angular motion involves rotation around a central axis or a fixed point. The axis can be:
 

- real
- imaginary
- internal
- external.

 The joints of the body are real, internal axes. In Figure 3.11 a, an imaginary external axis is the centre of gravity. In Figure 3.11 b, a real, external axis is the bar when performing a rotation on a high bar and in Figure 3.11 c, when spinning in figure skating, the axis is an imaginary, internal, vertical axis.

**Target**  
 The turning effect produced by force

**Angular motion**  
 Movement of a body part around an axis of rotation

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**Reflective folio and data analysis icons** remind students to document their findings and observations.

**Collaborative tasks and Data analysis activities** maximise opportunities for students to apply and practise their knowledge and skills.

**DATA ANALYSIS**

**Marathon**

**TABLE 3.30 5-kilometre split times and average speeds for each split for a female marathon runner**

Distance (km)	Time (min)	5 km split time (min)	Average speed in each 5 km split (km/h)
0	0:00	0:00	0.00
5	32:57	32:57	9.10
10	49:34	16:37	9.10
15	65:55	16:21	9.10
20	82:03	16:08	9.17
25	97:57	15:54	9.30
30	114:27	16:40	9.00
35	130:58	16:31	9.11
40	147:42	17:04	8.97

\*The time for the final 5 km of the race was used to calculate the average speed of 8.97 km/h.

1. Using the information in the table above, calculate the average speed for the whole race in km/h.
2. What was the average speed of the race in km/h?
3. What can be said about the running speed of the athlete throughout the race? Use data to support your answer.
4. Figure 3.30 shows speed and distance vs time. How could a coach use this data to provide feedback to the athlete on their performance?

**FIGURE 3.30** Graph of speed and distance covered during a marathon

Source: Watson, L [ed.] *Fundamental Biomechanics of Sport and Exercise*, 2014, Routledge

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**Above and beyond the Study Design** sections provide students with opportunities to extend their understanding outside the scope of the Study Design, but with clear links to knowledge included in the Study Design.

**CHAPTER 6**

**ABOVE AND BEYOND THE STUDY DESIGN**

**MODULE 1.1: ENERGY** **Blood redistribution during exercise**

**REAL WORLD APPLICATIONS**

**Eating before swimming**

Some swimmers believe that the risk of drowning is increased if you go for a swim immediately after eating a large meal. This is actually a myth.

Eating before swimming may not reduce the risk of drowning, but it might lead to more energy. Many professional swimmers are recommended eating for 30 minutes to 1 hour before a big race before jumping into the pool, one or two for a swim.

As we eat, the digestive system breaks down food and transports nutrients to various body parts, including muscles, to be used or stored as energy. If we exercise at the same time, the muscles need increased blood supply to transport oxygen and fuels. The digestive and muscular systems must then compete for blood supply and, in some cases, this conflict might lead to muscles competing through inefficient oxygen supply.

It is important to note that the body won't consume blood flow to the extent that it would significantly hinder the functioning of arm and leg muscles. If you find this is happening, don't panic. Reduce the intensity of arm and leg activities while in the water and try to make your way back to shore, the deck or the side of the pool.

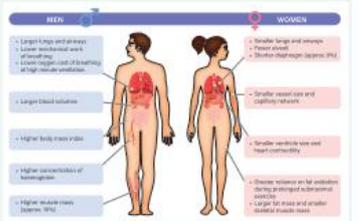
Swimmers take longer than other athletes to be digested. Broken down and used as fuels, and are not recommended to large quantities before a swim. Instead, meals or snacks containing carbohydrates digest quickly and are the recommended pre-swim meal. A sports drink consumed immediately can also speed up digestion. If you have to swim within an hour or so, opt for easily digestible sweaters are advised not to eat within 30 minutes of races.



**FIGURE 6.29** Competitive swimmers will not consume solid foods within 30 to 60 minutes of the scheduled start time of their event.

**MODULE 1.1: ENERGY** **Sex differences at the respiratory, cardiovascular and muscular levels**

Figure 6.30 summarises some of the sex differences at the respiratory, cardiovascular and muscular levels that explain why males outperform their female counterparts in endurance events. Use any of these to support your understanding of why males have smaller oxygen deficits and are able to return to pre-exercise levels faster than their female peers when competing in events such as the 20 kilometres cross-country skiing race on the flatland.



**MALES**

- Larger lungs and airways
- Lower percentage end-tidal  $\text{P}_{\text{O}_2}$
- Lower resting level of breathing at high relative ventilation
- Larger blood volumes
- Higher body mass index
- Higher concentration of haemoglobin
- Higher muscle mass (males: 75%)

**FEMALE**

- Smaller lungs and airways
- Higher  $\text{P}_{\text{O}_2}$  end-tidal
- Smaller resting rate and capillary networks
- Smaller muscle mass and heart connectivity
- Greater reliance on fat oxidation during prolonged endurance activities
- Larger fat mass and smaller skeletal muscle mass

**FIGURE 6.30** Sex differences at the respiratory, cardiovascular and muscular levels. Elite male marathon runners have relative  $\text{VO}_{2\text{max}}$  values that are approximately 10 per cent higher than those of their female peers.

**Signpost** boxes provide directions for extending students' understanding of a concept, with links to research, videos and other resources.

**CHAPTER 6**

**OPEN-CELLS**

Open-cells are characterised by a combination of:

- the ability to react to a rapidly shifting, unpredictable, dynamic and externally paced environment;
- the need to make tactical decisions;
- high-intensity movements;
- often directional changes over a short distance;
- specific skills/technical requirements unique to continuous changes in the sporting environment;
- the need to perform free while exhibiting aggression;
- high cognitive load;
- short reaction time;
- the need for anticipatory skills, which are critical for decision-making (Stambury, Sargent & Nisak, 2018).

**DID YOU KNOW?**

The word 'parcour' derives from the French phrase 'parcourir' (to conduct), meaning an obstacle course, which was used as part of military training in the 19th century by Georges Hebert.

**CASE STUDY** **PARCOUR**

Parcour (also known as free running) has grown in popularity as a physical activity and sport over recent years, and the first international tournament, the Red Bull Parcour, was held in October 2010. Parcour involves moving quickly and efficiently through a complex physical environment consisting of varying urban areas while performing a range of acrobatic (aerobic) manoeuvres over a human-made obstacle course set in the built environment. These obstacles may include walls, low and high beams that are set at different distances and have varying angles of inclines, sides and surfaces. Performers might need to pull, push, kick, roll and slide to get over, and may participate near very hot, smothering or broad set of technical skills that they use to negotiate obstacles. Parcour uses equipment such as a highly resistant, folding mobile, which focuses on functional exercises relating to general conditioning training, strength training, injury control, running, climbing, obstacle clearance. The focus is on highly speed skill, with a variety of performance techniques. It offers participants many opportunities for novel interactions in relation to jumping, landing, balancing, timing and changing direction to negotiate beams, surfaces and other obstacles for which there may not be an obvious solution. A research study (Stratford et al., 2010) of parcour performers (known as 'parcourists') found a correlation between movement skill performance (in jumping, timing and swinging) and the speed taken to run through the obstacle course.

**QUESTIONS**

1. Describe what skills would be used to perform parcour.
2. Identify what parcour is considered an open-cell.

**IF SIGNPOST**

Check out the following links to learn more about parcour. Don't if you have no intention of ever trying parcour, you can still see the different and skill of the parcourists.

- Read the article 'The science of parcour: the sport that seems ridiculous but tests your guts and skill' by James Craft in The Conversation.
- Watch the video Parcour: Parcour PST on the Open Channel on YouTube.

**THE OPEN CHANNEL**

**FIGURE 6.31** Parcour is a highly speed skill with a highly variable performance environment.

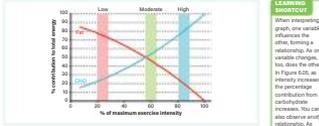
**Did you know?** boxes have been designed to spark students' interest and engagement with a topic or concept.

**CHAPTER 6**

**THE CHO/FAT RELATIONSHIP WITH INTENSITY**

Incremental physical activity occurs when someone starts out slowly, then gradually increases their intensity, often to exhaustion. Examples of this type of activity include the multiple fitness test and a laboratory test known as the  $\text{VO}_{2\text{max}}$  test.

As intensity increases during the test, the percentage of energy obtained from carbohydrates and fats changes. At lower intensities, there will be a greater contribution from fats as energy is not required at a rapid rate. As intensity increases, there is a greater contribution from carbohydrates, which provide energy faster. The point where carbohydrate takes over from fat as the major contributor to energy production is known in the exercise physiology world as the crossover point. Figure 6.32 shows the relationship of each of the fuels with exercise intensity.



**FIGURE 6.32** As intensity increases, there is a change in the contribution of different fuels used to provide energy to meet movement demands.

**LOOKING FORWARD**

**Assessment of fitness**

**Chapter 10**

In Chapter 10 you will investigate different types of fitness tests and perform a variety of different tests using reliable and accurate protocols.

**LOOKING FORWARD**

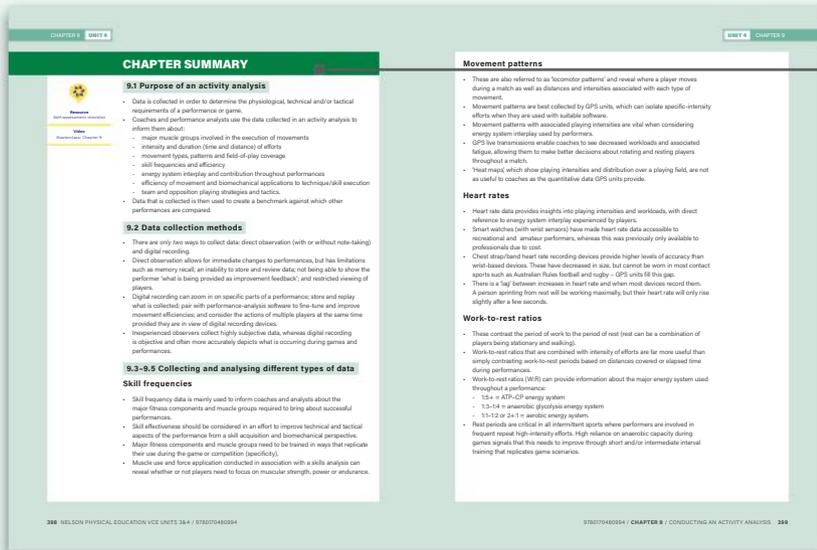
**Fuel and glycogen sparing**

**Chapter 15**

When exploring adaptations in Chapter 15, you will discover how trained athletes are able to use fat at a higher intensity, through the process of glycogen sparing and how this improves performance. This will result in a right shift in Figure 6.32.

**Integrated exam support** can be found throughout, providing students with advice and useful insights as they work through each chapter, including:

- Learning shortcuts
- Learning hacks.
- Key term definitions, which are collated in the Glossary at the end of the book.



**Chapter summaries** provide students with a concise overview of the key knowledge in each chapter, which is ideal for revision and exam preparation.



## NELSON MINDTAP

This series features Nelson MindTap, an online learning environment that puts you at the centre of your learning. Nelson MindTap for Nelson Physical Education gives you access to an eText with integrated activities and assessments.

### Nelson MindTap

#### An online learning space that provides students with tailored learning experiences.

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*Complimentary access to these resources is only available to teachers who use this book as part of a class set, book hire or booklist. Contact your Cengage Education Consultant for information about access and conditions.*

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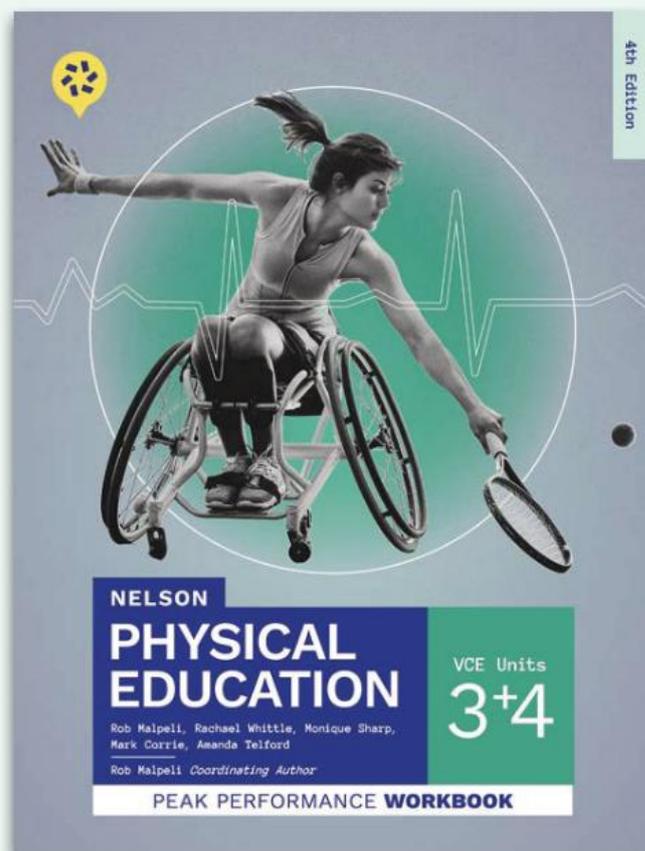
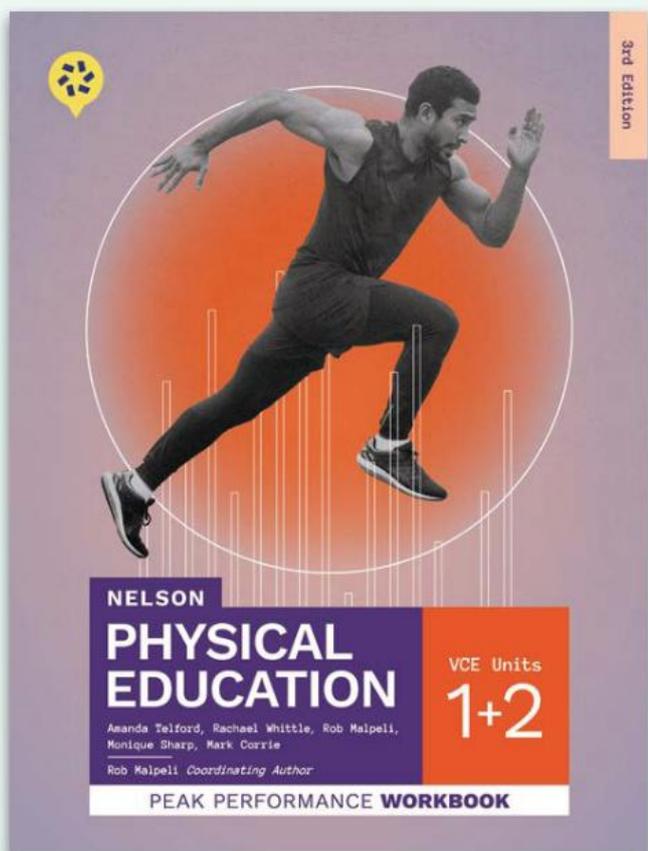
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## NELSON PHYSICAL EDUCATION VCE PEAK PERFORMANCE WORKBOOKS

The Nelson Physical Education Peak Performance workbooks for VCE Units 1 & 2 and Units 3 & 4 provide complete coverage of the *Victorian Certificate of Education Physical Education Study Design (2025–2029)*. These comprehensive workbooks scaffold questions to gradually build student understanding and skills. They are designed to provide students with the opportunity to apply their knowledge in a range of question types, while also preparing them for their internal assessments and the VCE Physical Education exam in Year 12.

### WORKBOOK FEATURES

- A range of multiple-choice, short-answer and extended-response questions for valuable end-of-year exam practice is included.
- The workbooks include both past VCAA exam questions and exam-style questions to emulate the exam as closely as possible.
- Unique exam-style questions are crafted by a trusted author team with experience in writing the VCE exam, and are designed to maximise exam success.
- Questions contain up-to-date data and research and case studies to allow students to apply their skills and understanding to real-world situations.
- Exemplar answers are provided to all questions.



# ABOUT THE AUTHORS

**Rob Malpeli** is based at The Knox School, Victoria. Rob works across multiple schools throughout Victoria but also in other states, and has been a leading light in senior Physical Education for over 30 years. His texts and resources are used in Victoria, New South Wales, Queensland, Western Australia and New Zealand. Rob has led professional learning sessions in HPE for teachers across multiple states over the last 20 years. He has been involved in curriculum benchmarking and focus groups that investigate curriculum improvements, and was previously a member of the Study Design panel.

**Dr Rachael Whittle** (PhD) is a highly respected educator with extensive teaching experience in both secondary and tertiary education settings, and in the development of VCE Physical Education curriculum. She has developed and delivered teacher professional learning, both nationally and internationally, on her area of expertise, which is senior secondary Physical Education curriculum, pedagogy and assessment. Rachael was involved in the development and assessment of high-stakes examinations for VCE Physical Education in Victoria for almost 20 years. Her research focus for her doctoral studies focused on influences on academic performance in VCE Physical Education.

Professor **Amanda Telford** (PhD) is a teacher and researcher in health and physical education, wellbeing, physical activity and educational leadership within the National School of Education, Faculty of Education and Arts at the Australian Catholic University. Amanda has over two decades' experience in senior learning and teaching leadership roles as a former secondary teacher and academic across four universities, including as Associate Dean Education (Learning & Teaching), Deputy Head of School (Learning & Teaching), Interim Associate Dean (Partnerships), Course Co-ordinator for the Master of Education and Director/Program Manager of Health and Physical Education teacher education degrees. Amanda is a multi-award-winning teacher, researcher and author. She has co-authored over 100 learning and teaching publications, including over 50 peer-reviewed journal articles and over 50 textbooks and book chapters used nationally and internationally at secondary and tertiary level. Amanda has collaborated on more than 45 research projects (over \$3 million of grants) with a learning and teaching, physical activity and/or wellbeing focus. As co-founder and co-director, with Rob Malpeli, of Peak Phys Ed, Amanda has been the conference director of the Discovery Health and Physical Education conferences since 2009, supporting thousands of teachers nationally.



**Mark Corrie** is the Assistant Principal at Scoresby Secondary College, where he continues to teach VCE Physical Education. He has been a Physical Education exam assessor for over 30 years. A respected presenter at numerous conferences for both teachers and students throughout the state, Mark was also a member of the VCAA review board that developed the previous (2017–2024) and current (2025–2029) study designs for VCE Physical Education.

**Monique Sharp** is currently Head of Health and Physical Education at Melbourne Girls Grammar School. She has taught VCE Physical Education for over 10 years and is an experienced assessor. Monique spent two years working in an exercise physiology laboratory and RTO, administering laboratory tests such as the  $VO_2$  max test and working to deliver and assess Certificate III and IV fitness and training. She has written chapters in textbooks for Years 7–10 in the NSW syllabus. She has delivered lectures and created support material for a variety of support organisations, including the Australian Council for Health, Physical Education and Recreation (ACHPER) in the VCE space.



# Welcome to VCE Physical Education Units 3&4

Your decision to study VCE Physical Education (PE) will reward you not only throughout this year but also well into the future. Studying PE will allow you to explore the way your body performs, along with factors that influence the decisions you make. Hopefully, your 'learnings' in physical education will contribute to a healthier and more physically active lifestyle throughout this year and the rest of your life.

This student book, the accompanying workbook and the digital resources located on Nelson MindTap have all been designed and written to meet the requirements of the *Victorian Certificate of Education Physical Education Study Design 2025–2029*. All key knowledge and key skills will be addressed and, more importantly, via close links between theory and active participation in practical activities, you will develop and expand your physical knowledge and behaviours through movement and physical activity.

You will take learnings and key knowledge from the classroom and make real world connections by applying these to physical activity, sport and exercise contexts. This will occur through participation in practical classes, school sport and any form of physical activity you undertake outside school as well.

We hope that you engage in your PE studies in a positive way and that this sets up a lifelong pattern of participation in physical activity.

Best wishes from  
Rob Malpeli, Rachael Whittle, Monique Sharp, Mark Corrie & Amanda Telford

## VCE Physical Education course overview

VCE Physical Education consists of four units of study, with at least 50 hours of scheduled instruction for each. Each unit addresses specific and, in some cases, integrated content and is designed to enable students to achieve a set of outcomes for that unit.

There are no prerequisites for entry to Units 1, 2 and 3. Students must undertake Unit 3 and Unit 4 as a sequence. Units 1–4 are the equivalent standard of the final two years of secondary education.

Unit and content with areas of study	Student/Study requirement
<b>Unit 3: Movement skills and energy for physical activity, sport and exercise</b>	
<p>Area of Study 1: How are movement skills improved? (Chapters 1, 2, 3 and 4)</p>	<ul style="list-style-type: none"> <li>▪ analyse and classify movement skills</li> <li>▪ analyse the link between motor skill development, participation and performance</li> <li>▪ participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill</li> <li>▪ analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills</li> <li>▪ perform a qualitative movement analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills</li> </ul>
<p>Area of Study 2: How does the body produce energy? (Chapters 5, 6 and 7)</p>	<ul style="list-style-type: none"> <li>▪ explain the changes in oxygen demand and supply at rest, and during submaximal and maximal exercise</li> <li>▪ participate in laboratory activities to collect and analyse data on the range of physical responses the body experiences during exercise</li> <li>▪ perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery</li> <li>▪ participate in a variety of physical activity, sport and exercise and describe, using appropriate terminology, the interplay and relative contribution of the energy systems</li> <li>▪ explain the muscular fatigue mechanisms associated with the use of the three energy systems and the individual and environmental factors that influence fatigue under various intensities and durations</li> <li>▪ develop nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery</li> </ul>
<b>Unit 4: Training to improve performance</b>	
<p>Area of Study 1: What are the foundations of an effective training program? (Chapters 8, 9 and 10)</p>	<ul style="list-style-type: none"> <li>▪ undertake an activity analysis and analyse associated data to justify the required physiological requirements</li> <li>▪ justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity</li> <li>▪ perform and observe a reliable, valid and accurate assessment of fitness</li> </ul>
<p>Area of Study 2: How is training implemented effectively to improve fitness? (Chapters 11, 12, 13, 14 and 15)</p>	<ul style="list-style-type: none"> <li>▪ participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio</li> <li>▪ participate in and conduct components of an exercise training session</li> <li>▪ design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components</li> <li>▪ analyse training data to identify and prescribe appropriate modifications to a training program</li> <li>▪ evaluate and critique the effectiveness of different training programs</li> <li>▪ explain how the cardiovascular, respiratory and muscular systems' chronic adaptations to training lead to improved performance</li> </ul>
<p>Area of Study 3: Integrated movement experiences (reflective consideration summary based on all chapters)</p>	<ul style="list-style-type: none"> <li>▪ reflect on primary data from participation in a practical activity</li> <li>▪ use primary data to demonstrate integration of theory and practice</li> <li>▪ analyse interrelationships between skill acquisition, biomechanics, energy production and training knowledge for the practical activity completed and for their impact on performance between movement skills or performers</li> </ul>

# Assessment in VCE Physical Education

## Units 3 and 4 Physical Education assessments

Unit and content with areas of study	Internal assessment tasks
<b>Unit 3: Movement skills and energy for physical activity, sport and exercise</b>	
Area of Study 1: How are movement skills improved?	<p>Levels of achievement in Units 3 and 4 will be determined by School-assessed Coursework. School-assessed Coursework tasks (SACs) will be completed mainly in class and within a limited timeframe. SACs for Unit 3 will contribute 20 per cent to the study score.</p> <p>Outcome 1: Analyse primary data collected from participation in physical activity, sport and exercise to develop and refine movement skills from an individual and coaching perspective, through the application of biomechanical and skill acquisition principles.</p> <p>Task: Structured questions that draw on primary data, which analyses a movement skill using biomechanical and skill acquisition principles.</p>
Area of Study 2: How does the body produce energy?	<p>Outcome 2: Use data collected in practical activities to analyse how the major body and energy systems work together to enable movements to occur, explain the factors causing fatigue and recommend suitable recovery strategies.</p> <p>Task: A laboratory report based on primary data collected during participation in a practical activity, which analyses the acute responses to exercise, energy system characteristics, energy system interplay fatigue and recovery.</p>
<b>Unit 4: Training to improve performance</b>	
Area of Study 1: What are the foundations of an effective training program?	<p>SACs for Unit 4 will contribute 30 per cent to the study score.</p> <p>Outcome 1: Analyse data to assess and justify the physiological requirements of an activity that informs an appropriate assessment of fitness, demonstrating correct implementation of testing protocols.</p> <p>Task: A written report analysing data from an activity analysis to determine the relevant fitness components and energy system requirements in a selected activity, including a justification of the selection of appropriate tests to assess fitness.</p>
Area of Study 2: How is training implemented effectively to improve fitness?	<p>Outcome 2: Participate in a variety of training methods, design and evaluate training programs and explain performance improvements due to physiological adaptations dependent on the type of training undertaken.</p> <p>Tasks:</p> <ul style="list-style-type: none"> <li>• A written report that draws on experiences from the participation in at least five training sessions to design a personalised six-week training program used for evaluation with a given case study.</li> <li>• A response in one or more of the following formats, which links chronic adaptations of the cardiovascular, respiratory and muscular systems to training methods and improved performance:             <ul style="list-style-type: none"> <li>– a case study analysis</li> <li>– a data analysis</li> <li>– structured questions.</li> </ul> </li> </ul>
Area of Study 3: Integrated movement experiences	<p>Outcome 3: Participate in and reflect on a movement experience that integrates theoretical and practical knowledge related to skill acquisition, biomechanics, energy production and training to improve fitness and performance.</p> <p>Task: An extended response question drawing on personal experiences from a chosen practical activity recorded in the reflective folio, which analyses the interrelationships between skill acquisition, biomechanics, energy production and training program theoretical knowledge for their impact on participation and/or performance. An emphasis is placed on using a suitable tool, such as a concept/mind map to plan a response.</p>

Note that achievement levels for Units 3 and 4 are also assessed by an end-of-year examination, which contributes 50 per cent to the study score.

# Using a reflective folio to consolidate learning

Students undertaking VCE PE must maintain a reflective folio of practical activities completed in each of Units 1–4. These can include activities conducted in a classroom, field or gym setting. They do not necessarily need be dedicated as 'pracs' – for example, they might involve a teacher demonstration of a concept followed by a brief set of activities performed in and around the classroom, and might not require students to change into their PE gear. This will strengthen the understanding of concepts across areas of study and be used for reflection and assessment purposes.

## Making connections

The use of a reflective folio throughout Units 1–4 gives students the opportunity to reflect on their participation and make interdisciplinary theoretical connections that extend beyond the key knowledge and key skills being explored at that time. Due to the standalone nature of Units 1 and 2 and the absence of Area of Study 3, students completing Units 1 and 2 are encouraged to use the reflective folio to make connections to knowledge across each unit in an integrated manner.

## Source of data

Your reflective folio will be a source of primary data (see data collection section) and as a requirement for satisfactory completion of each unit.

The reflective folio gives students the opportunity to reflect on and record perspectives on their participation in each activity completed. When you reflect on an activity, don't just describe what happened during the session. Instead, think about how the activity connects to the content being covered in class and what you learned as a result of your participation. Reflective folio data may include:

- a description of the activity and any session goals
- physical experiences of the activity – how did it feel physically?
- emotional experiences within the activity – was it enjoyable?
- social experiences within the activity – if applicable, describe the interaction and/or teamwork within the activity
- mental experiences within the activity – describe your motivation to undertake and complete the activity. What was the level of challenge during the activity?
- spiritual experiences within the activity – was the activity relaxing? Did you find yourself thinking deeply within the activity?
- theoretical links within the activity – guide questions and discussion points provided by teachers give students the opportunity to connect concepts. What other theoretical concepts explored this year can you connect to this activity?

**COLLABORATIVE TASK**  
Lab activity

Respiratory rate at rest and varied exercise intensity



**FIGURE 5.67** The step test

**AIM**  
To determine the change in respiratory rate in response to different workloads

**EQUIPMENT**

- stool or platform (40–50 centimetres high)
- online metronome

**METHOD**

**Submaximal exercise**

- 1 Subjects sit quietly for 1–2 minutes. Record their resting respiratory rate by counting how many breaths they take per minute (you can count how many breaths they take in 20 seconds and multiply this by 3).
- 2 Subjects complete 1 minute of continuous exercise step-ups to be performed at the same workload/pace. Start with the metronome rate set at 30 beats per minute (3 second up, 1 second down).
- 3 After 1 minute of stepping, record subjects' respiratory rate while they are standing still for 20 seconds. Then ask them to complete another minute at the same pace/workload. After another minute of stepping, record their standing respiratory rate for another 20 seconds while they are standing still.
- 4 Subjects then perform 1 minute of stepping at a higher workload – this time 30 bpm. After 1 minute of stepping, record subjects' respiratory rate while they are standing still for 20 seconds, then ask them to complete another minute at the same pace/workload (30 bpm). After another minute of stepping, record their standing respiratory rate for another 20 seconds while they are standing still.

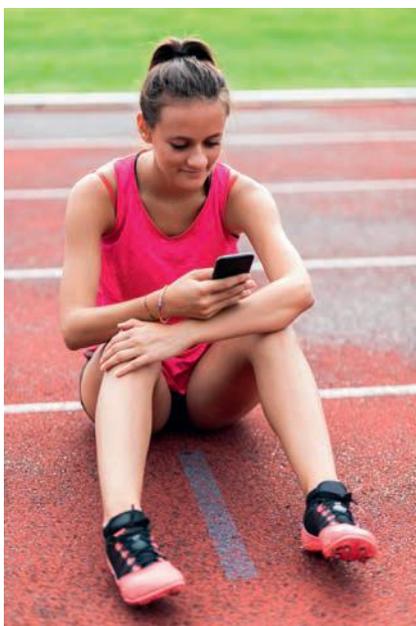
You will find a Reflective Folio icon beside practical activities throughout this student book as a reminder to record the primary data and your observations after each activity.

## Recording your reflections

Reflective folio entries can be in one or more formats: written, visual (drawing, photo), audio (a self-recorded audio) or audiovisual (self-recorded video). Some students may decide to record their reflective folio on their mobile phones via interview-style recordings. Students are expected to make direct reference to their involvement in practical activities via entries in their reflective folio.

Participant:		Goal:	
Day/Date:	Time:	Venue:	Weather:
Session details			
Frequency			
Intensity			
Time			
Type			
Form of physical activity			
Reflection:			
<ul style="list-style-type: none"> <li>• Barriers</li> <li>• Enablers</li> <li>• Benefits</li> </ul>			
Sketch			

Giorgio Fochesato/Westend61 on Offset/Shutterstock.com



You can use your smartphone to complete your reflections.

## Understanding command terms

While being assessed in VCE Physical Education, you will be asked questions that include specific 'command terms.' These are 'action words' and are also known as 'cognitive verbs.' They ask you to demonstrate your level of understanding of key knowledge, and are also highlighted in text with margin definitions. The following table is based on one provided by VCAA that lists the command words and their definitions. We have added sample questions as examples of their use in the form of an exam question.

Term	Explanation	Sample question using command term
account of	Describe a series of events or transactions.	Give an <b>account of</b> how participation in the 'early bird fitness classes' has affected your motivation to participate in higher levels of physical activity.
account for	State reasons for; report on.	After considering the heart rate data, <b>account for</b> why there was a higher frequency of walking and jogging by the midfielder in the second half of the game.
analyse	Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information.	<b>Analyse</b> the effect working above the lactate threshold has on performance.
apply	Use; employ in a particular situation or context.	<b>Apply</b> your understanding of force summation in a demonstration of the hockey push.
assess	Make a judgment about, or measure, determine or estimate, the value, quality, outcomes, results, size, significance, nature or extent of something.	<b>Assess</b> the validity and reliability of the fitness test chosen to measure levels of muscular endurance.
calculate	Determine from given facts, figures or information; obtain a numerical answer showing the relevant stages in the working; determine or find (e.g. a number, answer) by using mathematical processes.	<b>Calculate</b> the maximum heart rate for a 30-year-old and state the range of their continuous training zone.
clarify	Make a statement or situation more comprehensible.	<b>Clarify</b> what is meant by the term 'reciprocal inhibition'.
compare	Recognise similarities and differences and the significance of these similarities and differences.	<b>Compare</b> three characteristics of slow-twitch and fast-twitch muscle fibres.
construct	Make, build, create or put together by arranging ideas or items (e.g. an argument, artefact or solution); display information in a diagrammatic or logical form.	<b>Construct</b> a flow chart to show the sequencing of body parts involved in performing the shot-put.
contrast	Show how things are different or opposite.	<b>Contrast</b> the different distances a baseball can be struck from the tee when using different types of grip.
deduce	Draw a conclusion from given information, data, a narrative, an argument, an opinion, a design and/or a plan.	Based on your data/survey results, <b>deduce</b> a program that might increase the number of students who meet the sedentary behaviour guidelines.
define	Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity.	<b>Define</b> the term 'qualitative movement analysis'.
demonstrate	Show ideas, how something can be done or that something is true by using examples or practical applications, or by applying algorithms or formulas.	<b>Demonstrate</b> your understanding of how constraint-based coaching can be used to improve performances in hockey.
describe	Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way.	<b>Describe</b> the type of coaching and feedback a national level soccer player is likely to be receiving.
discuss	Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions.	<b>Discuss</b> possible reasons why there is a sharp drop-off in participation rates in sport and recreational pursuits among students once they complete Year 10.
distinguish	Make clear the differences between two or more arguments, concepts, opinions, narratives, artefacts, data points, trends and/or items.	By referring to the case study data, <b>distinguish</b> why males will almost always have faster running times in the marathon than females.
evaluate	Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information.	<b>Evaluate</b> the effectiveness of performing a warm-up on the ability of a muscle to produce force.



Term	Explanation	Sample question using command term
examine	Consider an argument, concept, debate, data point, trend or artefact in a way that identifies assumptions, possibilities and interrelationships.	<b>Examine</b> the playing intensities in the last 3 minutes of the game and discuss the energy system interplay. Your response should include fatigue factors that might influence energy system use.
explain	Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident.	<b>Explain</b> why people living in areas with high-density housing are likely to have lower participation rates in physical activity than those living in regional areas.
extract	Select relevant and/or appropriate detail from an argument, issue or artefact.	Refer to the table and <b>extract</b> any evidence that supports the notion that centre players have higher levels of aerobic power than key defenders.
extrapolate	Infer and/or extend information that may not be clearly stated from a narrative, opinion, graph or image by assuming existing trends will continue.	The graph shows the heart rate during 3 minutes of a passive recovery. <b>Extrapolate</b> and draw what you believe this would be like if the subject had performed an active recovery.
identify	Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment.	<b>Identify</b> the top three barriers VCE students find to participating in more physical activity than they currently do.
infer	Derive conclusions from available information or evidence, or through reasoning, rather than through explicit statements.	Use the graph to <b>infer</b> the relationship between practice frequency and performance improvement.
interpret	Draw meaning from an argument, point of view, description or diagram, text, image or artwork and determine significance within context.	Use the information presented in the case study to <b>interpret</b> the influence peers have on participation in physical activity.
investigate	Observe, study or carry out an examination in order to establish facts and reach new conclusions.	<b>Investigate</b> the effectiveness of different types of practice on performing open and closed skills.
justify	Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information.	<b>Justify</b> the decision to include performing bone-strengthening activities in the Australian physical activity guidelines for older adults (65+ years of age).
list	Provide a series of related words, names, numbers or items that are arranged consecutively.	<b>List</b> two factors that affect the application of muscular power.
name	Provide a word or term (something that is known and distinguished from other people or things) used to identify an object, person, thing, place etc.	<b>Name</b> the mechanism that summarises the redistribution of blood to different parts of the body during exercise.
outline	Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image.	<b>Outline</b> two reasons why an informed consent process needs to be undertaken before any fitness testing is conducted.
persuade	Induce (someone) to do something through reasoning or argument; convince.	After considering the evidence presented, <b>persuade</b> another classmate that warm-ups do not reduce the likelihood of injury during competitions.
predict	Give an expected result of an upcoming action or event; suggest what may happen based on available information.	<b>Predict</b> what would happen to the rate of improvement if the subject applied overload to training volumes by 5 per cent every week.
propose	Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action.	<b>Propose</b> a way of improving the outcomes of the training program given the training diary entries and reflections.
recall	Present remembered ideas, facts and/or experiences.	<b>Recall</b> the key stages in the socio-ecological model.
recommend	Put forward and/or approve (someone or something) as being suitable for a particular purpose or role.	<b>Recommend</b> two ways in which bone density can be maintained once people retire from full-time work at the age of 65.



Term	Explanation	Sample question using command term
recount	Retell a series of events or steps in a process, usually in order.	<b>Recount</b> the four parts of a RAMP protocol.
state	Give a specific name or value or other brief answer without explanation or calculation.	<b>State</b> the antagonist muscle while performing a biceps curl (elbow flexion).
suggest	Put forward for consideration a solution, hypothesis, idea or other possible answer.	<b>Suggest</b> the main cause of fatigue experienced by the netball centre by referring to the graph below.
summarise	Retell concisely the relevant and major details of one or more arguments, text, narratives, methodologies, processes, outcomes and/or sequences of events.	<b>Summarise</b> primary and secondary data about enablers and barriers to physical activity in your chosen group and provide three recommendations that might increase the uptake and continued participation in physical activity.
synthesise	Combine various elements to make a whole or an overall point.	The movement sequence <b>synthesised</b> elements from each of the three fundamental movement skills developed as a child.

## Collecting and using data

As well as the key knowledge covered in class, you will be required to conduct research and collect data. Knowing how to collect, analyse and draw appropriate conclusions from your data will increase your understanding of key factors influencing participation and performance in physical activity. During the study of Physical Education you will be required to draw on a combination of primary and secondary data.

### Primary data

Primary data is data that you collect (either individually or as a team), and includes the following.

- Observations: these are data gathered while watching performances, events or behaviours, and should be supported by note-taking for future reference. Recording/ data sheets and checklists are often used when collecting data in this way. The data can be either qualitative or quantitative, or a combination of both. Plan ahead, think about what it is you are hoping to observe/capture and, if possible, practise beforehand to become familiar with what is involved.
- Digital recordings: these include recordings made using mobile phones, tablets, drones and other digital video equipment. Prepare ahead of time and consider what needs to be captured/collected, the best positioning of the recorder, and whether wide-angle or close-up will give the best capture. Downloading and saving your recordings allows them to be archived and shared with others, as well as ensuring they are not deleted or recorded over.
- Reflective folios: this record of your feelings, opinions and thoughts on participation in an activity is an important way of collecting primary data. This is qualitative data, on the whole, and provides links to key knowledge covered in class as well as the performance context and outcomes.
- Interviews: these are generally conducted face to face and allow you to collect qualitative data. It is a great idea to record discussions (audio or video) so this can be stored and referred to in future. Plan ahead, prepare questions you will ask and rehearse these on a classmate. Be prepared to expand on your list of questions and change them based on the responses provided by the person being interviewed.
- Surveys/questionnaires: these involve respondents answering a set of questions in writing or online. Both qualitative and quantitative data can be collected. Questions need to be carefully constructed: you cannot provide further explanation as they are completed remotely.

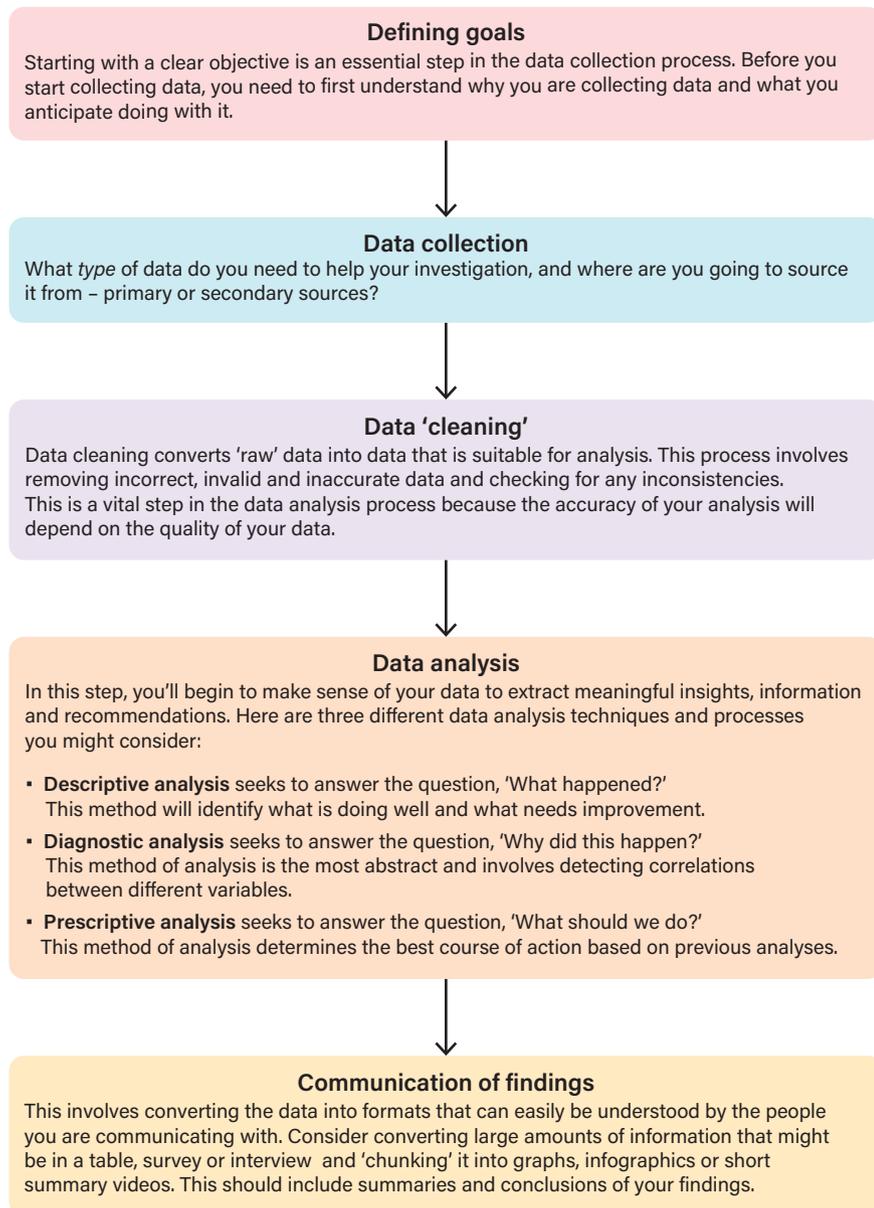
## Secondary data

Secondary data is data that has been collected by others, which you can use to increase your understanding and apply to your existing knowledge; it includes the following.

- Published sources: these include textbooks, magazines, newspapers, journals, TV news reports, and reports by governments and sporting associations.
- Online sources: this option offers the easiest access and can include websites, online journals, news sites and blogs.

## Data collection and analysis

Data collection and analysis follows a detailed step-by-step process and should include the following.



Adapted from Erdelyi, L. (2020), 'The five stages of the data analysis process,' Lighthouse Labs

## Acknowledging sources and citations

While conducting research, you need to keep a record of details that will be cited in your reference list or bibliography. You should check with your teacher as to which style or format is required (e.g. APA or Harvard). In most cases, details need to include:

- author surname(s) and initial(s)
- year of publication
- title of book/document
- date of publication/posting
- publisher/organisation name
- page(s)/URL/web address.

Here is an example:

Malpeli R, Whittle R., Sharp M., Corrie M and Telford A (2025), *Nelson Physical Education VCE Units 3&4 7ed*, Cengage Australia, p. xxv.

### Using AI in your research

**Most schools will have their own policy regarding the use of artificial intelligence (AI) so it is very important that you check with your teacher before you begin any research using AI to ensure that your school allows it.**

If you use AI to generate text or images, you should acknowledge this in your citations, just as you would for a human author, artist or photographer. If your school and your teacher allow you to use AI, you must cite each time you include something AI-generated.

Several citation guides have released official or semi-official guidance on how to cite AI-generated content. You can cite AI in your work using the following APA guidelines:

- author – the creator of the AI (e.g. OpenAI or Google)
- date – the date the content was generated
- title – the name of the AI tool (e.g. ChatGPT or Bard)
- version – the version of the AI tool (be as specific as possible)
- description – in brackets, clarify whether this is a large language model, or another specific type of generative AI
- location – the URL for the tool. If possible, give the URL for the specific content. (Note: It is now possible to send someone a URL of your ChatGPT conversation. This is the URL you should use in your citation.)

Here is an example:

OpenAI. (2023). ChatGPT (Mar 14 version) [Large language model].  
<https://chat.openai.com/chat>.

### How to cite your sources

Citations and their formatting are time-consuming and might seem irritating, but they are an important part of providing reliable information to an audience. Writing gets its credibility from sourcing the claims it makes. Readers need to be able to fact-check a writer's sources and trace where the claims made in a piece come from.

# Preparing for your exams

## Examination format

An end-of-year examination will contribute 50 per cent of the final study score for Units 3 and 4 Physical Education. Physical Education examinations will typically include three sections:

- **Section A: multiple-choice questions**
- **Section B: short-answer and extended-answer questions**, including integrated questions with multiple parts. One of the extended-answer questions will be worth 6–10 marks and will not have multiple parts.
- **Section C: extended and integrated response questions**, requiring students to make connections to knowledge across each unit in an integrated manner. This will contain multiple inclusions/parts and will be worth 8–12 marks.

The examination may include questions that refer to visual and/or written material, including scenarios. All questions and sections are compulsory.

## Examination conditions

The end-of-year exam for Units 3 and 4 is 2 hours in duration, with 15 minutes of reading time. It is developed by the VCAA, to be completed under supervision and in the same conditions (same time, same date etc.), and is externally marked. Any Unit 1 and 2 examinations, where conducted by schools, are developed by your teachers and, if there are multiple classes, will usually be sat under the same conditions. These are internally marked by PE teachers at your school.



Chinnapong/Shutterstock.com

## Reading time

As the name suggests, during this time you can *only* read and not write anything down. You are not allowed to pick up your pen, so do not even write your name or student number. Wait for the supervisor or teacher to give you the all-clear to start writing. Reading time is vital to familiarise yourself with each question and the associated stimulus material (graphs, images, tables etc.) and start to mentally plan your responses. It is also important that you mentally note the command words in questions and zero in on how you are being asked to respond to a question (more on this to come).

Reading time is when you work out a 'plan of attack' – how you intend to approach the responses. You do not need to answer the questions in any specified order or numerically and should answer questions you feel most comfortable first – this forms part of your plan. Some students like to answer the multiple-choice section first, while others leave this until they have attempted the other section(s) – it's totally up to each individual student.

Research has shown that students who first answer questions they feel most comfortable with approach the exam with a more positive mindset, tend to have more time to devote to longer questions, and generally perform better than those who are more challenged by questions they consider in numerical order. It is worth noting that the VCAA tends to develop exams in which Question 1 is fairly straightforward in an effort to ease any nerves students may have. This should allow you to proceed with higher levels of confidence than if the question had been more difficult to respond to, requiring more information-processing and cognitive thought in creating a response.

## Writing time

Do not start writing anything until you have reread the question and underlined or highlighted the command words and anything that is relevant from the stimulus material. Images, graphs, tables etc. are not placed in exams to make them look pretty or to confuse students; they contain important information that should inform your response.

### Unpacking any stimulus material

All stimulus material needs to be carefully considered and referred to in some way in your response. Before responding to the question, underline the axis labels and heading in a graph or highlight the key parts of a table (this could be column headings) and look for trends and relationships between variables being presented for your consideration.



- a. Identify **one** method of data collection that a coach could have used to obtain the data above and provide **one** benefit of using this method.

2 marks

### Identifying command words

**Command words** or 'action words' are also known as cognitive verbs (see the list on pages xxi–xxiii). These actions are used to demonstrate your level of understanding of key knowledge and in most cases appear at the start of a question. This tells you how you should respond.

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Let's consider two different commands for an otherwise identical question and how this significantly changes the way you are expected to respond.

Sample question: **Justify** why progression was applied during week 6 of the training program.

Justify: show, prove or defend an argument

Sample answer: *Progression was applied during week 6 because the subject indicated that training was becoming easy and the fitness test results showed significant improvement from pre-test values.*

Sample question: **Identify** how progression was applied during week 6 of the training program.

Identify: recognise and name an example

Sample answer: *Progression was applied during week 6 by increasing the duration of the continuous run from 25 minutes to 27 minutes. Additionally, the training diary reveals an additional repetition was undertaken for each of the long-interval runs. The subject went from three sets of 5 × 600 m runs at 85% max HR to three sets of 6 × 600 m.*

## Multiple-choice questions

**Multiple-choice questions** will not include the same command words, and are generally structured to ask you 'what', 'why', 'which', 'how' etc. They will most likely refer to stimulus material, and once again this needs to be carefully considered before you try to eliminate the responses that cannot be correct, and thus end up with the correct, or most correct, response. Once you have 'knocked out' each incorrect response, put a line through this letter on the exam booklet. Why? If you find yourself thinking that there could be two possible responses to a multiple-choice question, asterisk the question or use another signal that reminds you to come back to it before the end of the exam. If you have already drawn a line through incorrect options, you will then only need to decide between two, rather than all four, options. Never leave a multiple-choice question unanswered: at least make an educated guess!

## What the marks and answer lines for a question can tell you

**Pay attention to the marks allocated per question** (or question part) as well as the number of lines or amount of space provided for your response. Both indicate the depth and level of detail your response needs. For example, a question asking you to outline may be worth 2 marks, whereas another that seeks you to explain may have 4 marks associated with it and twice the number of lines provided. If you find yourself needing to write more than the space provided, it may be that you have included irrelevant information.

Remember – clear and concise responses score better than long and convoluted ones. If you find it difficult to contain your responses into the space provide during trial exams, make sure to work on this. Otherwise, you may find yourself running out of time and not answering all the questions on the exam or rushing to complete them all (both will result in you performing below your best). Similarly, if you have many lines left after you have finished your response, ask yourself if you have addressed all aspects of the question.

**Do not restate the question in your answer or simply state facts and/or chunks of information, hoping the assessor will sift through these to find marks for the correct parts!**

The key knowledge you have attained during the year has been applied to practical activities, SACs and other internal tasks via key skills you have developed. These skills will allow you to interpret, analyse, explain and evaluate what is in the question and structure an appropriate response.

### Extended-response questions

**Extended-response questions** will consist of multiple parts and require students to call upon their knowledge of different key concepts and parts of coursework contained in different units of study. It's often a good strategy to make a list of bullet points you intend to include before starting your response. This will encourage you to think about all relevant aspects and possible links between them. This is like creating a plan before writing an English essay, and referring back to it will ensure you have covered everything.

Make sure you address every part of the extended question being asked. You can use diagrams to assist your response and demonstrate your understanding (in some questions this is a stated requirement). Extended responses require careful attention to ensure you have linked together the different parts of the course, as required. For example, you might be required to discuss different practice settings and types of feedback that can be used alongside biomechanical principles to improve movement sequences. Or you could be required to discuss how energy system fatigue needs to be considered when designing a program to target certain fitness components for improvement, while maintaining others identified as strengths.

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## FINAL NOTE

Participating in practical activities with regular reflections throughout the year will strengthen links between the theory/key knowledge covered in class and physical activity (real world and sporting) contexts. Making strong connections between the two throughout the year, as well as your participation in sport outside school, is vital in consolidating key learnings and understandings.



Jeffrey Isaac Greenberg 18+/Alamy Stock Photo

# UNIT 3

# MOVEMENT SKILLS AND ENERGY FOR PHYSICAL ACTIVITY, SPORT AND EXERCISE



master1305/Adobe Stock

- » covers many principles used to analyse human movement from a biophysical perspective
- » presents several tools and coaching techniques used to analyse movement skills and apply biomechanical and skill-acquisition principles to improve and refine movements and skills
- » considers the cardiovascular, respiratory and muscular systems and their roles in supplying oxygen and energy to the working muscles
- » investigates the characteristics and interplay of the three energy systems for performance during physical activity, sport and exercise
- » explores the causes of fatigue and consider different strategies used to postpone fatigue and promote recovery.

<b>CHAPTER 1</b>	Classification of skills	4
<b>CHAPTER 2</b>	Coaching to enhance participation and performance	30
<b>CHAPTER 3</b>	Biomechanical analysis of human movement	96
<b>CHAPTER 4</b>	Performing a qualitative movement analysis	170
<b>CHAPTER 5</b>	Acute physiological responses to exercise	194
<b>CHAPTER 6</b>	The production of energy for human movement	232
<b>CHAPTER 7</b>	Muscular fatigue mechanisms and nutrition and hydration strategies	274

## CHAPTER

# 1

## CLASSIFICATION OF SKILLS

UNIT 3 - AREA OF STUDY 1



EpicStockMedia/Adobe Stock

**FIGURE 1.01** Surfing is undertaken in unpredictable environments.

### Quizzes

Chapter 1 Pulse check

**1.1** Check-in questions

**1.2** Check-in questions

Chapter 1 Review questions

### Videos

Masterclass: Chapter 1

**1.1** In focus: Transferability

**1.1** In focus: Stability of the environmental context

### Resources

Chapter 1 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



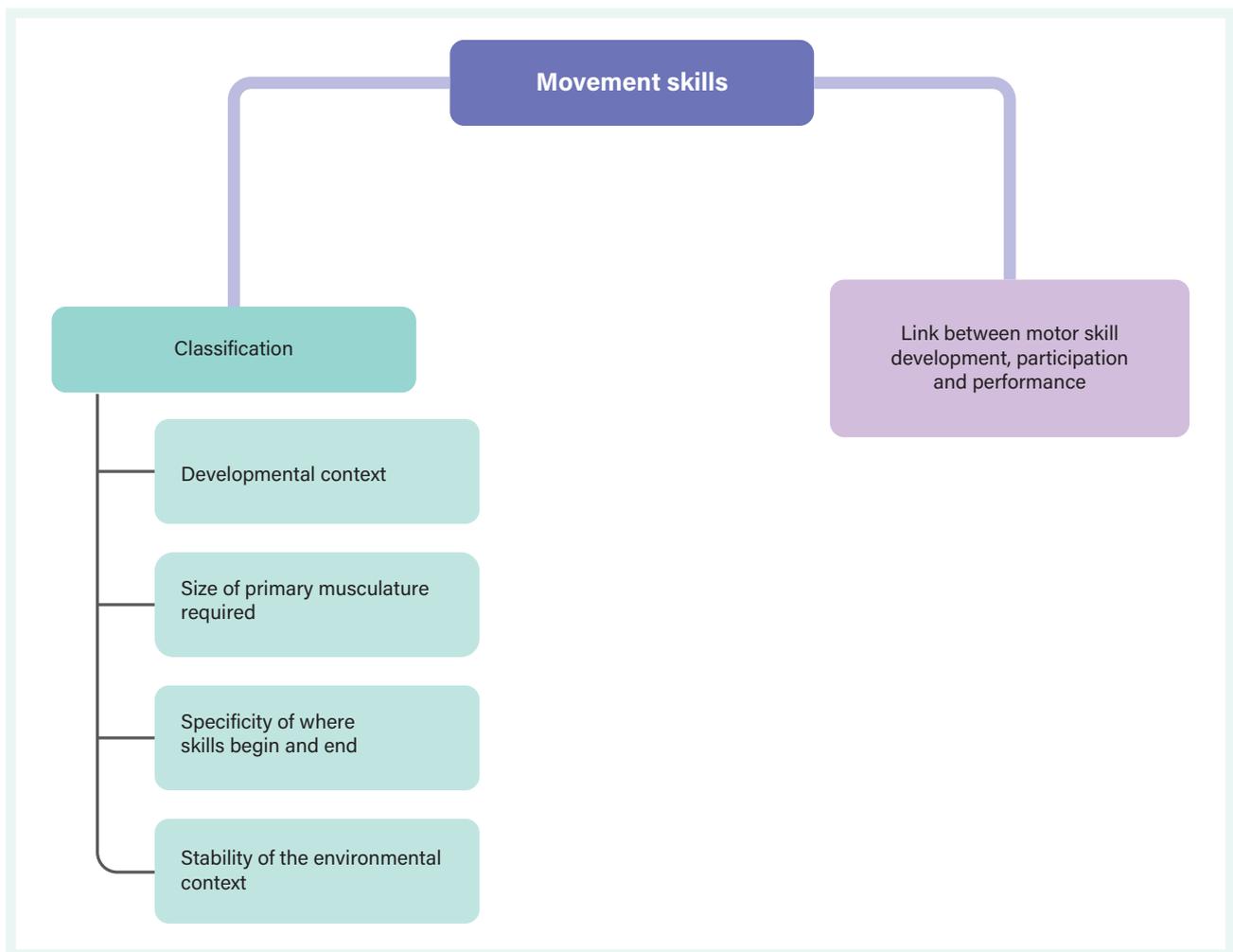
- » classification of movement skills, including fundamental movement skills, sport-specific skills, open and closed skills, gross and fine skills, and discrete, serial and continuous motor skills
- » the link between motor skill development, participation and performance

## KEY KNOWLEDGE

- » analyse and classify movement skills
- » analyse the link between motor skill development, participation and performance

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)





Video

Masterclass: Chapter 1

Assessment  
Pulse check

Skill acquisition is an area that explores how we learn movement skills. It is influenced by the type of skills to be learnt, the developmental stage of the learner and the environmental context.

### PULSE CHECK

You may have come across some of these concepts before while studying Physical Education. Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- 1 **List** five examples of fine motor skills.
- 2 **Identify** three characteristics of gross motor skills.
- 3 **Suggest** an example of a discrete motor skill.
- 4 **Describe** what is meant by a closed motor skill.
- 5 **Explain** the difference between an open and a closed motor skill.
- 6 **Discuss** the link between motor skill development, participation and performance in activities.

## 1.1 CLASSIFICATION OF MOVEMENT SKILLS

In this module you will learn about:

- classification of movement skills, including fundamental movement skills, sport-specific skills, open and closed skills, gross and fine skills, and discrete, serial and continuous motor skills
- and learn to:
- analyse and classify movement skills.

When you throw a ball, walk, hit a tennis ball, play computer games, drive a car, dance, get dressed or play a musical instrument, you are performing a motor skill. As part of this study, you will be considering biomechanical and skill acquisition principles that can be applied when analysing and improving movement skills for participation and performance. As a starting point, it is important to gain an understanding of the broad categories that are used to classify motor skills. Skills can be classified based on their characteristics. Understanding the characteristics and demands of a skill enables coaches and teachers to assess performance, plan skill development and training sessions, and provide relevant, tailored and developmentally appropriate feedback.

### LOOKING FORWARD

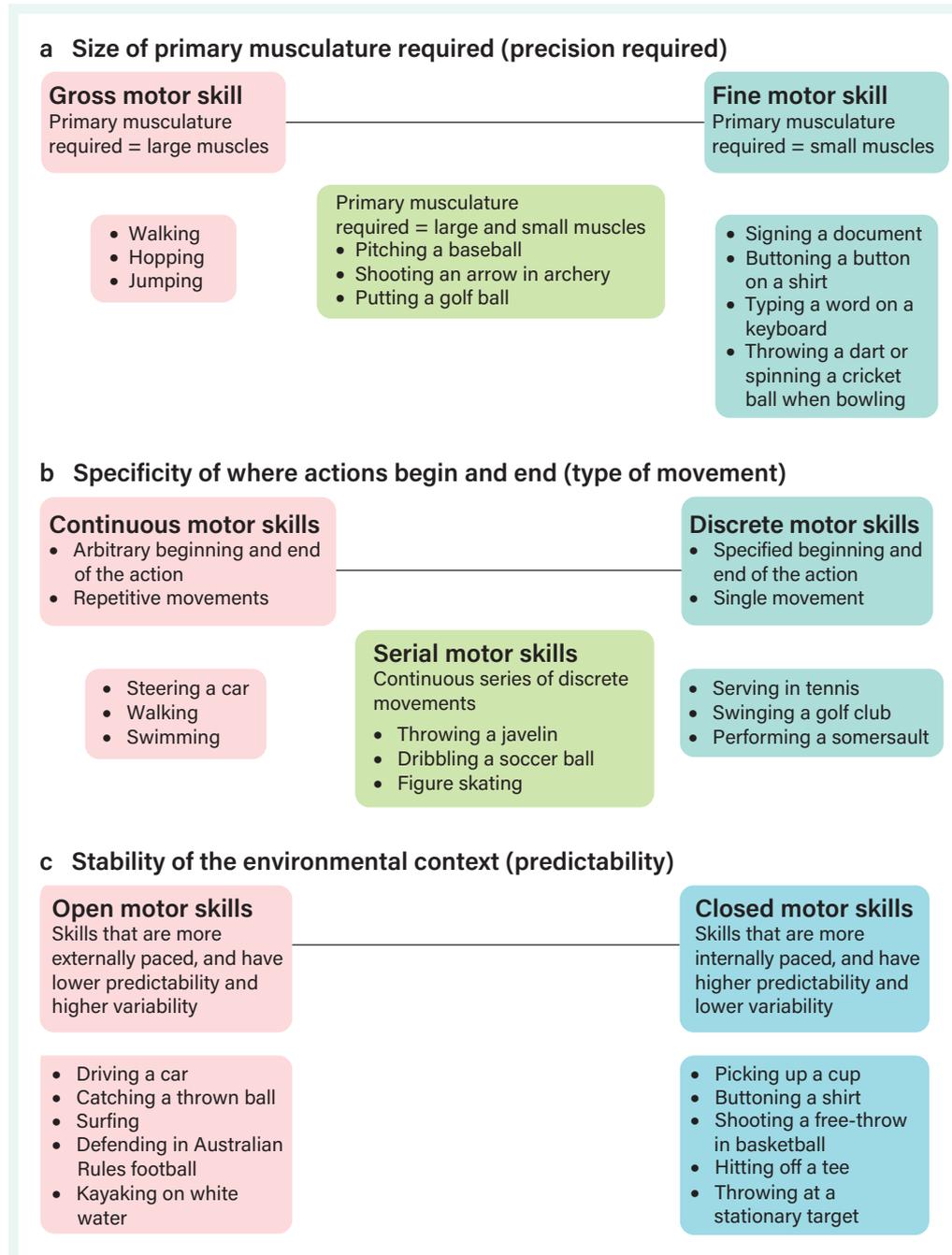
#### Feedback

#### Chapter 2

In Chapter 2, we will be taking a close look at the importance of frequency and type of feedback.

We can classify movement skills in many ways. For the purpose of this chapter, we will use four one-dimensional motor skill classification systems, based on:

- developmental context
- size of primary musculature required (precision required)
- specificity of where actions begin and end (type of movement)
- stability of the environmental context (predictability).



**FIGURE 1.02** Movement classification systems

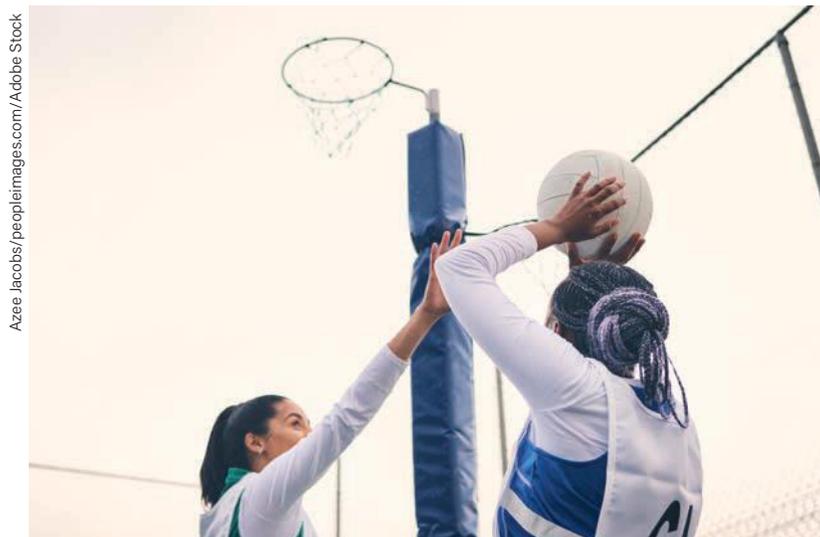
Adapted from Magill, R. & Anderson, D. (2021), *Motor Learning and Control: Concepts and applications*, McGraw Hill

## What are motor skills?

### motor skill

A skill that requires voluntary body and/or limb movement to achieve its goal

A **motor skill** is a skill that requires voluntary body and/or limb movement to achieve its goal. Motor skills are considered an activity that we learn through practice and experience. Learning motor skills is a crucial part of child development and daily living throughout the rest of our lives; from getting dressed to playing sport, motor skills are essential.



**FIGURE 1.03** Goal shooting in netball is an example of a motor skill.

## Developmental context

Fundamental movement skills developed during childhood are considered to be the building blocks for sport-specific movement patterns. Within a sport-specific environment, mastery of fundamental movement skills can separate children for potential success in sport. Some people believe that without the effective development of fundamental movement skills in childhood, future sporting success at a higher level may be unattainable (Jukic, Prnjak, Zoellner, Tufano, Sekuli & Salaj, 2019).

## Fundamental movement skills

**Fundamental movement skills (FMS)** are defined as basic learnt patterns that do not occur naturally (Barnett, Stodden, Cohen, Smith, Lubans, Lenoir et al., 2016) and that it is suggested are foundational for more complex physical and sporting activities (Newel, 2020). The terms 'fundamental motor skills', 'fundamental movement patterns' and 'fundamental movements' are often used interchangeably with 'fundamental movement skills'. FMS are considered important to the initiation and maintenance of participation in physical activity as they provide the foundation for competent and confident participation in a range of physical activities, including more sport-specific movement skills.

### Transferability

Most advanced skills used in sports are advanced or specific versions of the fundamental movement skills. For example, Figure 1.04 (State Government Victoria, 2009) shows a range of movement skills that have a similar basic action – in this case the fundamental movement skill of the overhand throw. This forms the basis for throwing a baseball, a softball or a cricket ball overarm, the serve in tennis or volleyball, the smash or overhead clear in badminton and the shoulder pass in netball or basketball.

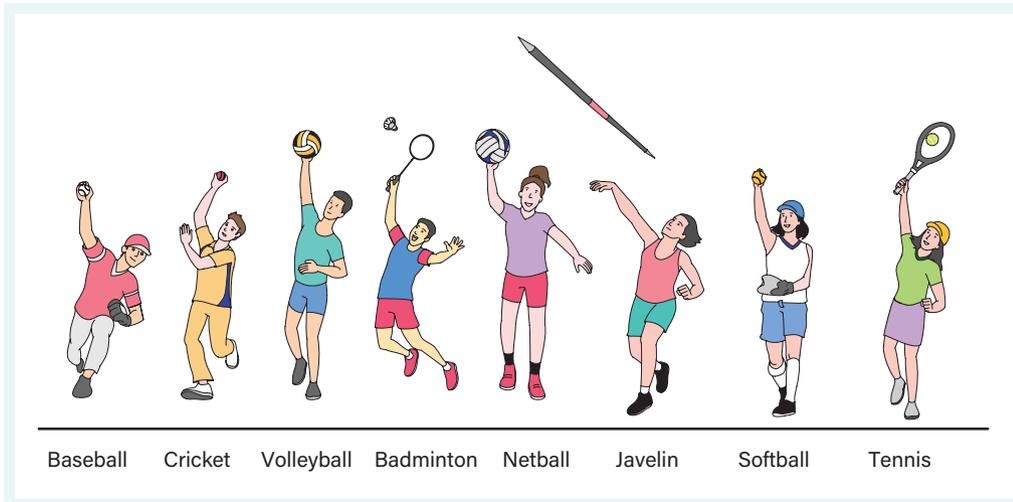
### fundamental movement skills (FMS)

Basic learnt patterns that do not occur naturally, and that form the basis of more complex sport-specific skills

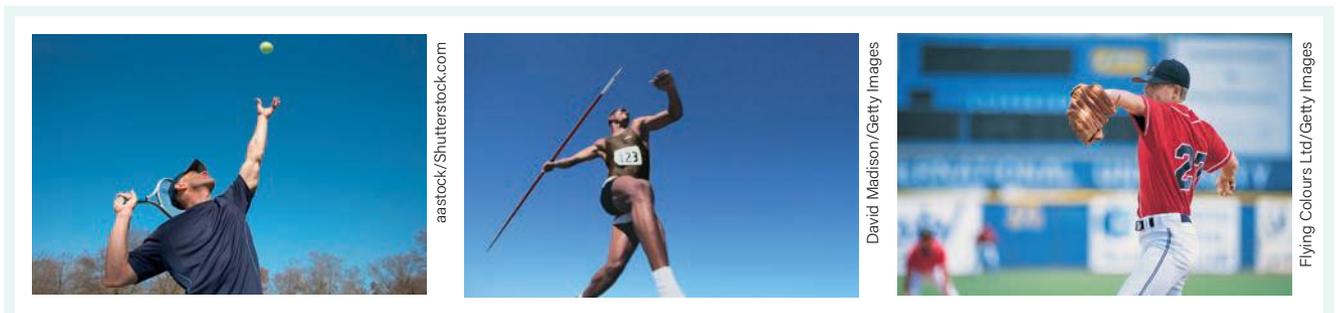


Video

In focus: Transferability



**FIGURE 1.04** The relationship between a fundamental motor skill (overarm throw) and specific sports skills



**FIGURE 1.05** All these sport-specific skills are advanced forms of the overarm throw.

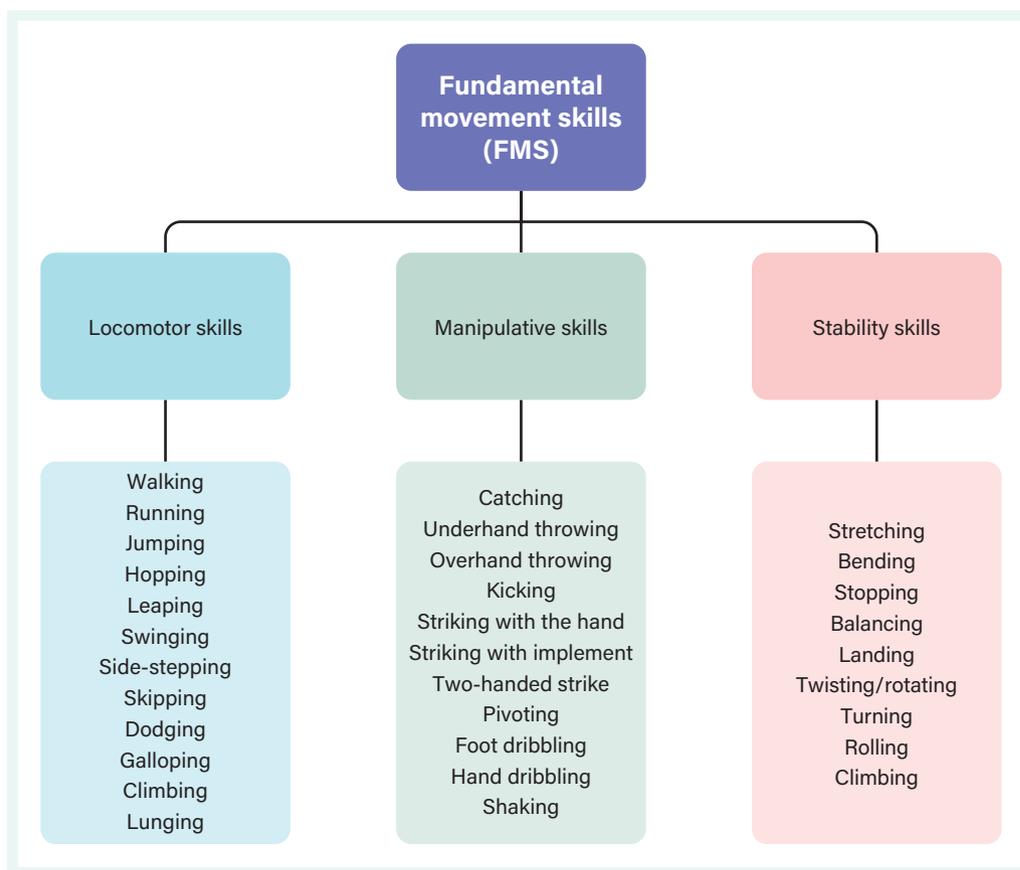
## Classifying fundamental movement skills

Fundamental movement skills can be classified into three distinct categories:

- stability (body control) skills involving balance and control of the body (e.g. balancing, dodging, twisting)
- locomotor (movement) skills that enable us to move through space (e.g. walking, skipping, hopping)
- manipulative (object control) skills involving the control of an object (e.g. throwing, catching, striking).

There are many lists available that attempt to categorise fundamental movement skills. In fact, there is no universal consensus on what skills should be included, nor is there a universally accepted, definitive list. Figure 1.06 is just one example, and it includes an extensive list of components of the various classifications of fundamental movement skills. You would most likely be engaging in many of these skills within a quality secondary physical education and sport program. In primary school Physical Education (PE) programs, the list of fundamental movement skills is kept simple to include:

- **locomotor and non-locomotor skills** – rolling, balancing, sliding, jogging, running, leaping, jumping, hopping, dodging, galloping, skipping, floating and moving the body through water to safety
- **object control skills** – bouncing, throwing, catching, kicking, striking.



**FIGURE 1.06** Categories of fundamental movement skills

## Critical window to develop fundamental movement skills

The ages from 6 to 10 years are considered a critical window for children to develop their fundamental movement skills. This is considered an optimal time to train skill and movement competency because the neuromuscular system is most susceptible to change and neural plasticity at this age (Tompsett, Burkett & McKean, 2014). Motor control, although age-related, is not age-determined nor linear with chronological age, and development beyond age 10 is possible but will occur at a much slower rate. Research has shown that fundamental movement skill (FMS) competence is associated with participation in physical activity during childhood, and intervention programs have the potential to increase daily levels of moderate to vigorous physical activity (Graham, Azevedo, Wright & Innerd, 2022). Often, fundamental movement skills have been considered developmental. They have been mapped for individual children and compared on an average age-group basis (Newell, 2020). Several studies have shown that intervention programs targeting early childhood that provide well-equipped free play time do not significantly improve FMS; only when children are provided instruction do they display significant improvement in FMS (Newell, 2020).

## Teaching fundamental movement skills

In Chapter 2 we will explore in more detail considerations for enhancing skill development and refinement of skills. In the meantime, here are a few key points to note about the instruction of FMS:

- It can address individual student learning styles and developmental levels.
- A broad range of both 'instructional models' and teaching strategies can be implemented.
- It can be taught and practised within a game-like environment, where game play, either structured or non-structured, is integrated in the curriculum or practice environment.
- Expertise in skills can be taught within the game context.
- Teachers who exhibit a deep understanding of game-centred pedagogy can balance the teaching of skills/tactics in a game-play context.
- Simultaneous development of FMS and tactical skill has been demonstrated using a game-sense approach.
- Promoting a mastery or high-autonomy climate is an approach that aids learning through autonomous motivation and can be attached to both skills-based and games-based pedagogies.
- Using a mastery approach promotes the development of skills in a non-competitive, non-threatening learning environment. In this inclusive environment, all students have an opportunity to succeed and receive instruction and positive reinforcement, and are encouraged to improve, which can lead to higher levels of intrinsic motivation, enjoyment and perceived competence (Newell, 2020).

### CASE STUDY

#### THE USE OF EXERGAMING TECHNOLOGY TO DEVELOP CHILDREN'S FUNDAMENTAL MOVEMENT SKILLS

Typically, screen-based technology is considered in a negative light for young people as it promotes long hours of passive screen use and sedentary behaviour. However, advances in technology have enabled users to actively interact with digital screens using their body (exergaming) rather than just by pressing a button on a controller. You might own an Xbox or a Nintendo Sports or Ring Fit. These immersive technologies offer new opportunities to develop children's fundamental movement skills through digital engagement. Exergaming enables the child to explore and adapt to a wide range of movement activities, such as tenpin bowling, boxing, baseball, tennis, golf, **Chanbara**, volleyball, badminton, football and many others. In exergaming, in contrast to the traditional pressing of buttons on a controller, children can interact within games using movements of their body while holding a controller, with the manipulation of their body parts in space and movement of the controller allowing them to see the movement on screen. This technology has enormous potential for children with low fundamental movement skills, who might find it difficult to participate in real activities.

A systematic review and meta-analysis (Oppici, Stell, Utesch, Woods, Foweather & Rudd, 2022) of the impact of exergaming technologies on fundamental movement skills development in children aged 3–12 years found a small positive effect in favour of the use of exergaming. The researchers recommend the quality of future outcomes will be enhanced by technical design to ensure that specificity of the skills used in the games compares closely to the real skills.

#### Chanbara

A Japanese term for adapting the fighting arts to film



**Command terms****list**

Provide a series of related words, names, numbers or items that are arranged consecutively

**identify**

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

**constraints**

Limitations or restrictions. A constraints-based approach allows the learner to explore movement skills and to find solutions to movement problems with less input from the coach and greater interaction with other learners.

**QUESTIONS**

- 1 **List** five fundamental movement skills that could be developed using exergaming.
- 2 **Identify** three active games you have engaged in or observed someone else play.
- 3 **Describe** an advantage of using exergaming with children to develop fundamental movement skills.
- 4 **Discuss** an example of a situation where exergaming might be a useful tool to develop fundamental movement skills for children who might find it difficult to participate in real activities.
- 5 **Justify** whether or not you think exergaming should be made accessible during lunchbreaks on wet-weather days in primary schools.
- 6 **Explain** why the researchers mentioned that specificity is important when designing future games.

**LOOKING FORWARD****Specificity****Chapter 12**

In Chapter 12, we will look more closely at the training principle of specificity.

**REAL WORLD APPLICATIONS****Learn FMS with parents**

The 'Active 1 + Fun' program (Ma, Lonsdale, Lubans, Ng & Ng, 2021) was evaluated with 171 families over nine months of free sporting equipment and 10 coach-led workshops and activity sessions. The program was effective in improving children's fundamental movement skills, and a secondary outcome of the program was that parents spent more time participating in physical activity with their children.

**ABOVE AND BEYOND THE STUDY DESIGN**

Cross-cultural comparison of fundamental movement skills, page 27

**Sport-specific movement skills**

Sport-specific skills are the technical skills that apply specifically to the demands of a particular sport. As mentioned earlier, fundamental movement skills provide the building blocks that enable a child to progress to develop sport-specific skills. Many coaches think training starts with sport-specific skills, but the most successful coaches understand the importance of ensuring the foundation is solid. Perfecting your sport-specific skills in terms of technique is important; however, practising those skills in a highly varied environment, simulating game-like scenarios and manipulating different **constraints** will enhance adaptability and the ability to adjust to any situation.

## COLLABORATIVE TASK

### Prac activity/Lab activity

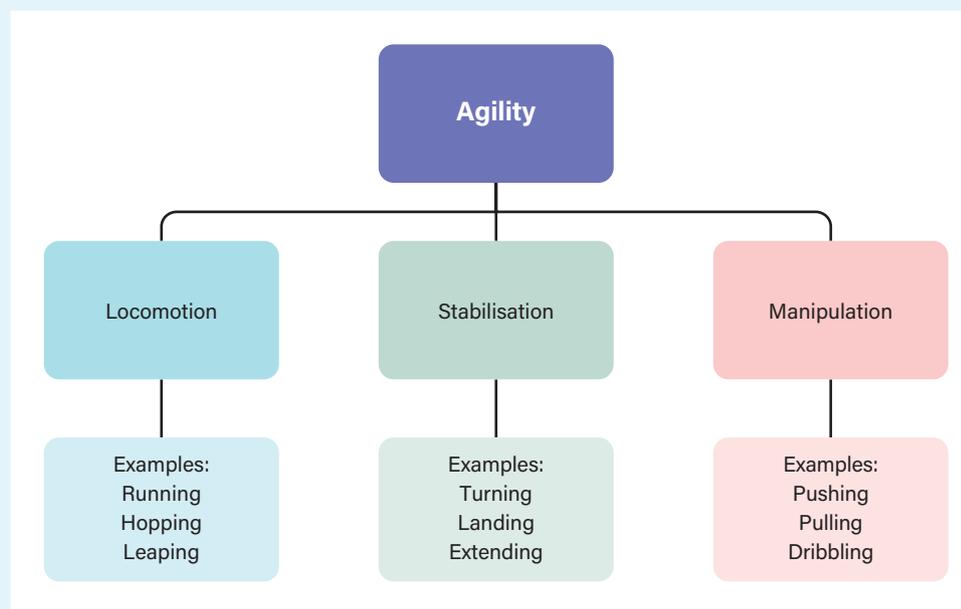
#### Analysing sport-specific skills

Sport-specific skills often combine several different movements. In Figure 1.07, agility is displayed as the example of sport-specific skills. Agility is a common feature of many sports and will look and feel different in different contexts: for example, the nature of the agility needed by a hockey goalkeeper will be very different from that of a baseball catcher. An agile movement can be made up of a combination of locomotion, stabilisation and manipulation skills combined into a rapid sequence of movement. Our baseball catcher might need to make a rapid throw over to second base because the baserunner on first base has stolen to second base. The catcher uses locomotion to leap up into a semi-standing position, stabilisation to rotate their body to make the throw, and manipulative skills to throw the ball.

Participate in a sport as a class (e.g. basketball, netball, cricket). Nominate some students to observe the activity and record examples of sport-specific skills.

#### QUESTIONS

- 1 Discuss the sport-specific skills identified and what combinations of fundamental movement skills would be involved in those skills.
- 2 Complete this thinking exercise for one of your chosen sports.



**FIGURE 1.07** The sport-specific skill of agility can be made up of a combination of fundamental movements, depending on the context.

## LOOKING FORWARD

### Enhancing adaptability

#### Chapter 2

In Chapter 2, we will look more closely at strategies coaches can implement to enhance the variability of a practice environment using a constraint-based approach to coaching.

## Movement similarities across different contexts

You will know from playing sport that many sports use similar movement skills – for example, the leap is used in gymnastics, parkour, basketball layups and long jump.

### CASE STUDY

### ANALYSING MOVEMENT SIMILARITIES

Table 1.01 displays the association between fundamental movement skills and sport-specific skills and play activities.

**TABLE 1.01** Association between selected fundamental movement skills and sport skills

Fundamental movement skill	Example in sport or play activities
Vertical jump	Jumping up on a surfboard Landing from a jump or height Skipping-rope games, elastics games, leapfrog Shooting a hoop
Dodge	Evading an opponent
Overarm throw	Badminton smash or clear Baseball/cricket/softball overarm throw Volleyball serve or spike Javelin throw
Forehand strike	Tennis/badminton/squash/pickleball/racquetball forehand
Two-handed strike	Baseball/softball swing Cricket hit Hockey swing Golf swing
Catch	Rugby Baseball/softball Netball/basketball Cricket/rounders Gymnastics (rhythmic)
Kick	Football (AFL) passing and kicking for goal Soccer passing and shooting Rugby field goal kick
Run	Track – all distances All invasion sports Basketball fast break Cricket running to field a ball

#### Command terms

##### analyse

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

##### synthesise

Combine various elements to make a whole or an overall point

### QUESTIONS

- Identify** three sport-specific skills associated with the catch.
- List** three sport and/or play skills you engage in while participating in your favourite sport.
- Describe** how fundamental movement skills link to sport-specific skills.
- Discuss** how sport-specific skills can share similarities across different sports.
- Consider the sport of basketball and **analyse** which sport-specific skills are mentioned in the table by making a list and explaining when each of these movements would be used during a game of basketball.
- Synthesise** this table by adding a different sport-specific example to each row.



## ABOVE AND BEYOND THE STUDY DESIGN

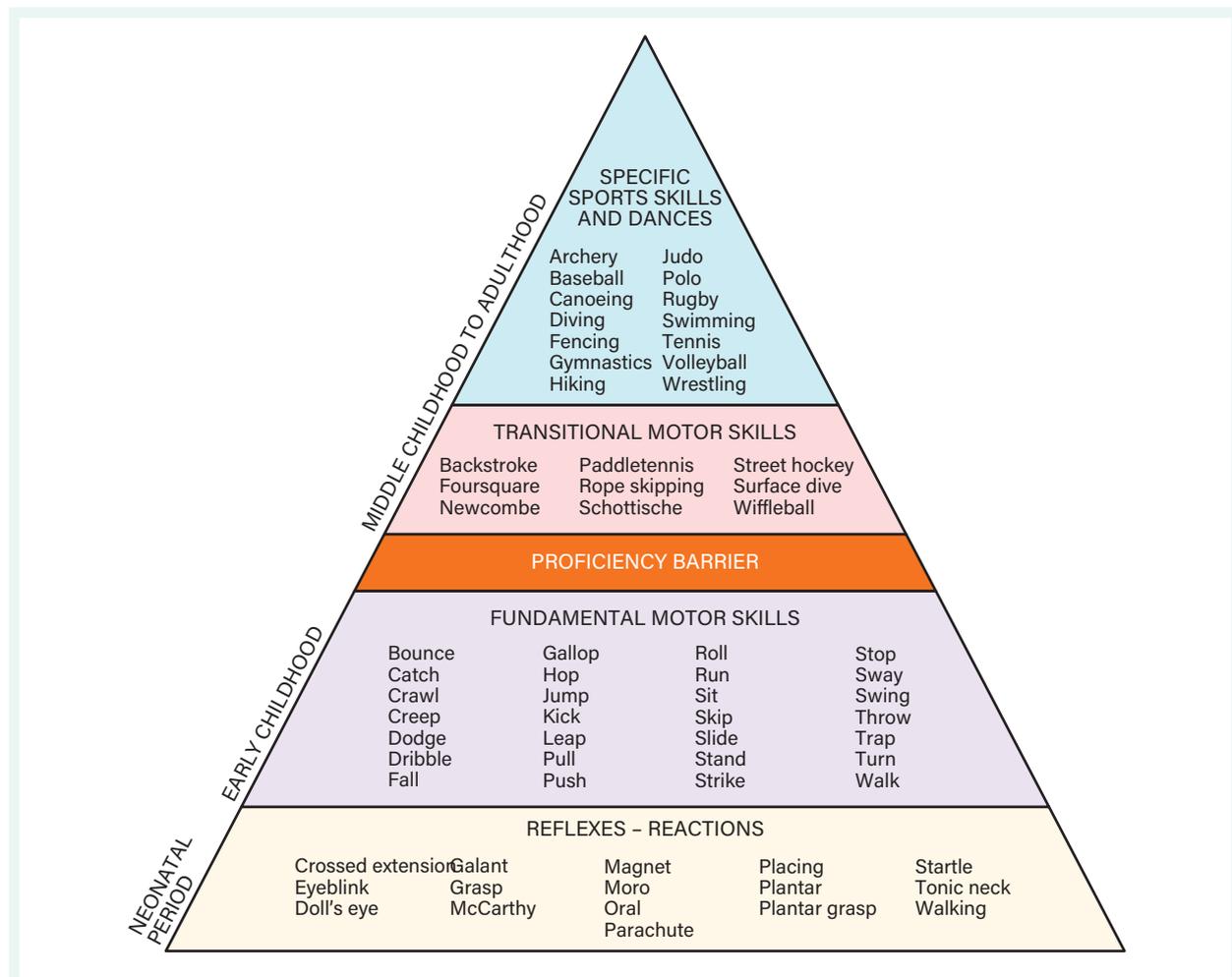
The following two FMS models have been provided for context and comparison to demonstrate the progression of skill development. The *Victorian Certificate of Education Physical Education Study Design 2025–2029* does not expect students to memorise these or any other FMS models.

### The Seefeldt (1980) Pyramid Taxonomy

Probably the most comprehensive **taxonomy** of motor skill development was proposed by Seefeldt (1980). It overviews development from birth to adulthood (see Figure 1.08). The pyramid formation represents the idea that motor skills at different developmental stages are the preceding building blocks for subsequent development of new motor skills. The pyramid includes one of the most comprehensive lists of fundamental movement skills, particularly in contrast to that of the Victorian Government (see Figure 1.09). There is debate about the usefulness of the transitional motor skills layer (Newell, 2020). Seefeldt (1980) also introduced the notion of a proficiency barrier to the transitional and complex skills of sport and physical activity that needed to be crossed to ensure a child would have success in their sport of interest. The barrier represented a competency level in the FMS necessary to achieve successful learning in more complex activities of sport.

#### taxonomy

A scheme of classification

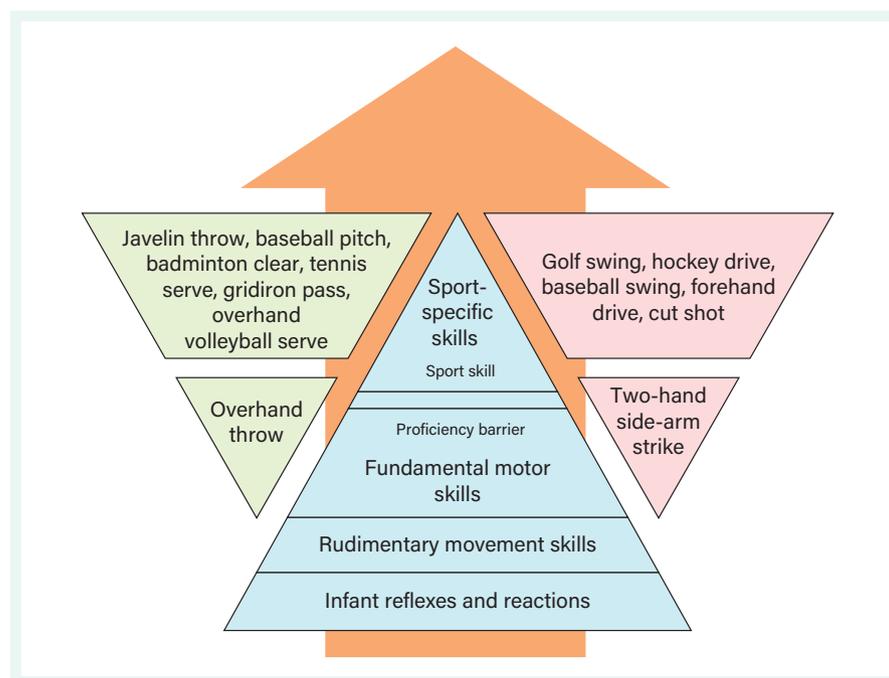


**FIGURE 1.08** Seefeldt (1980) Pyramid Taxonomy of fundamental motor skills

Source: Seefeldt, V. (1980), 'Developmental motor patterns: Implications for elementary school physical fitness', in Nadeau, C.H., Halliwell W.R., Newell, K.M. & Roberts, G.C. (Eds), *Psychology of motor behavior and sport*, pp. 314–323, Champaign, IL: Human Kinetics



## ABOVE AND BEYOND THE STUDY DESIGN



**FIGURE 1.09** Effects of fundamental motor skills instruction on the performance of sport-specific skills

Source: Adapted from *Fundamental Motor Skills: A manual for classroom teachers*, State of Victoria, 2009

## Victorian model of FMS to sport-specific skills

The 'Effects of Fundamental Motor Skills Instruction on the Performance of Sport-specific Skills' model (Victorian Government, 2009) suggests mastery of skills is necessary not only for development of higher-level skills, but also to foster students' persistence with difficult tasks as they will avoid activities that might expose them to 'public failure'. The model proposed that, if children encounter a sport skill proficiency barrier they are unable to pass, they will reject participation in physical activity as part of their lifestyle. Critics of this framework call for a broader range of activities to be considered fundamental motor skills, and what makes a person physically educated to form a lifespan approach across a full range of motor skills and inclusion of activities of daily living, self-help and communication skills (Newell, 2020).

## Size of primary musculature required (precision required)

Another method we can use to classify movement skills is based on the size of the muscle groups and muscles required to perform a particular movement.

### Gross motor skills

#### gross motor skill

A motor skill that requires the use of large musculature to achieve the goal of the skill

**Gross motor skills** involve the recruitment of large muscle groups or the whole body. There is less emphasis on precision, and they are generally considered easier to learn than fine motor skills. Gross motor skills develop from birth and become progressively more complex. Examples include running, swimming, throwing, kicking, jumping, skipping and tackling.



iStock.com/MJPS

**FIGURE 1.10** Gross motor skills are used constantly in sports.

## Fine motor skills

**Fine motor skills** involve the recruitment of smaller muscles associated with movements requiring precision, such as bouncing the ball before serving in tennis, or the precise finger and hand movement required when throwing a dart. Other examples include:

- volleyball – tap of the ball for a set (finger touch)
- snooker – hand movement to take a shot
- baseball – adjustment of grip to throw a slider or curve ball.

### **fine motor skill**

A motor skill that requires control of small muscles to achieve the goal of the skill. Typically it involves eye–hand coordination and requires a high degree of precision of hand and finger movement.



Serhii Kucher/Alamy Stock Photo

**FIGURE 1.11** We use fine motor skills in sports and in our everyday lives.

## DID YOU KNOW?

Even the finest movements that we perform when holding a pen or pencil use multiple muscles, including the flexor pollicis longus, the flexor digitorum superficialis and the flexor digitorum profundus. The flexor pollicis longus enables us to flex the thumb, while the other muscles allow for finger flexion.

## COLLABORATIVE TASK

### Activity

#### Classifying movement skills

Reflect on three physical activities you engage in regularly at school, at home or within the community. Identify several motor skills that you use to engage in these physical activities. For each skill, analyse whether it would be classified as a gross or a fine motor skill, and also whether it would be classified as a discrete, serial or continuous motor skill. Discuss with at least one other person.

## Specificity of where actions begin and end (type of movement)

Movement skills can also be classified according to the type of movement, as:

- discrete motor skills
- serial motor skills.
- continuous motor skills.

### Discrete motor skills

**Discrete motor skills** have an obvious beginning and end, such as kicking a ball or making a netball pass.

### Serial motor skills

Sometimes, several discrete skills are performed in a sequence, such as in a gymnastics floor routine. This combination of discrete skills is classified as a **serial motor skill**. Serial skills are a group of discrete skills combined to make a new and complex movement. For example, a basketball layup combines dribbling, catching, jumping and shooting, and the triple jump consists of the hop, step and jump. Other examples include:

- a dance routine with deliberate choreography
- specific strokes in swimming
- higher-level gymnastics
- a rally in tennis.

---

#### discrete motor skill

A motor skill with clearly defined beginning and end points, usually requiring a simple movement

---

#### serial motor skill

A motor skill involving a series of discrete skills

## Continuous motor skills

**Continuous motor skills** have no definite beginning or end point and include activities such as walking and running. For cycling, the end of one cycle of movement is the beginning of the next and the skill is on a repeated cycle that can be stopped at any time. Sometimes, such as in a 100-metre running race, beginning and end points are assigned, but the actual motor skill is continuous in nature. Other examples include:

- juggling
- rowing
- skipping.

### continuous motor skill

A motor skill with arbitrary beginning and end points, usually involving repetitive movements



**FIGURE 1.12** Examples of (from left to right) discrete, serial and continuous motor skills: a volleyball spike is a discrete skill; a gymnastics floor routine is a serial skill; and rolling a racing wheelchair is a continuous skill.

## COLLABORATIVE TASK

### Prac activity

#### Classifying movement skills

Participate as a class in three different physical activities that are representative of discrete, serial and continuous motor skills. Refer to the examples provided to work with your teacher to determine which motor skills will be selected.

#### QUESTIONS

- 1 **List** the three physical activities you selected and link them to the relevant category.
- 2 **Describe** why each activity meets the criteria to be classified as either a discrete, a serial or a continuous motor skill.
- 3 **Contrast** the start and finish of each motor skill. What determines the start and finish of each one?
- 4 **Identify** three other examples for each motor skill category. Select one you participate in regularly and **explain** why it would be classified as either a discrete, a serial or a continuous motor skill.

#### Command term

##### contrast

Show how things are different or opposite

##### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

**Video**

In focus: Stability of the environmental context

# Stability of the environmental context

## Predictability of the environment

The final classification of motor skills we will explore in this chapter relates to the predictability of the environment in which you are performing the skill. This is best represented as a continuum, with closed motor skills at one end and open motor skills at the other (refer to Figure 1.02, earlier).

### Closed skills

Motor skills can be classified according to the extent to which they are influenced by environmental factors. **Closed motor skills** are those where the performer has the greatest control over the performance environment. This relates to external factors such as the weather, the playing surface and the opposition. Examples of closed motor skills are an indoor individual diving routine and taking a shot from the free throw line with no opposition. In the case of the diver, they determine the routine they will perform and when their dive will commence, and are not affected by weather conditions.

In contrast to open skills, closed skills are comparatively:

- steady
- stable
- self-paced
- fixed
- reliant on predetermined patterns with reduced cognitive load.

Closed skills tend to occur in:

- self-directed sporting environments
- consistent environments where sport-specific demands persist through the entirety of the action/execution.

### Open skills

The opposite of a closed motor skill is an **open motor skill**, which is performed in a less predictable environment. In an open environment, the conditions are constantly changing and the performer has limited, if any, control over their environment. Surfing, playing team sports, horseriding, playing tennis and skiing are examples. White-water kayaking is an extreme example of an open environment.

#### closed motor skill

A motor skill that is more internally paced, and has higher predictability and lower variability

#### open motor skill

A motor skill that is more externally paced, and has lower predictability and higher variability

Paolo Bona/Shutterstock.com



Justin Setterfield/Getty Images

**FIGURE 1.13** **a** Closed and **b** open motor skills. Which performer has more control over their environment?

Open skills are characterised by a combination of:

- the ability to react to a rapidly shifting, unpredictable, dynamic and externally paced environment
- the need to make tactical decisions
- high-intensity movements
- abrupt directional changes over a short distance
- specific whole-body movements in response to continuous changes in the sporting environment
- the need to perform them while attacking opposition
- high cognitive load
- short reaction time
- the need for anticipatory skills, which are critical for decision-making (Chakraborty, Suryanshi & Nayak, 2023).

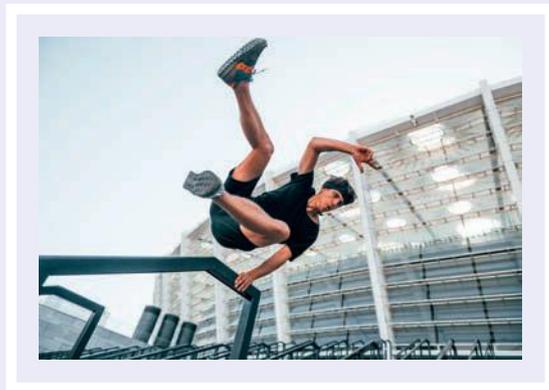
### DID YOU KNOW?

The word 'parkour' derives from the French phrase *parcours du combattant*, meaning an obstacle course, which was used as part of military training in the method developed by Georges Hébert.

### CASE STUDY

### PARKOUR

Parkour (also known as free running) has grown in popularity as a physical activity and sport over recent years, and the first International Gymnastics Federation World Parkour Championships were held in Japan in October 2022. Parkour involves moving rapidly and effectively through a complex physical environment. It consists of running through urban areas while performing a range of freestyle gymnastic manoeuvres over a human-made obstacle course within the built environment. These obstacles may include walls, rails and buildings that are set at different distances and have varying angles of inclination, sizes and textures. Parkour might seem reckless, but it takes great poise and skill to perform, and most participants train very hard, practising a broad set of individual skills that they use to negotiate obstacles. Parkour was originally influenced by Georges Hébert's training model, which focused on functional exercises relating to physical conditioning (walking, climbing, jumping, rising, carrying, running, throwing, attack/defence). Parkour is a highly open skill, with a very variable performance landscape. It offers participants many opportunities for novel interactions in relation to jumping, landing, twisting, turning and changing direction to negotiate ledges, surfaces and other obstacles for which there may not be an obvious solution. A research study (Strafford et al., 2022) of parkour performers (known as 'traceurs') found a correlation between movement skill performance on jumping, running and swinging tests and the speed taken to run through the obstacle courses.



**FIGURE 1.14** Parkour is a highly open skill within a highly variable performance environment.

### QUESTIONS

- 1 **Describe** what skills would be used to perform parkour.
- 2 **Justify** why parkour is considered an open skill.

### 🚩 SIGNPOST

Check out the following links to learn more about parkour. Even if you have no intention of ever trying parkour, you can admire the athleticism and skill of the traceurs.

- Read the article 'The science of parkour, the sport that seems reckless but takes poise and skill' by James Croft in *The Conversation*.
- Watch the video *Paris Rooftop Parkour POV* on the Storrer channel on YouTube.



#### Weblinks

The science of parkour  
Paris Rooftop Parkour POV

## WORKED EXAMPLE

©VCAA Exam 2022, Section B, Q2 a and b

In baseball, the pitcher may throw different types of pitches, such as fastballs, curveballs and change-up pitches. The batter has to respond differently to these pitches because they travel at different speeds, come from different directions and are thrown at different heights.

- Is batting in baseball classified as an open skill or a closed skill?
- Give **two** reasons to support your response in part **a**.

## Sample responses

**a** *Open skill*

**Rationale:** Had the batter been hitting a stationary ball off a tee, it would have been a closed skill.

**b** Acceptable responses included (two of):

- *Externally paced (based on the pitcher)*
- *There is high inter-trial variability (each pitch is different)*
- *Environment is unpredictable and variable*

**Rationale:** In baseball the pitcher follows the signal from the catcher about what pitch to throw and this sign is hidden from the batter. The starting point for the pitch and the speed of the wind-up to pitch is determined by the pitcher. Other than the type of pitch, the batter also has to contend with variables such as number of base runners, position of fielders, the sun and wind, and the dimension of the field – all of which will vary from ground to ground and game to game.



## Assessment

1.1 Check-in questions

## Command terms

**outline**

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

**describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

## 1.1 CHECK-IN QUESTIONS

- List** three examples of fundamental movement skills.
- Outline** three classifications of fundamental movement skills.
- Discuss** three examples of factors that would reduce the predictability of an environment.
- Describe** what a gross motor skill is and provide three examples.
- Describe** what is meant by a discrete skill.
- Explain** the link between the development of fundamental movement skills and sport-specific skills.
- Contrast** an open skill to a closed skill. Provide an example of each in your response.
- Select a motor skill you perform regularly and **analyse** it, using at least two different systems of classification. What types of movement skills are involved?

## 1.2 THE LINK BETWEEN MOTOR SKILL DEVELOPMENT, PARTICIPATION AND PERFORMANCE

In this module you will learn about:

- the link between motor skill development, participation and performance and learn to:
- analyse the link between motor skill development, participation and performance.

## Motor skill development enhances participation and performance

The development of fundamental movement skills is positively associated with being more physically active during both childhood and adolescence, and the mastery of fundamental movement skills is considered the building block to more sport-specific and complex skills and activities. A systematic review (Xin, Chen, Clark, Hong, Lui & Cai, 2020) of preschool-aged children showed evidence of associations between moderate to vigorous physical activity (MVPA) and fundamental movement competence and object control skills. There was also an association between total physical activity and total fundamental movement skill competence and object control. This suggests that development of fundamental movement skill influences both intensity and total activity. A different longitudinal study that tracked competency in object control skills showed that level of skill competency at ages 6–9 significantly influenced application of these skills at age 12 (Pienaar, Gericke & du Plessis, 2021).

A lack of fundamental movement skill development can lead to a negative spiral of disengagement from physical activity. Children with poor performance in fundamental movement skills may have poor confidence to move and may not enjoy participating in physical activities they are not competent in. This can lead to them either not taking sport up or dropping out. Beyond movement competence, participation in sport leads to many social, physical and behavioural benefits (Kress, Seelig, Bretz, Ferrari, Kellar, Kühnis, Storni & Herrmann, 2023).

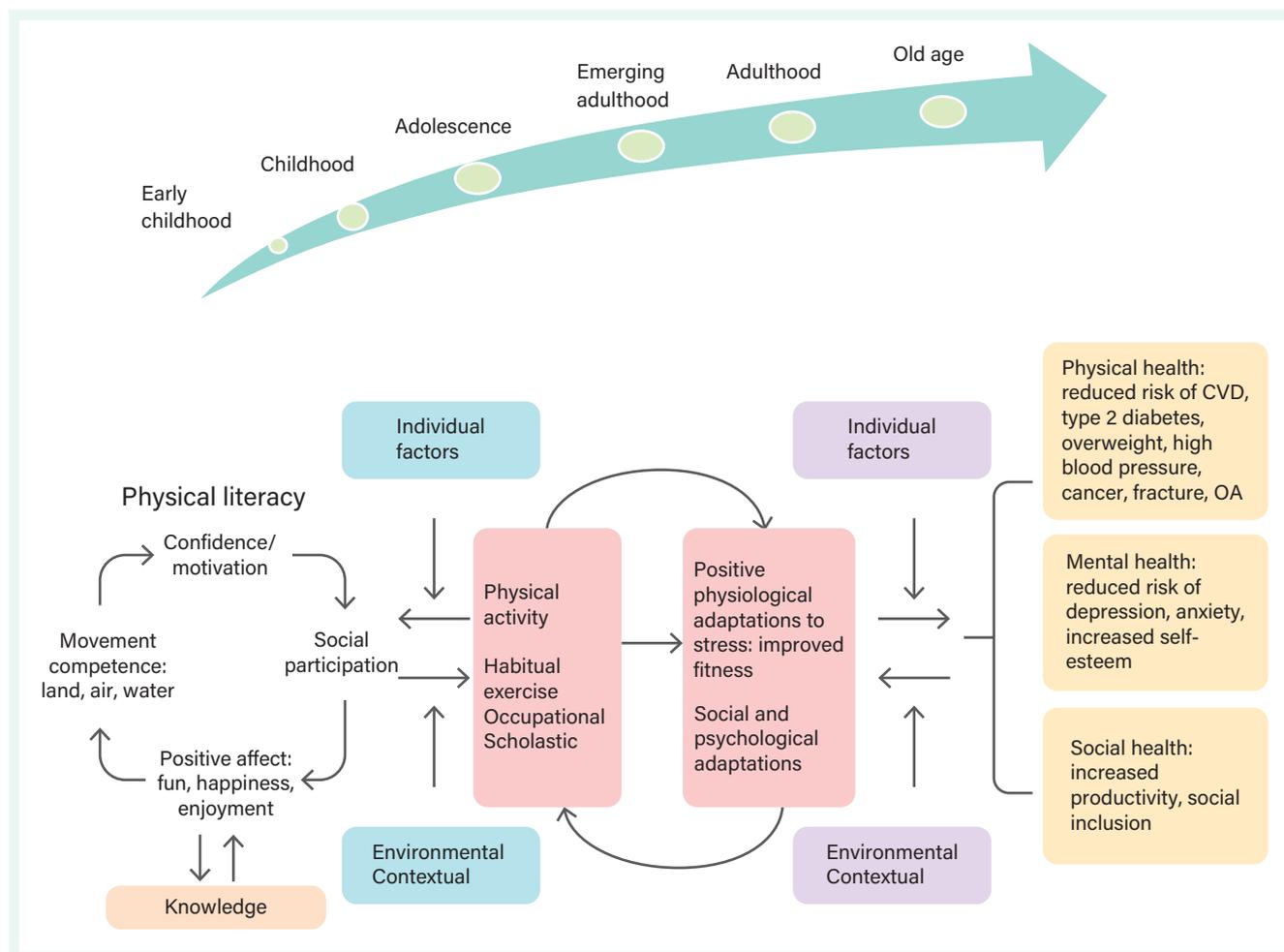
Ultimately, greater participation is associated with greater performance, and this is true at all levels of sport. In fact, countries with the highest participation rates usually have the most success in terms of performance, and this is one of the reasons why governments around the world that are pursuing national sporting success try to increase the base participation rates in sport and physical activity at the community level. Countries that invest in boosting participation in physical activity and that support grassroots sports often reap rewards several years later in medals on the international stage.

### DID YOU KNOW?

Researchers have shown that fundamental movement skill competence levels at the beginning of the school year were a predictor for extracurricular sports participation at the end of the school year (Kress et al., 2023).

## Conceptual models of physical literacy

Physical literacy is achieved when children have developed the skills, confidence and love of movement to be physically active for life. The notion of physical literacy (PL) provides a powerful, multidimensional, holistic conceptual lens to examine movement in relation to physical activity, motor skill outcomes, environmental contexts, and broader social and effective learning processes (Cairney et al., 2019).



**FIGURE 1.15** Conceptual model linking physical literacy, physical activity and health

Source: Cairney, J., Dudley, D., Kwan, M. et al. (2019), 'Physical literacy, physical activity and health: Toward an evidence-informed conceptual model', in *Sports Med* 49, pp. 371–383. Reproduced with permission from Springer Nature.

The model suggests physical literacy is a determinant of health and disease and is affected by:

- participation in physical activity
- the positive physiological adaptations resulting from acute and chronic exposures to physical activity
- the interacting effects of individual-level and social environmental conditions on the process.

The concepts form an interdependent learning cycle. For example, successfully learning a new skill can lead to a sense of confidence, which increases confidence to participate with others, which in turn produces positive feeling states such as enjoyment and a sense of fun. As this is fundamentally a learning cycle, we can think of what emerges from this cycle of engagement as embodied knowledge, which itself encourages further participation (Cairny, Dudley, Kwan, Bulten & Kriellaars, 2019).

## REAL WORLD APPLICATIONS

### Active for life

Here is an example infographic from Active for Life™, a resource that is aimed at educating parents about the importance, benefits and development of physical literacy from infancy to age 12. The role of parents is critical as they are often the gatekeepers to their children’s opportunities to be active.



### WHAT IS PHYSICAL LITERACY?

**PHYSICAL LITERACY LIFE CYCLE**

Physical literacy is when kids have developed the skills, confidence, and love of movement to be physically active for life.



**HOW IS PHYSICAL LITERACY DEVELOPED?**

Kids develop physical literacy gradually through a variety of structured and unstructured activities. The nature of these activities changes as kids grow in age and ability.



**ACTIVE FOR LIFE**

Learn more at: [ActiveForLife.com](http://ActiveForLife.com)



© Active For Life 2015

Source: Physical Literacy Lifecycle. Permitted for use by ActiveforLife.com, 2024.

## WORKED EXAMPLE

Steph Catley captained the Australian Olympic women's football team (the Matildas) in France in 2024. It was her third Olympic Games. When Catley receives a pass from a teammate, she traps the ball and continues to control the ball and dribble around several opponents towards the Australian goal. If she is trapped near the sideline with none of her teammates nearby, she kicks the ball into an opponent so that it deflects over the sideline. In this way she maintains possession and gives her teammates time to join her as she performs a throw-in. During training sessions in a lead-up to the Olympics, Catley would often have to complete a 1-kilometre run as part of the warm-up.

Identify the skill classification for each of the following activities performed by Steph Catley and justify each of your selections.

Skill	Classification (discrete, continuous, serial)	Justification
a Receiving a pass from a teammate, trapping, controlling and dribbling around several opponents		
b Performing a throw-in		
c 1 km run during warm-up		

### Steps to answering the question

In responding to this question, firstly, look at the command terms: **identify** and **justify**. To identify something means to recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment. In this example, you simply need to select from a list. Don't assume, however, that you must use every item in a list provided, and note that it is possible to use the same term more than once. Next, you need to justify your selection. To justify means to show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information.

**TIP:** In this question you need to think about skill classification and the type of movement in relation to where actions begin and end. Don't be confused by the predictability of the environment here, nor the size of the musculature required. This is about the timing of when skills start and stop.

### Sample response

- a *Serial. The skills described in the first example are linked in a chain and therefore are usually considered serial.*
- b *Discrete. The throw-in has a distinct beginning and end, making it a discrete skill.*
- c *Continuous. Although the 1-kilometre run has a beginning and an end, it is largely repetitive and is therefore classified as a continuous skill.*

## 1.2 CHECK-IN QUESTIONS

- 1 **Outline** what is meant by the term 'physical literacy' and explain what this means in relation to positive physical and social outcomes.
- 2 **Describe** the association between the development of fundamental movement skills and participation in physical activity and sport.
- 3 **Discuss** the association between motor skill development, participation rates and performance.
- 4 **Explain** how poor performance in fundamental movement skills may affect participation in sports.
- 5 **Justify** why it is essential to educate parents about the importance of developing physical literacy, including the development of fundamental movement skills.



### Assessment

#### 1.2 Check-in questions

#### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

#### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

MODULE 1.1, PAGE 12

## Cross-cultural comparison of fundamental movement skills

Cross-cultural differences in fundamental movement skills were examined in a research study (Ma, Duncan, Chen, Eyre & Cai, 2022) of 272 children aged 9–10 years in England and China. Using the test of Gross Motor Development-2 (TGMD-2), four fundamental movement skills (run, jump, throw and catch) were assessed. Chinese children scored higher than English children on total fundamental movement skills, locomotor and object control skill subsets and mastery levels of skills. Researchers attributed these cross-cultural differences to aspects of physical education provision and process, educational policy and other physical opportunities (e.g. extracurricular and organised sport).

The TGMD-2 is one of many test batteries used to assess FMS; you are not expected to know the different tests used to assess FMS.

ABOVE  
AND  
BEYOND  
THE STUDY  
DESIGN



# CHAPTER SUMMARY



## Resource

Self-assessment checklist

## Video

Masterclass: Chapter 1

## 1.1 Classification of movement skills

Skills can be classified based on their characteristics. Understanding the characteristics and demands of a skill enables coaches and teachers to assess performance, plan skill development/training sessions and provide appropriate, tailored and developmentally appropriate feedback.

- We can classify motor skills in many ways, but for the purpose of this chapter we used four one-dimensional motor skill classification systems based on:
  - developmental context
  - size of primary musculature required (precision required)
  - specificity of where actions begin and end (type of movement)
  - stability of the environmental context (predictability).
- A motor skill is a skill that requires voluntary body and/or limb movement to achieve its goal. Motor skills are considered an activity that we learn through practice and experience.
- Fundamental movement skills (FMS) are defined as basic learnt patterns that do not occur naturally and are suggested to be foundational for more complex physical and sporting activities.
- Most advanced skills used in sports are advanced or specific versions of the fundamental movement skills.
- Fundamental movement skills can be classified into three distinct categories:
  - stability skills (body control) involving balance and control of the body (e.g. balancing, dodging, twisting)
  - locomotor skills (movement) that enable us to move through space (e.g. walking, skipping, hopping)
  - manipulative (object control) skills involving the control of an object (e.g. throwing, catching, striking).
- Age 6–10 is considered a critical window for children to develop their fundamental movement skills. It is considered an optimal time to train skill and movement competency because the neuromuscular system is most susceptible to change and neural plasticity.
- Sport-specific skills are the technical skills that apply specifically to the demands of a particular sport.
- A gross motor skill requires the use of large musculature to achieve the goal of the skill, whereas a fine motor skill requires control of small muscles to achieve the goal of the skill. A fine motor skill typically involves eye–hand coordination and requires a high degree of precision in hand and finger movement.
- Discrete motor skills have clearly defined beginning and end points, usually requiring a simple movement. Continuous motor skills have arbitrary beginning and end points, and usually involve repetitive movements. A serial motor skill is a motor skill involving a series of discrete skills.
- Closed motor skills are performed in a stable or predictable environment where the performer determines when to begin the action. Open motor skills involve a nonstable, unpredictable environment where an object or environmental context is in motion and the performer determines when to begin the action.

## 1.2 The link between motor skill development, participation and performance

- The development of fundamental movement skills is positively associated with being more physically active during both childhood and adolescence, and the mastery of fundamental movement skills is considered the building block to participation in more sport-specific and complex skills and activities. Greater participation leads to enhanced performance.

## CHAPTER REVIEW

- Identify** four systems that can be used to classify movement skills.
- Outline** three distinct categories for classifying fundamental movement skills.
- List** five examples of fine motor skills used in sport.
- What is a continuous motor skill? **Describe** what it is and provide an example.
- If you were performing a dive off a 1-metre platform board, how would you classify this movement activity? **Discuss**.
- Contrast** open and closed skills and provide three examples of each.
- Justify** why a coach might elect to teach a fundamental movement skill in a closed and predictable environment.
- Explain** the association between development of fundamental movement skills, participation and performance.



**Assessment**  
Chapter 1 review

### Command term

#### **justify**

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

## CHAPTER

# 2

## COACHING TO ENHANCE PARTICIPATION AND PERFORMANCE

UNIT 3 – AREA OF STUDY 1



matimix/Adobe Stock

**FIGURE 2.01** Coaching strategies can encourage participation and improve performance.

### Quizzes

Chapter 2 Pulse check

**2.1** Check-in questions

**2.2** Check-in questions

**2.3** Check-in questions

**2.4** Check-in questions

**2.5** Check-in questions

**2.6** Check-in questions

Chapter 2 Review questions

### Videos

Masterclass: Chapter 2

Professor Damian Farrow interview

**2.3** In focus: Examples of linear and non-linear approaches

**2.4** In focus: Differences between the types of practice

### Resources

**2.2** Template: Motor learning and skill acquisition

Chapter 2 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



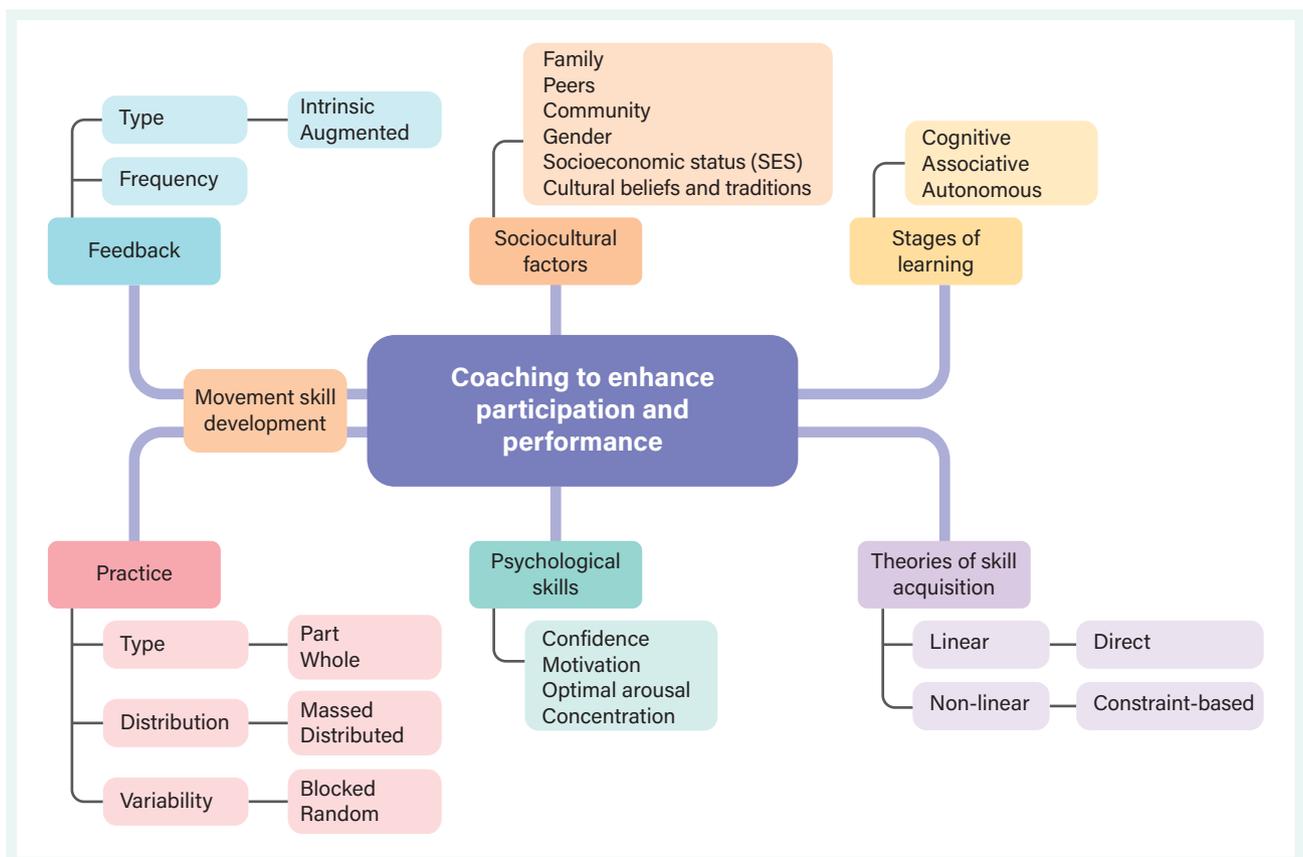
## KEY KNOWLEDGE

- » considerations when coaching to enhance participation and performance:
  - sociocultural factors that affect skill development
  - characteristics of the three stages of learning
  - theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches
  - psychological skills (confidence, motivation, optimal arousal and concentration) and accompanying strategies
  - in session and scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)
  - frequency and type of feedback including intrinsic and augmented (knowledge of results and knowledge of performance)

## KEY SKILLS

- » participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 2

**Assessment**

Pulse check

The study of skill acquisition looks at factors that affect the learning, performance and retention of movement skills. These factors include why individuals engage in physical activity, sport and exercise; how skills are learnt and practised; feedback; and psychological strategies. A good coach inspires, motivates, teaches and encourages individuals and teams. They can be the reason why individuals (children and adults) stay in sport – and, sometimes, why they leave. This chapter will look at the skill acquisition principles that can be applied through coaching to enhance both participation and performance in physical activity, sport and exercise.

**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 **List** five sociocultural factors that may impact skill development.
- 2 **Identify** the three stages of learning and list at least two characteristics of each stage.
- 3 **Describe** the difference between linear and non-linear approaches to coaching.
- 4 Name one strategy that could be used to increase confidence, motivation, optimal arousal and concentration.
- 5 **Explain** the difference between part and whole practice.
- 6 **Suggest** an example of feedback on knowledge of performance that a coach could provide.

**Video**

Professor Damian Farrow interview

**SIGNPOST**

Professor Damian Farrow is one of Australia's leading experts in the fields of motor learning and skill development. Go to Nelson MindTap to see an interview with Professor Damian Farrow, discussing skill acquisition.

## 2.1 SOCIOCULTURAL FACTORS THAT AFFECT SKILL DEVELOPMENT

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- sociocultural factors that affect skill development and learn to:
  - participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

**sociocultural**

Of, or relating to, the interaction of social and cultural factors such as family, peers, community, gender, socioeconomic status, and cultural beliefs and traditions

There are many **sociocultural** factors that can influence participation (or non-participation) and performance in physical activity, sport and exercise.

Sociocultural factors are those that affect physical activity, sport and exercise from a societal (hence 'socio-') and cultural perspective.

For the purpose of VCE Physical Education, we will focus on the following factors:

- family
- peers
- community
- gender
- socioeconomic status (SES)
- cultural beliefs and traditions.

The impact of each factor can vary from one person to another and across their lifespan. For example, for children, parental support is a key factor in their participation. This support may be financial (paying for membership, equipment, uniform), it may be practical (transport to training and games) or it might be psychological support (attending games, encouraging).

For an elite athlete to continue to improve their performance they may also need financial support. The funding arrangements for some sports may enable an athlete to focus on their performance; for other sports, the athlete themselves may need to contribute financially, at which point their socioeconomic status will become a factor.

**TABLE 2.01** Factors that have a positive and a negative influence on sports participation

Factors that support sports participation	Factors that consistently appear as negative or contributing to non-participation or dropout
<ul style="list-style-type: none"> <li>• parental and family support</li> <li>• peer interaction</li> <li>• positive environment</li> <li>• venue accessibility</li> </ul>	<ul style="list-style-type: none"> <li>• excessive travel</li> <li>• the expense of training and competition</li> <li>• inconvenient training times</li> <li>• low levels of physical literacy or perceptions of competence</li> <li>• an environment that is 'too competitive'</li> </ul>

Source: 'Factors influencing sport participation', The Clearinghouse for Sport, Australian Sports Commission, [www.ausport.gov.au](http://www.ausport.gov.au)

## LOOKING BACK

### Link between participation and performance

#### Chapter 1

In Chapter 1 we looked at the link between motor skill development, participation and performance. As we unpack each of the sociocultural factors that influence skill development, you will need to keep coming back to how participation in physical activity, sport and exercise is directly linked to performance and the development of motor skills. Participation in different movement experiences can help to develop motor skills, and increased motor skill competency is associated with higher levels of participation.

## DID YOU KNOW?

### Sports funding

Funding for national sporting organisations in Australia in 2023–24 totalled \$193,719,591. Swimming topped the funding list, with more than \$16 million dollars invested. Sport climbing, a relatively new sport, received \$218,000 in funding.

To see the full breakdown of funding allocations, go to the table of 'National Sporting Organisation (NSO) investment allocations for 2023–24' on the Australian Sports Commission website.



**Weblink**  
National Sporting Organisation (NSO)  
investment allocations  
for 2023–24

## Family

Family influences our participation in physical activity, sport and exercise very strongly. For example, families can influence the activities that we are exposed to (playing and watching), the behaviours that are modelled (parents who exercise or play sport) and the resources (equipment, time, financial) we have access to. Family also influences your culture, education, political and religious views, and the value you place on physical activity, sport and exercise. Your family may even influence your friendship group (peers) and your attitude toward physical activity, sport and exercise.

For example, if you grew up in a home where your parents exercise regularly or play sport, you are more likely to think this is normal. As shown in Figure 2.02 below, this is a key factor that influences children to participate in organised sport and physical activities. Parental involvement is significant in a child starting and continuing in sport and in having a positive outlook to remaining physically active for life. Parents are also critically important in developing a child's confidence and competence in their movement skills.

The behaviour of adult figures (coaches, teachers, extended family, etc.), as well as peers and siblings, play an important role in influencing a child's behaviour. However, parents are the enduring role models that their children use as a basis for their own development.



**FIGURE 2.02** Factors that influence a child's involvement in sport

'QUICK FACTS', The Clearinghouse for Sport, <https://www.clearinghouseforsport.gov.au/participation-in-sport>



**FIGURE 2.03** Geoff Marsh (right) with his sons Shaun and Mitchell. Can you think of other examples of athletes who come from the same family?

Many elite athletes have parents and/or siblings who also excelled in the same sport and different sports. Examples of familial advantage include multiple BMX world champion Caroline Buchanan, who rode and competed in BMX with her dad and her brother.

Australian cricketing brothers Shaun and Mitchell Marsh watched their father Geoff play Test cricket and had their own backyard cricket battles, in which Mitchell was often relegated to bowling to his older brother.

# Peers

A peer is someone at your own level – a friend, another student in your class or a teammate. Your peers are a social group that may have similar interests to yours or be at a similar stage of life. The influence of your peers can be positive and negative, but children playing sport because their friends play is a positive outcome of peer pressure!

During adolescence the desire to fit into your peer group is strong and can impact on your continuation of physical activity, sport and exercise. If your peer group is sporty, and everyone rushes to sign up for house swimming, athletics and cross-country, you are more likely to want to do this as well.

Your peer group may also encourage you to join a team so that you can play together. You might go to the local park and kick a ball around, or you might go the skate park or ride your bikes together.

As we get older, many people exercise for social reasons, and again peers influence the type of activity that we do. Research has found that without the influence of peers, sedentary behaviour increases. In this study (Mema et al., 2022), social interactions were found to be the most important social parameter that influenced people to become and remain physically active.



iStock.com/FatCamera

**FIGURE 2.04** Playing in a team with your peer group can be a key motivator for participation in sport.

# Community

A community is made up of people living in the same place as each other or people who have common interests and attitudes. The social and cultural characteristics of a community can influence the sports that are popular within that community. Sporting clubs are often referred to as a community, and can provide support and opportunities to develop and enhance motor skills through participation in training and competitions within that community.

Opportunities for physical activity, sport and exercise can be increased for all in your local community (i.e. where you live) by implementing a range of evidence-based strategies relating to each of the areas shown below.



**FIGURE 2.05** A range of strategies for increasing opportunities for physical activity, sport and exercise in your local community

Source: Division of Nutrition, Physical Activity and Obesity, National Center for Chronic Disease Prevention and Health Promotion

## Gender

Socially and culturally, boys and men have traditionally been more physically active and have been provided with more opportunities (e.g. to run around) and equipment (e.g. bats, balls) to develop movement skills (Vealey & Chase, 2016). However, a strong source of motivation for girls and women to participate in physical activity, sport and exercise is to improve their motor skills and their ability to play sport.

### DID YOU KNOW?

For girls, playing sport with their brothers and male friends when they are developing their movement skills is a contributor to sporting success later in life. Playing with male peers not only provides an avenue for skill progression, enhanced mental toughness, fitness and physical robustness, but can also be supportive and motivating.

For many years, strategies have been implemented to help equalise opportunities for girls and women in sport, and great progress has been made. However, there are still some concerns that gender bias may prevent girls and women from benefiting from participation in physical activity, sport and exercise.

Barriers for women and girls to participate in physical activity, sport and exercise are higher in some demographic groups, particularly in culturally and linguistically diverse communities, among First Nations peoples and those with disability, and even among mature-aged women.



**Weblinks**  
This Girl Can

Daughters and Dads Active and Empowered

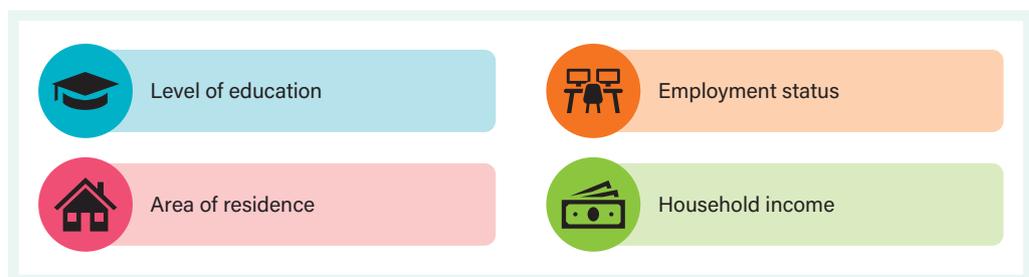
### SPOTLIGHT

There are many programs designed specifically to encourage girls and women to participate in physical activity, sport and exercise. These include:

- This Girl Can – a campaign aimed at ‘inspiring women to get active – however, wherever and whenever they choose, without being judged’
- Daughters and Dads Active and Empowered – a program that ‘educates and empowers girls alongside their fathers to improve physical activity, sport skill proficiency and social and emotional wellbeing.’

## Socioeconomic status

Socioeconomic status (SES) can be defined by a number of factors, most commonly those shown in Figure 2.06.



**FIGURE 2.06** The factors that define socioeconomic status

These factors overlap and can influence each other, and the combined impact of lower levels of education, lower household income and area of residence is that people of lower SES are less likely to participate in physical activity, sport and exercise. The cost of equipment and fees associated with playing organised sport and access to suitable facilities within their local area are significant contributing factors.

Conversely, adults who do participate in physical activity, sport and exercise are more likely to be employed and to have higher incomes and higher levels of education than adults who do not. Children and adolescents living in higher-socioeconomic status households are more likely to participate in sport and participate for longer, giving them more opportunities to develop their motor skills. They are also more likely to own 'active play equipment' (Dumuid et al., 2016), again increasing their opportunity to engage in activities that may enhance their motor skill development.

## Cultural beliefs and traditions

Cultural beliefs and traditions can include customs, values, beliefs and celebrations. They can relate to use of language, clothing, holidays, religion and music, and to physical activity, sport and exercise. Cultural beliefs may place some restrictions on when or how people can participate in physical activity, sport and exercise, and this may impact on motor skill development of individuals who do not have the same opportunities for participation as others.

Among Aboriginal and Torres Strait Islander peoples and those from cultural and linguistically diverse (CALD) backgrounds, it is common to find lower participation rates in organised sports than in the wider Australian population. Other factors (such as SES) can contribute to this, but access to culturally appropriate programs and facilities is a barrier. For example, to enable Muslim women to participate fully in sport, we need to create environments and sporting activities that can be undertaken in line with their religious beliefs. In this way, their exposure to a range of movement experiences will not be limited due to their cultural beliefs.

### LEARNING HACK

SES is an acronym for socioeconomic status. As with all acronyms, you should always write the term out in full before using the abbreviated version, especially in assessment tasks, so the reader knows exactly what you are referring to!

What else can SES stand for?



Cameron Spencer/Getty Images

**FIGURE 2.07** A young Muslim Australian woman playing Australian Rules football

**Weblink**

US Centers for Disease Control and Prevention

**Assessment**

2.1 Check-in questions

**Command terms****describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

**suggest**

Put forward for consideration a solution, hypothesis, idea or other possible answer

**discuss**

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

**🚩 SIGNPOST****Strategies to increase access to physical activity for everyone!**

To find out more about the evidence-based strategies that communities can use to increase the access that community members have to physical activity, go to the US Centers for Disease Control and Prevention website and search for 'state and local strategies' on the 'Physical activity' page.

Increasing the level of physical activity across the community brings benefits for individuals, the health system and the environment, and has been shown to increase community wellbeing.

**LOOKING FORWARD****Practice and feedback****Modules 2.4 and 2.5**

In Modules 2.4 and 2.5 we will look more closely at the types, distribution and variability of practice and the frequency and type of feedback. The stage of learning that an individual is in will influence decisions around the structure of the training session and the amount, frequency and type of feedback a coach will give a player.

**2.1 CHECK-IN QUESTIONS**

- Which one of the following is a sociocultural factor that could influence the development of motor skills?
  - arousal levels
  - parenting practices
  - geographical location
  - the physical size and shape of an individual
- What does the acronym 'SES' stand for? How can someone's SES impact positively and negatively on their participation in physical activity, sport and exercise?
- Describe** the relationship between education, employment, income and area of residence.
- In 2022, 32 per cent of the female population (aged 15+) participated in sport-related activity at least once a week, compared with 50 per cent of the male population (15+). **Suggest** three reasons why girls and women have lower participation rates than boys and men.
- Select a belief or tradition from your culture and **discuss** with a partner how it may influence participation in physical activity, sport and exercise within your community.

## 2.2 STAGES OF LEARNING

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- characteristics of the three stages of learning and learn to:
- participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

Learning a motor skill takes time and practice and, once the skill is learnt, further practice aims to continue to improve and refine the skill. Coaches play a role in helping athletes through the different stages of learning a motor skill by providing feedback and opportunities to practice. The learning process is the path taken from being a novice (unskilled) to an expert (highly skilled), and progress through the stages is dependent on the learner, the skill and the learning environment. The time taken to progress through the stages will be different for each individual. It may take many years, and not everyone will reach the expert stage!



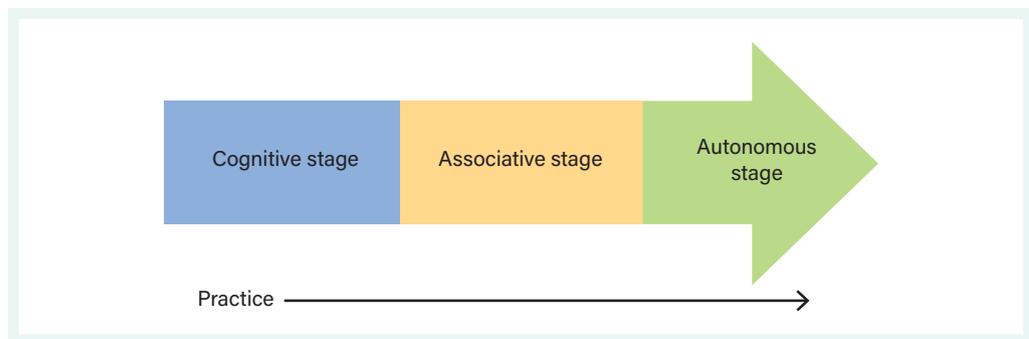
PA Images/Alamy Stock Photo

**FIGURE 2.08** Ash Barty developed her exceptional tennis skills over many years. She began playing in tennis competitions in 2002, when she was only six. She achieved success throughout her junior career before winning Wimbledon in 2021 at the age of 25.

There are several different models that categorise motor skill learning into distinct stages. Models allow coaches to identify and attend to the needs of the learner, based on where they are in their learning journey. In this module we will look specifically at the three stages of learning as proposed by Fitts and Posner (1967). This model identifies three stages of learning:

- cognitive
- associative
- autonomous.

The three stages of learning are on a continuum, and the amount of time a learner spends in each stage is dependent on the skill being learnt, the amount of practice and the individual.



**FIGURE 2.09** The three stages of motor skill learning on a continuum

## Cognitive stage

The cognitive stage is the first stage of learning. The novice learner or beginner in this stage of learning is trying to work out what it is they need to do. The cognitive load on the learner is high as they are trying to process more information than the human brain can process at one time.

The beginner is mentally trying to work out all the movement requirements of the motor skill: what needs to be done?

For example, a young tennis player who is picking up a racquet for the first time is trying to work out the answers to these questions:

- How do I hold the racquet?
- Do I stand side-on or facing forwards?
- When do I swing the racquet?
- Where am I hitting the ball to?

When teaching or coaching learners in new skills, it is more effective to provide explicit guidance (short and to the point) accompanied by practice and feedback to the learner. In the case of the first example above – How do I hold the racquet? – the explicit instruction might be, 'Hold the racquet as if you were shaking hands with someone'.

Beginners will make lots of mistakes and their performance will be inconsistent, but improvement and performance gains are usually made quickly in this stage of learning.

## Characteristics of learners in the cognitive stage of learning

In the cognitive stage, learners show:

- poor sequencing and coordination of skills
- frequent errors
- poor error detection and correction
- inconsistent performance
- high attentional demand on the skill
- low movement efficiency
- rapid improvement.



**FIGURE 2.10** Explicit instruction on how to hold a racquet is part of the cognitive stage of learning to play tennis.

Learners in the cognitive stage of learning are often aware of the mistake they have made. For example, if the young tennis player in our example above swings and misses the ball, they know they have missed the ball and that their movement was not correct. What they don't yet know is why the movement was incorrect and what they need to do to correct the problem. Learners in the cognitive stage have not yet developed their error detection and correction abilities.

At this stage of learning, coaches should:

- give clear, short and simple verbal instructions
- provide demonstrations
- use part practice for complex skills
- give feedback on:
  - » error detection (how they are performing)
  - » error correction (how they can improve).

## Associative stage

The associative stage is the second stage of learning and is sometimes referred to as the 'practice stage'. The learner is focusing on how to perform the skill and are constantly refining their movement. Their performance is becoming more consistent, with fewer errors and less variability. Progress through the stage is slower than in the cognitive stage, and some learners never progress beyond the associative stage of learning.

### Characteristics of learners in the associative stage of learning

Learners in the associative stage demonstrate:

- greater consistency and accuracy in skill performance
- fewer errors
- ability to self-detect errors and self-correct movements
- improved timing and coordination
- decreased attentional demand on the skill.

The cognitive load on the learner to perform the movement skill has decreased in this stage of learning so the learner is able to focus on other factors and start to take cues from the environment.

The learner can start to adapt their movement pattern based on the cues they pick up. For example, our young tennis player will now start to think, 'Where is my opponent?', and then adjust their movement pattern to hit away from the player.

In the associative stage, the learner is able to detect the cause of their errors and can develop strategies to self-correct the error. There are gradual improvements in the motor skill as the learner continues to refine their performance.

At this stage of learning, coaches should:

- design practice opportunities that expose the learner to relevant and irrelevant cues to increase player decision-making
- provide specific feedback to address learners' needs
- support with error detection and correction.



**FIGURE 2.11** Learners in the associative stage of learning can focus on environmental cues.

## Autonomous stage

The autonomous stage is the final stage of learning, and at this point the skill is largely automatic; the performer no longer consciously thinks about the skill. This stage of learning is characterised by consistent performances, with minimal errors. Performers in this stage of learning often appear to have all the time in the world to execute the skill, and can detect their own errors and correct them. Improvement in skill execution at this stage is slow, but even small improvements at this level are important.

### Characteristics of learners in the autonomous stage of learning

Learners in the autonomous stage demonstrate:

- low attentional focus on the skill required
- highest accuracy (few errors) and efficiency of skill
- smooth, coordinated movement
- a dramatic slowing in improvement
- an increased understanding of their performance and an ability to self-correct errors.

The cognitive load has been reduced on skill execution so the athlete can focus on other aspects of the game such as decision making. They are also able to perform multiple activities at once. A tennis player in this stage of learning will be analysing all of the information they have detected from the environmental cues to determine the best option of where to place the ball in the court to either set up the point or hit the winner while also evaluating the position of their opponent and the sun, the direction of the wind and the noise of the crowd! That's a lot to think about, which is why it is lucky at this stage that they don't need to think about performing the actual skill.

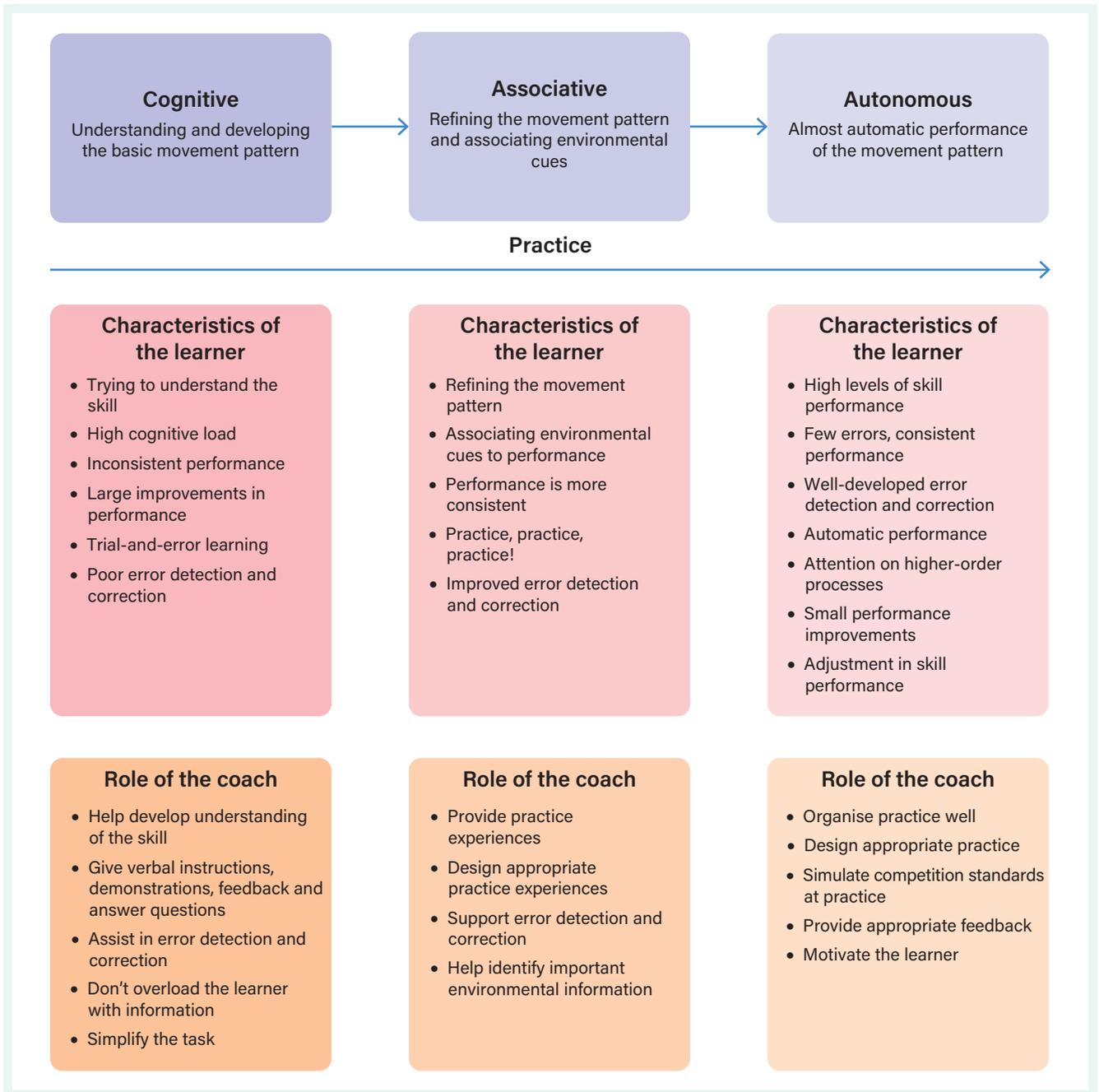
At this stage of learning, coaches should:

- provide precise feedback
- design and organise high-quality training sessions
- maximise practice time and simulate competition
- motivate the learner to continue to improve their performance.

Figure 2.13 summarises the three stages of learning, the characteristics of the learner and the role of the coach at each stage.



**FIGURE 2.12** Simulating competition in practice sessions is an example of a coaching technique to support someone in the autonomous stage of learning.



**FIGURE 2.13** Summary of the three stages of learning

Source: Adapted from Fitts, P. & Posner, M.I. (1967), *Human Performance*

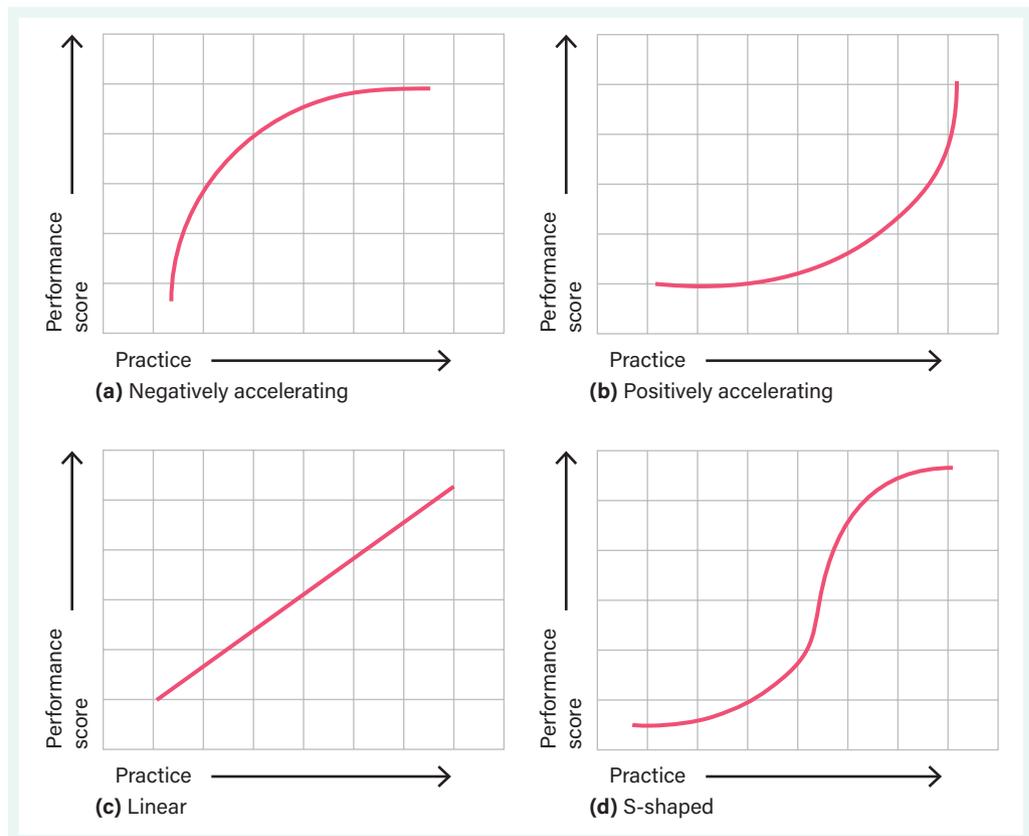
## Performance curves

With appropriate practice, learners will progress through the stages of learning.

Performance curves can be used to track improvement. There are four general shapes of performance curves, as shown in Figure 2.14:

- a** negatively accelerating – improvement is rapid at first and then slows
- b** positively accelerating – improvement is slow at first and then increases rapidly
- c** linear – increases in performance are directly proportional to the practice time
- d** S-shaped – improvement starts slowly, increases and then tapers off.

There is no 'normal' pattern of motor skill learning. The negatively accelerating curve is common, however, as increases in performance occur early with practice and then, as practice continues, the gains in performance decrease. This is known as the 'power law of practice'.



**FIGURE 2.14** Four general shapes of performance curves

### LOOKING FORWARD

#### Diminishing returns

##### Chapter 12

The power law of practice is similar to the law of diminishing returns that you will learn more about in Chapter 12. The physiological gains made through training occur quickly when a relatively sedentary individual starts a training program; as training continues, however, the improvements tend to plateau, as is represented visually in Figure 2.14 a.

## COLLABORATIVE TASK

### Prac activity

#### Stages of learning

##### AIM

To determine which stage of learning the performer is in through an analysis of motor skill performance

##### METHOD

- 1 Working in pairs, participate in the five skill stations (see below).
- 2 Complete five trials of each skill.
- 3 Record the average score for each skill.
- 4 Observe your partner performing the skill and **identify** some key characteristics of the movement.
- 5 Determine which stage of learning your partner is currently in for each skill.

##### SKILL STATIONS

###### Skill 1: basketball dribbling

Arrange five cones in a straight line, 1.5 metres apart. Dribble around the cones in a zigzag fashion, up and back. Record the average time taken to complete the trials.

###### Skill 2: soccer juggling

Juggle a soccer ball by keeping it off the ground using your body (feet, thighs, chest and head – *no* hands). Record the number of juggling moves performed before the ball hits the ground. Record the average of the five trials.

###### Skill 3: Australian Rules handpass

Handpass the ball to a concentric circles target from a distance of 5 metres. Record the combined score for five handpasses.

###### Skill 4: netball goal shooting

Shoot five goals at the netball ring from a distance of 1.5 metres. Record the total number of successful shots from the five trials.

###### Skill 5: hockey push pass

Set up five targets along a wall (using chalk or cones). Each target should be 20 centimetres wide. Pass five times to a target from 5 metres away. Award five points for the centre target, three points for the next target out on either side, decreasing to one point for the two outermost targets. Record the combined score for all five passes.

##### RESULTS

Record each student's performance and their partner's observations. Complete an observation sheet for each participant. Report the stages of learning for each student on each skill.

##### DISCUSSION

Describe the three stages of learning using examples from the data collected. Describe changes that occur as we learn a motor skill. From the data, choose a skill and provide three examples of how you could assist the learner in developing their skills further.



#### Command term

##### identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment



#### Template

Motor learning and skill acquisition



## Assessment

2.2 Check-in questions

## Command term

## name

Provide a word or term (something that is known and distinguished from other people or things) used to identify an object, person, thing, place etc.

## 2.2 CHECK-IN QUESTIONS

- 1 **Name** and identify one characteristic of each of the three stages of learning.
- 2 In the cognitive stage of learning, what does 'having a high cognitive load' mean for the learner?
- 3 Hypothesise as to why many learners don't progress through the associative stage of learning.
- 4 **Describe** the changes in the characteristics of the learner as they move from the cognitive stage of learning to the associative stage of learning.
- 5 Why are athletes in the autonomous stage of learning able to attend to environmental cues more easily?
- 6 As a coach, why is it important to understand the three stages of learning?

## 2.3 THEORIES OF SKILL ACQUISITION

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches and learn to:
  - participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

Nina/peopleimages.com/Adobe Stock



**FIGURE 2.15** There is no one-size-fits-all model for coaching, and good coaches will select the approach that allows their players to learn in a way that suits them best.

Theories of skill acquisition (linear vs non-linear) are underpinned by learning theories and applied to the learning of movement skills in physical activity, sport and exercise. Different learning theories, or ways of understanding learning, impact on how learners are coached, from how a coach sees their own role and how they plan the coaching session to how they provide instruction and how they give feedback. In this module we will look at linear and non-linear approaches to the teaching of movement skills and how each approach is represented in a coaching context.

## 🚩 SIGNPOST

The Australian Institute of Sport (AIS) offers a free online course to encourage more people to play, coach and enjoy sport. The course, known as Community Coaching – Essential Skills, has eight self-paced modules that help coaches create fun, safe and inclusive environments for participants.

More information can be found on the 'Community Coaching – Essential Skills' page of the Australian Sports Commission website.

At the elite level, Australia is investing in high-performance coach development. To see what is being done as Australia prepares for the Brisbane 2032 Olympics, watch the video *AIS HP Coach Development* on the AIS YouTube channel.



### Weblinks

Community Coaching –  
Essential Skills

AIS HP Coach Development



### Video

In focus: Examples of linear and  
non-linear approaches

## Linear and non-linear approaches to learning

### Linear approaches to learning

A linear approach to skill acquisition is based on a behaviourist model of learning, where the learner's 'behaviour' is shaped by the external environment – that is, by how the learning time is used, by how the feedback is given or how the behaviour is rewarded.

Consider a coach who yells at a young soccer player every time they take a shot rather than passing the ball. The learner is then conditioned to not take a shot, even when that is the correct decision.

The same can be said for a player who is praised and rewarded for a behaviour (e.g. the player maintains possession when no option for a pass presents itself); this leads to an increase in the positive behaviour.

Traditionally, learning has been considered linear, and the role of the coach in learning was to provide the template of the ideal movement pattern, usually through demonstrations, and then to tell the learner what to do and provide opportunities to repeat that behaviour over and over to recreate the ideal movement pattern.

A study by Lee et al. (2014) found that learners who were exposed to a linear approach while learning the tennis forehand ground stroke had difficulty retaining the expected (and taught) movement skill and exhibited fewer movement solutions.

Linear approaches to learning movement skills are characterised by:

- expected movement form
- high volume of practice trials
- lots of drills and repetition
- absence of a simulated game environment.



**FIGURE 2.16** Direct instruction is structured and directed by the coach.

imac/Alamy Stock Photo

## Non-linear approaches to learning

Non-linear approaches to skill acquisition are based on a constructivist model of learning, where there is recognition that learning is an active process that is developmental and multi-dimensional. Non-linear approaches emphasise the use of exploratory behaviours to find movement solutions and develop movement skills. They recognise that the individual plays a role in their learning and has preferences regarding how they like to learn, how they feel, the interaction with their environment coupled with what they already know, and how these factors impact the learning of the skill.

Effective skill acquisition is dependent on how the learner explores, adapts and finds solutions in the way they use their movement skills in different performance contexts. Non-linear approaches involve manipulating constraints to facilitate movement skill learning and decision-making.

Non-linear approaches to learning movement skills are characterised by:

- representativeness – practice mimics how the movement skills could be performed in an actual game
- task simplification – making performance of the movement skill easier
- informational constraints – focusing on the movement outcome
- variability in practice through manipulation of task constraints.

Hoxton/Alamy Stock Photo



**FIGURE 2.17** Small-sided games provide opportunities for learners to problem-solve and find alternative solutions to movement challenges.

## Direct and constraint-based approaches to coaching

### Direct instruction

Linear approaches to skill acquisition are generally applied through direct instruction. Direct instruction (**explicit learning**) is a highly structured approach to coaching where the coach controls and directs the learning process and passes the knowledge on to the learner. The instructor is the authority and holder of the knowledge, they make all the decisions, provide all the activities and tell the learner how to complete the activity and skills through verbal instructions and demonstrations.

#### explicit learning

Learning through direct instruction on how to perform the skill

Direct instruction is instructor-led and involves:

- being coach-centred
- developing explicit steps to learning a skill
- ensuring mastery at each stage
- giving specific corrective feedback
- providing adequate and systematic practice
- reducing coach-directed activities towards independent participants.

**TABLE 2.02** Advantages and disadvantages of direct instruction

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Learner is aware they are learning the skill</li> <li>• Quick and easy to organise and implement</li> <li>• Keeps learners on task</li> <li>• Maximises practice time</li> <li>• Facilitates rapid early learning</li> </ul>	<ul style="list-style-type: none"> <li>• Learners are forced to pay conscious attention to the skill (if the learner is performing the skill automatically, then by asking them to focus on the movement, the process becomes less automatic, leading to a decrease in performance)</li> <li>• Skills are more likely to break down in situations of high pressure – when the athlete is fatigued or under stress</li> </ul>

## Constraint-based approach

Non-linear approaches to skill acquisition are generally applied through indirect instruction. One perspective on indirect instruction is known as a **constraint-based approach**. A constraint-based model allows the learner to explore movement skills and to find solutions to movement problems with less input from the coach and greater interaction with other learners. **Implicit learning** occurs through performing the practice tasks without specific instruction on how to complete the task; the learner works out what is required through exploring different options and movement solutions. The coach supports the learner to do this through the manipulation of the practice conditions and task constraints, and, with questioning, becoming a facilitator who guides the learner toward the desired outcome.

Constraint-based approaches involve:

- being learner-centred
- coach as facilitator
- questioning of the learner, not telling them what to do
- exploration of the movement context
- generation of knowledge.

**TABLE 2.03** Advantages and disadvantages of a constraint-based approach

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Practice mimics the game environment</li> <li>• Variability of practice</li> <li>• Implicit learning occurs</li> <li>• Movement and problem-solving skills are developed</li> <li>• Promotes independent learning</li> </ul>	<ul style="list-style-type: none"> <li>• Coach familiarity with how to effectively structure the sessions</li> <li>• Can be more time-consuming to prepare and plan</li> <li>• Level of comfort for the coach to relinquish control</li> </ul>

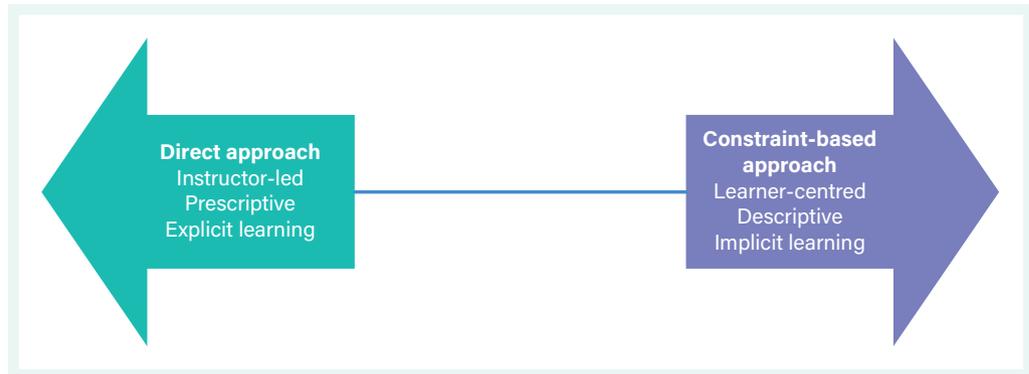
### constraint-based approach

An indirect instruction approach that allows the learner to explore movement skills and to find solutions to movement problems with less input from the coach and greater interaction with other learners

### implicit learning

Learning skills through practice tasks without direct instruction on how to complete the task

Direct and constraint-based approaches both have advantages and disadvantages, and good coaches will use both approaches when appropriate. Selecting the most suitable approach will depend on the individual characteristics of the learner, their skill level and stage of learning, the objective of the practice session and the complexity of the skill being learnt. The two approaches lie at either end of a continuum, as shown in Figure 2.18.



**FIGURE 2.18** Constraint-based approach continuum

## Understanding constraint-based skill acquisition

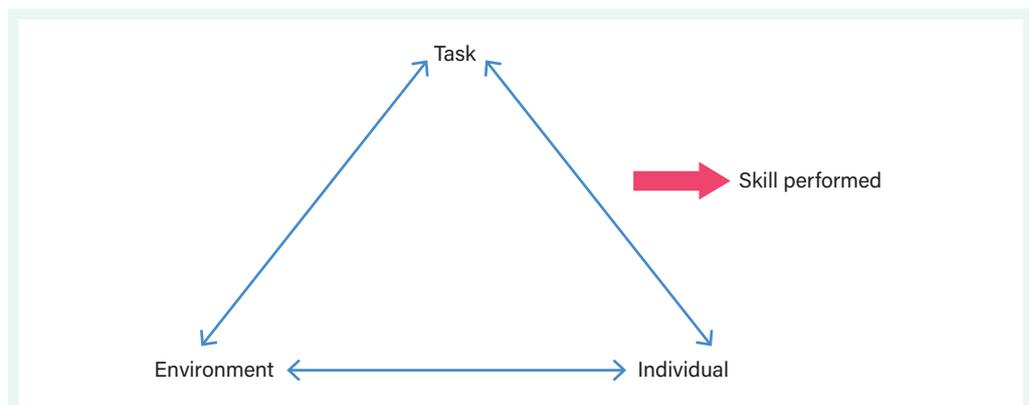
### constraints

Limitations or restrictions; the boundaries that influence the movement capabilities of individuals

In a dynamic system view of motor learning, movement patterns self-organise depending on the **constraints** placed on them. The self-organisation is determined by the interaction of the constraints and can limit movement capabilities, but the constraints can also enable movement or serve as resources that a learner uses to perform the movement skill. Coaches manipulate constraints to structure learning experiences for learners and provide a specific focus. The learner then generates a specific movement solution or decision that takes into account the interaction of the individual, task and environmental constraints.

There are three types of constraint that influence movement capabilities:

- individual
- environmental
- task.



**FIGURE 2.19** The interaction between the individual, the task and the environment shapes movement skill acquisition.

## Individual constraints

**Individual constraints** are characteristics of the individual that influence movement.

Examples of individual constraints are:

- physical characteristics (height, weight, limb length, body composition)
- fitness level (agility, balance, endurance, flexibility, power, speed, strength)
- psychological and behavioural characteristics (confidence, motivation, arousal, concentration)
- perceptual, decision-making and tactical knowledge (anticipation, recognising patterns of play)
- technical skills.

Individual constraints influence movement and can be manipulated so that the system self-organises, resulting in a specific movement pattern.

For example, a midfield player in soccer may have less explosive speed than a striker. As a result, they are more likely to present as a passing option in the midfield to hold the ball, rather than making a run to space to create a scoring opportunity.

### LOOKING FORWARD

#### Fitness components

##### Chapter 8

Physical activity, sport and exercise have varied requirements in terms of the physiological attributes of the participant. In Chapter 8 we will look specifically at fitness components, and the factors that affect their contribution to different activities.

#### individual constraints

Characteristics of the individual that influence movement

#### environmental constraints

Characteristics of the physical and social environments that influence movement

## Environmental constraints

**Environmental constraints** are those characteristics of the physical and social environments that influence movement.

### Constraints in the physical environment

Examples of environmental constraints in the physical environment include:

- weather conditions (temperature, rain, wind, hail etc.)
- gravity
- natural light
- sounds (noise level)
- playing surface (dry, wet, muddy).



**FIGURE 2.20** How does the playing surface impact on the players' ability to control the ball?



**FIGURE 2.21** How does having parents watch a game influence the way a soccer player plays?

### Constraints in the social environment

Examples in the social environment are:

- spectators
- peer group (teammates)
- family
- cultural norms (Australia produces good tennis players and swimmers)
- social expectations (Australian Rules football is more popular in Victoria and South Australia, but more people play and follow the rugby codes in Queensland and NSW)
- culture of the sport club and access to high-quality coaching.

## Task constraints

### task constraints

Characteristics of the task, such as rules, goals and equipment, that influence movement

**Task constraints** are the characteristics of the task, such as rules, goals and equipment, that influence movement. Task constraints are context-specific. The rules of the game can constrain the movement. For example, not being able to use your hands in soccer, not being able to run with the ball in netball and not being able to throw the ball in Australian Rules football all constrain movement.

Task simplification relates to making the performance of the movement skill easier. In non-linear approaches, task simplification allows players to complete the movement successfully without making the practice of the movement unrepresentative of how it would be performed in game or performance contexts. Two forms of task simplification are to reduce the number of players in the game, or to use modified equipment that reduces the difficulty of the task.

In modified sports, task constraints such as equipment (pitch sizes, net height, size of the bat) and rules (the number of players) are easy to manipulate so that the game becomes more accessible to younger learners. The modified activity still represents the key features of the adult form of the game, but it promotes more effective skill adaption for the learner and provides opportunities for the learner to explore movement behaviours in various contexts.

Research has shown that children prefer to use modified equipment. It leads to greater engagement in the task and results in greater self-efficacy in executing skills (Buszard et al., 2016). This outcome is likely twofold: the modified equipment (task constraint) is easier to use for young children, who may lack the strength (individual constraint) required to use adult equipment, which means they are able to perform the skills.



Vince Caligiuri/Getty Images

**FIGURE 2.22** Modified sporting equipment, such as smaller racquets and lower nets, makes playing tennis more engaging for children. They are able to achieve success, which leads to greater enjoyment and builds confidence to try new things. Of course, getting to play with Novak Djokovic is pretty inspiring, too!

In summary, in a constraint-based approach, the interaction between the learner, the task and the environment will shape the movement patterns that would be observed.

## COLLABORATIVE TASK

### Activity

#### Modifying task constraints

##### TASK

Watch the video 'From a Child's View, Parents Find Full-Ice Hockey No Fun' on the US Hockey channel on YouTube.

The video shows what it is like for young children when they are faced with trying to play sport on full-sized pitches with full-sized equipment, and the challenges they face.

This video clearly demonstrates that, when junior games are played on adult pitches and courts using adult equipment, the game looks and feels very different to the children when compared to the game played by adults.

##### QUESTIONS

- 1 How did the players feel after participating in this game?
- 2 Using examples from the video, **discuss** the impact the size of the rink has on the players' level of engagement, interest and motivation.
- 3 **Suggest** three ways in which you could manipulate the task (rules, goals or equipment) to positively influence the development of movement skills in ice hockey.



##### Weblink

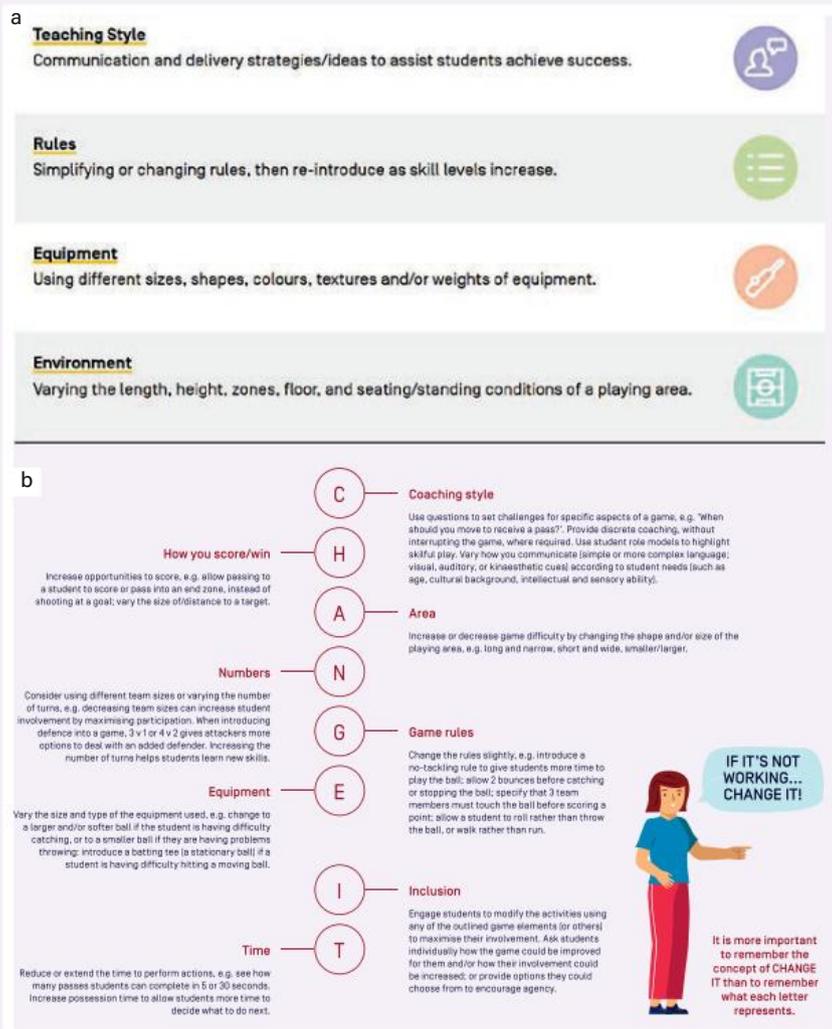
From a Child's View, Parents Find Full-Ice Hockey No Fun

## REAL WORLD APPLICATIONS

### Modified sport

Modified sports have been part of the Australian sporting landscape since the 1980s and continue to provide structured age-appropriate and developmental skills-appropriate ways of introducing sport to children. Modified sports have evolved over the years, and modifications are now made to ensure a fun, socially relevant and inclusive activity is available to everyone – children, people with a disability and older adults. Some sports modify the ‘rules’ so that teams can be mixed-gender, or so that individuals with lower fitness levels can still participate (e.g. walking football). All modifications are designed to develop movement skills and encourage participation in the sport.

Physical education teachers and coaches will often modify a game using one of the acronyms TREE (see Figure 2.23 a) or CHANGE IT (see Figure 2.23 b).



Australian Sports Commission, www.ausport.gov.au

**FIGURE 2.23** Acronyms used in modified sports

## COLLABORATIVE TASK

### Prac activity

#### Walking football (soccer)

##### INTRODUCTION

Walking football is a small-sided, low-impact, modified version of soccer, suitable for all levels of ability and fitness. Walking football aims to provide participants physical and mental health benefits and social contentedness, and to promote the benefits of ongoing physical activity.

Football Victoria's walking football program caters for individuals of all ages, with a focus on men and women aged over 55 years.

##### TASK

Participate in a game of walking football.

Team size: 5v5 or 6v6

Pitch size: 30 m × 20 m or 40 m × 30 m

Goal size: variable

Ball: regulation soccer ball

Game time: variable

##### RULES

- No running (player must always have one foot on the ground).
- No contact.
- The ball cannot be kicked above head height.
- No heading of the ball.
- No throw-ins.
- No corner kicks.
- No offside.

The complete national rules, regulations and guidelines for walking football can be found on the Football Victoria website.

##### DISCUSSION

- 1 **Identify** two task constraints that have been manipulated in this activity.
- 2 **Outline** the influence of the social and cultural environmental constraints on participants involvement in walking football.
- 3 Bryan is 55 years old, very fit and active, and has decided he would like to play soccer, but he has no prior experience. **Discuss** the suitability of walking football as an opportunity for Bryan to develop the movement skills and patterns that would be required for him to play soccer.

Alternatively, participate in a game of walking basketball. The only rule change to the game is, simply, no running! More information can be found on the 'Walking basketball' page of the Basketball Victoria website.



##### Weblinks

[Walking football rules](#)

[Walking basketball](#)

##### Command term

##### outline

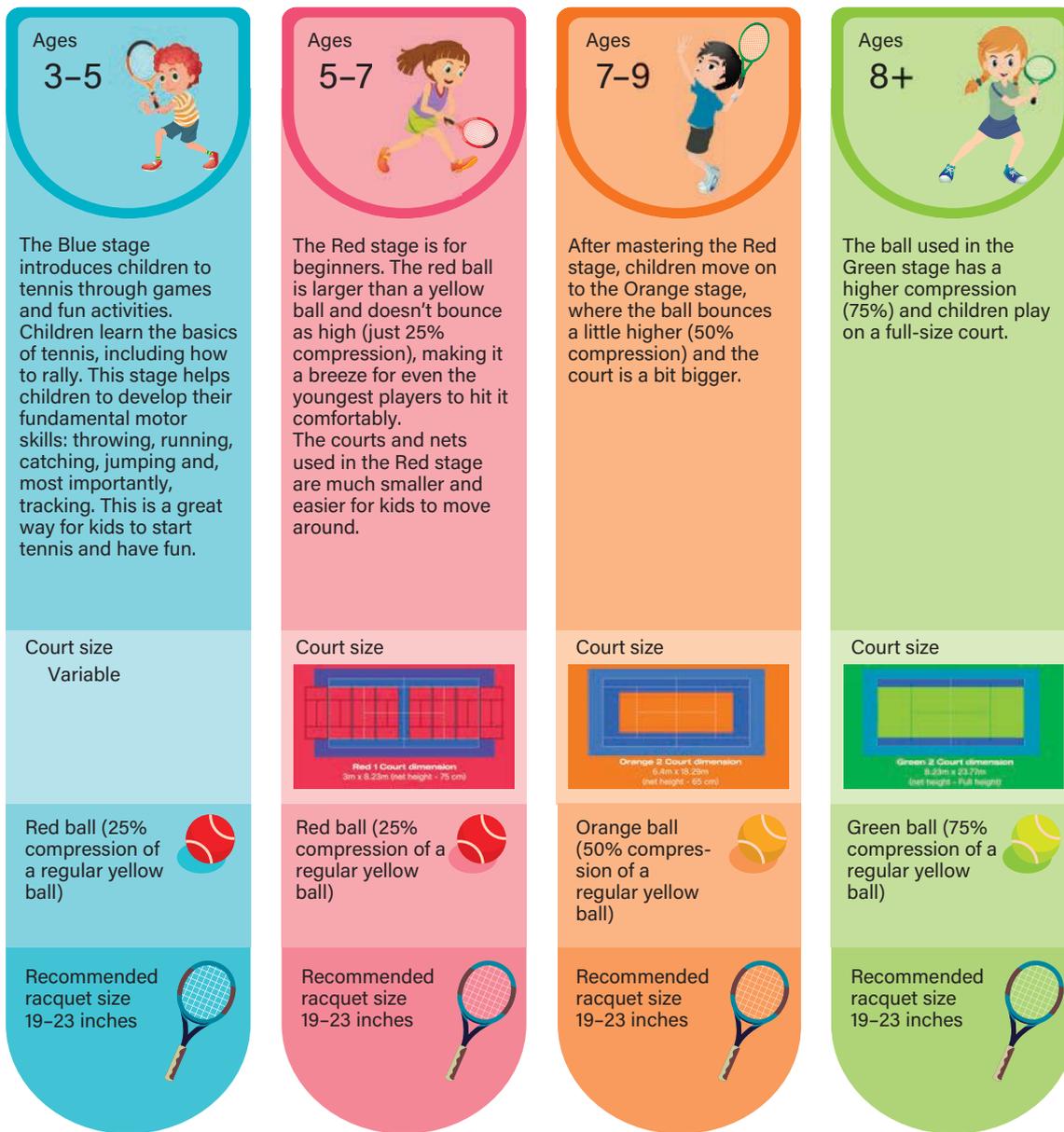
Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

**CASE STUDY** HOT SHOTS TENNIS

Hot Shots Tennis is a program for children of any age or ability to play and learn tennis. The program is divided into four stages. At each stage, children are provided with the right equipment and court size to match their ability and interest in playing tennis.

Hot Shots Tennis is played on smaller courts with modified equipment, including lighter and smaller racquets, lower nets and low-compression balls that don't bounce too high.

The low-compression tennis balls used in the Hot Shots Tennis program (red, orange and green balls) bounce lower than a normal tennis ball, allowing children to hit the ball in an optimal location relative to their height (i.e. at waist height; Kachel et al., 2015). This allows the learner to generate greater ball velocity while maintaining the accuracy of their shot. For the child, this means that they can confidently hit the ball harder without the ball going out or hitting the back fence!

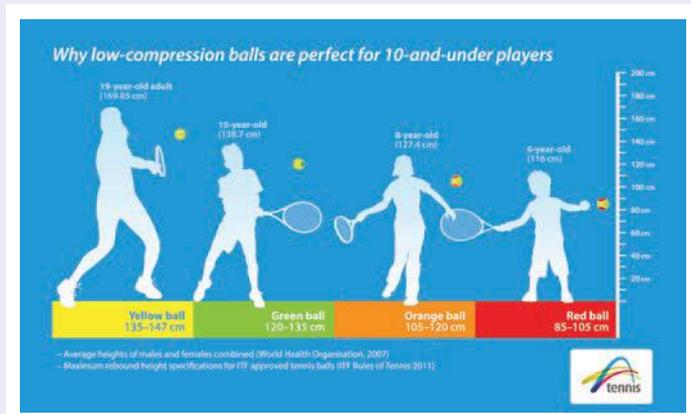


Tennis Australia

**FIGURE 2.24** Hot Shots Tennis

&gt;

In terms of practice and learning, when compared with 'adult' tennis conditions, learning with low-compression tennis balls has been shown to increase the number of hitting opportunities for the learner. This means that the learner has more opportunities to practise. Research (Fitzpatrick et al., 2017) has found that these modified conditions, imposed by the task constraints outlined in Figure 2.24, result in more successful forehands and backhands. This allows the learner to rally for longer with their peers, have fun and enjoy their tennis, as they experience greater success in the sport.



**FIGURE 2.25** Bounce heights of low-compression balls

### THE DEBATE

J.C. Roddick, the nephew of the last American to win the US Open, Andy Roddick, learnt to play tennis with a full-sized racquet, on a full-sized court and with yellow (full-compression) balls. At 9 years old, he entered a local United States Tennis Association (USTA) tournament. He was placed in an orange-ball tournament and was told that if he wanted to play, he would have to use an orange ball, play on a smaller court and use a shorter racquet. The decision by the USTA to change the rules for children under 10 has divided the tennis community in the USA. Some parents and coaches disagree on the best method for attracting and retaining young athletes to the sport and producing future champions. Those opposed to the modified version of the sport claim that it is a marketing ploy to 'sell more racquets' and that the decision was not evidence-based. They argue that low-compression balls are created for recreational players and should not be used in tournaments for competitive players. Those in favour of the modified version say that it can 'attract more kids and have them stay in tennis longer.'

### QUESTIONS

- 1 Identify** the task constraints that are used in Hot Shots Tennis.
- What is the relationship between ball compression, bounce height and the age of the learner?
- Based on your understanding of individual constraints, **explain** why the Hot Shots Tennis program has four stages.
- What is the benefit to movement skill development for learners using low-compression tennis balls?
- What evidence can be used to counteract the argument for the USTA's decision to introduce orange ball rules to all tournaments for children under 10?
- 6 Discuss** the advantages and disadvantages of modified vs non-modified sports on participation and performances.



**FIGURE 2.26** The USTA's 10-and-under system requires players to play with low-compression balls.



## Assessment

## 2.3 Check-in questions

## Command term

## explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

## 2.3 CHECK-IN QUESTIONS

- Which one of the following is an important component of the constraint-based approach to skill acquisition?
  - practising the skill in isolation from the game
  - repetition of the skill without opponents present
  - task simplification that maintains links between perception and action
  - a coach explicitly instructing an individual on how to perform the skill
- When the condition of the playing surface influences performance, this would be classified as:
  - a task constraint
  - a social constraint
  - an individual constraint
  - an environmental constraint
- Outline** three advantages of a direct approach to coaching.
- Describe** non-linear approaches to learning movement skills.
- The size of a playing area for soccer can be manipulated using the constraint-based approach to skill coaching and instruction. Outline what type of constraint the size of a playing area is and **explain** how reducing the size of the playing area will influence opportunities to improve skills for players in the game of soccer.

## 2.4 PRACTICE STRATEGIES

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- in session and scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random) and learn to:
  - participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

matimix/Shutterstock.com



**FIGURE 2.27** A coach oversees a practice session.

Learning a motor skill requires two things:

- feedback – which we will explore in detail in Module 2.5
- practice.

In this module we will look at different types of practice (part and whole) and the distribution of practice – both within a practice session, and in the scheduling of practice sessions and the variability of practice sessions (blocked and random).

## Type of practice

Coaches need to plan and design practice that is appropriate for the learner and effective for skill learning. If the task is not challenging, the learner will lose interest and become bored, and if the task is too difficult and the learner doesn't experience any success, this can become disheartening for the learner and cause them to lose interest as well. Coaches need to find the optimal level of challenge for the learner, so that they achieve some success. Modifying the complexity of the skill by breaking the skill into parts to make it simpler – rather than requiring them to perform the whole skill – is one method a coach may use.

## Part and whole practice

### Part practice

Motor skills can be broken down into parts or segments, and **part practice** is a term that is applied when the skill has been broken down into parts and each part is practised in isolation. Part practice can be useful for beginners when they are learning complex skills because they can practise individual components of the skill and gain success in each aspect before moving on to perform the whole skill.

Learners should be provided with a demonstration of the whole skill, even if they are going to practise individual parts, so that they understand the context of the whole skill.

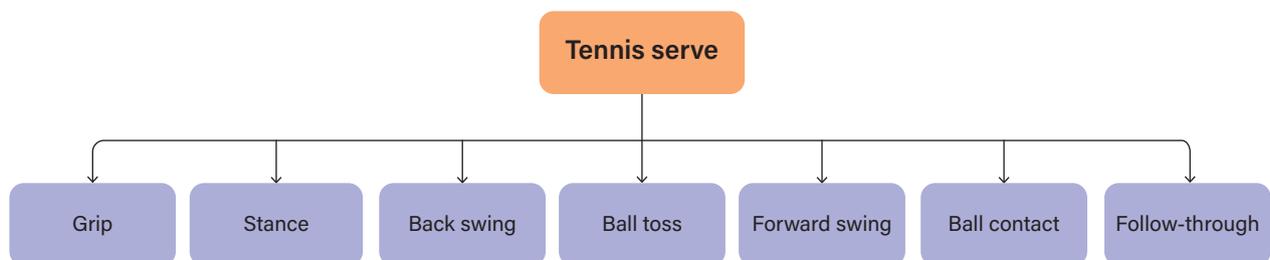


Video

In focus: Differences between the types of practice

### part practice

Practice of the individual parts of a skill



Small365/Adobe Stock

**FIGURE 2.28** A tennis serve can be broken down into many different parts. A skill should be broken down into the largest components the learner can manage.

**whole practice**

Practice of the whole skill

**Whole practice**

**Whole practice** is the practice of the whole skill. A coach may provide a demonstration of the skill and the learners then imitate the coach's movement to replicate the whole skill.

One advantage of whole practice is that the relative timing and movement dynamics are not affected. In the tennis serve example in Figure 2.28, practising the follow-through in isolation from the forward swing and ball contact may produce a disjointed movement.

Generally, more skilled learners can cope with the whole skill and, if they can, it is better to practise the whole skill.

Deciding whether to use part or whole practice is influenced by two main factors: the skill and the learner.

- Skills that are low in complexity but high in organisation are best learnt through whole practice.
- Skills that are high in complexity and low in organisation are learnt best through part practice.

**TABLE 2.04** Part practice vs whole practice

	Part practice	Whole practice
<b>Skill</b>		
Complex*	✓	
Simple		✓
Classification of skills		
Serial	✓	
Discrete		✓
Continuous		✓
Organisation of skill**		
Low	✓	
High		✓
<b>Learner</b>		
Stage of learning		
Beginner	✓	
Skilled		✓
Overwhelmed by the skill	✓	
Able to attend to whole skill		✓
Having difficulty with some parts of the skill	✓	
Familiar with some skills		✓
Likely to have difficulty with whole skill	✓	
Capable of performing whole skill		✓

Adapted from Spittle, 2012

\* Complexity of a skill refers to the number of parts of a skill and a high cognitive demand.

\*\* Organisation of a skill refers to the relationship between the parts of the skill.

## COLLABORATIVE TASK

### Prac activity

#### Part and whole practice

##### AIM

To compare part and whole practice in learning a new skill (cup stacking)

##### EQUIPMENT

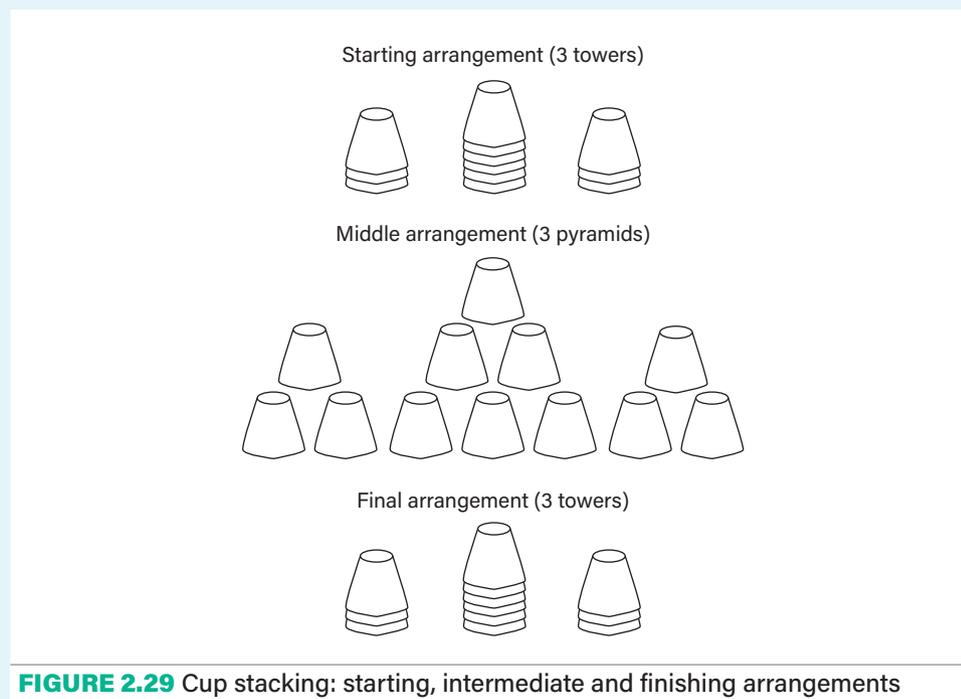
- 12 plastic cups (per pair)
- stopwatch or timer

##### TASK

Cup stacking involves taking 12 cups and stacking them in a 3-6-3 formation (see Figure 2.29) in the quickest time possible. Before starting this activity, watch a demonstration of the skill online in the video *Fastest Speed Stacking Ever! – Guinness World Records* on the Guinness World Records YouTube channel.



**Weblink**  
Fastest Speed Stacking Ever!



**FIGURE 2.29** Cup stacking: starting, intermediate and finishing arrangements

##### METHOD

In groups of three, allocate each student a practice strategy to complete:

Strategy 1 – Part practice:

10 trials of the 3-stack part of the skill

Strategy 2 – Whole practice:

30 trials of the 3-6-3 stack

Strategy 3 – Whole-part practice:

10 trials of the 3-6-3 stack, followed by 10 trials of the 3-stack, followed by 10 trials of the 6-stack part of the skill.

##### RESULTS

After completing the practice trials, each student completes five timed trials of the 3-6-3 stack.





Record the strategy the students used, and the times for each trial, in a table.

Student	Strategy	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Zachary	Whole-part practice	12.8 seconds	10.2 seconds	13.6 seconds	10.1 seconds	8.5 seconds

Graph the results.

**DISCUSSION**

**Analyse** the results to determine which practice strategy was most effective for learning the skill. Provide an explanation for your decision.

Adapted from Spittle, 2013, pages 380–1

**Command term**

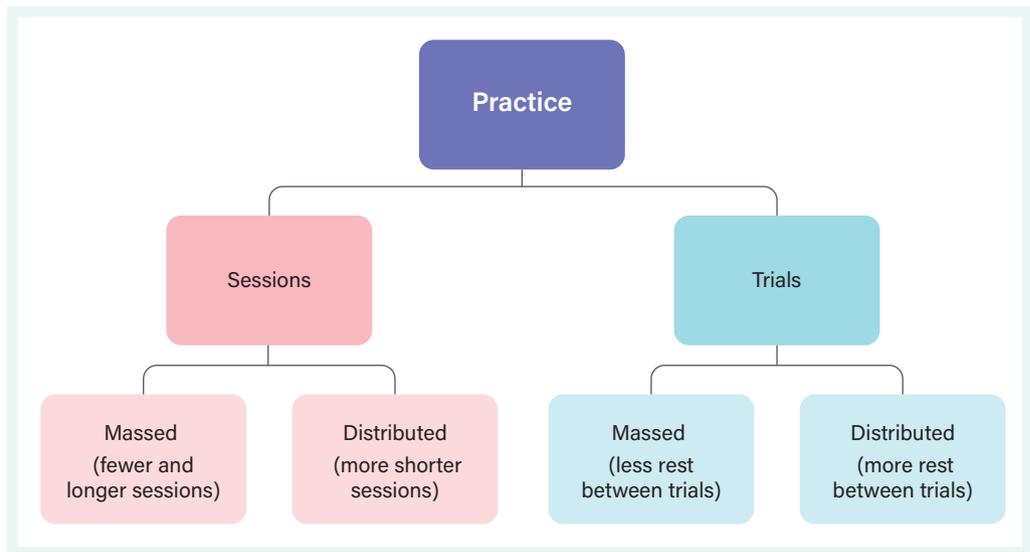
**analyse**

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

## Practice distribution

Practice distribution can refer to the:

- scheduling of practice sessions (how frequent and how long the sessions are) or
- spacing of practice trials within a session.



**FIGURE 2.30** Breaking down practice

There is no definitive answer to the optimal number and length of practice sessions, but what we do know is that the more a learner practises, the more they will learn. So is it better to have fewer, longer sessions or more, shorter sessions per week? Generally, it is recommended that practising more often for shorter periods of time is beneficial to learning a skill; in junior sport, however, practice schedules are often determined by the availability of venues or facilities and/or coaches.

An example of a training schedule for an under-16 soccer team is shown in Table 2.05. The team completes a total of 4.5 hours of training per week, and this training is spread (distributed) over three days.

**TABLE 2.05** Example of a training schedule for an under-16 soccer team

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Game	6.00–7.30 pm	7.30–9.00 pm		7.30–9.00 pm		

The distribution of practice trials within a session can also vary. A distance runner may practise their skill with minimal rest between trials. By comparison, a gymnast may have three vaulting practice trials within an hour's session, with rest breaks between each trial. When describing different practice schedules, we use the terms 'massed' and 'distributed'.

## Massed practice

When scheduling practice sessions, **massed practice** involves fewer practice sessions that last for a longer period of time. When considering practice trials, massed practice involves minimal, or very short, rest periods so that the practice within the session is almost continuous.

Examples of massed practice are:

- hitting a bucket of golf balls
- completing 50 handballs
- hitting tennis forehands for 5 minutes with no rest.

Massed practice can become repetitive and boring for the learner, but has been shown to be more beneficial for the learning of discrete skills.

---

### massed practice

Practice that has fewer, but longer sessions, or shorter rest periods between practice trials within a session

## LOOKING BACK

### Classification of skills

#### Chapter 1

In Chapter 1 we looked at classifying skills as open or closed, gross or fine, and discrete or continuous. You will recall that discrete skills are skills that have a distinct beginning and end – for example, putting in golf – and continuous skills are those with no discernible beginning and end points, such as running or cycling.

## Distributed practice

When scheduling practice sessions, **distributed practice** involves spreading the practice across more sessions of shorter duration. When considering practice trials, distributed practice involves increasing the amount of rest between trials.

Examples of distributed practice are:

- training four times per week for 45 minutes per session (not twice a week for 90 minutes)
- goal-kicking practice: kick from 50 metres out, rest for 1 minute, repeat five times
- 4 × 800-metre intervals with 5 minutes rest between trials.

Distributed practice is beneficial in learning continuous skills, such as running or swimming, as it allows for rest periods, decreasing the impact of physiological and psychological fatigue, and can break up the monotony of the session to increase motivation and minimise boredom.

Massed and distributed practice are relative terms that allow us to compare practice sessions and trials. Most research suggests that distributed practice sessions are more beneficial to learners, so scheduling more, shorter sessions is more effective than fewer, longer sessions. This is not always practical, and coaches need to consider many factors when planning the distribution of the practice time that is available. The age and stage of learning of the learner, the skill being practised, the nature of the task and the level of physiological and psychological fatigue – as well as the practical aspects of training such as the availability of equipment, court/pitch/field and coaching personnel – all need to be considered when scheduling practice.

---

### distributed practice

Practice of a skill, or each part of a skill, with rest between activities or as shorter sessions throughout the week

## Practice variability

Practice variability refers to the range of different skills and drills that the learner experiences during the practice session. Practice variability has been shown to help in the learning a skill and in applying the skill to different situations.

### Blocked practice

#### blocked practice

Practice of a skill where the learner practices the same skill over and over again

**Blocked practice** refers to practice where the same skill is repeated over and over again. Each skill is practised in isolation and practice is organised so that the learner focuses on one skill at a time.

In an example of blocked practice for netball, players complete:

- 20 chest passes
- 20 lob passes
- 20 right-handed passes
- 20 left-handed passes.

Blocked practice is considered a traditional approach to skill learning where learners repeat the skill over and over again in a closed and predictable environment until they are able to perform it correctly. The multiple opportunities to practise the same skill allow the learner to correct errors and refine the movement skill.

Blocked practice is more suited to younger learners who are in the cognitive stage of learning as the learner is trying to understand the skill and develop the basic movement patterns. Blocked practice limits the number of variables the learner needs to consider, so they can focus on a few things and not overload their cognitive capacity.

Blocked practice may lead to the apparent learning of the skill. Learners may not always, however, be able to translate the performance of the skill from practice (in a closed performance environment) to a game situation (open performance environment).

#### random practice

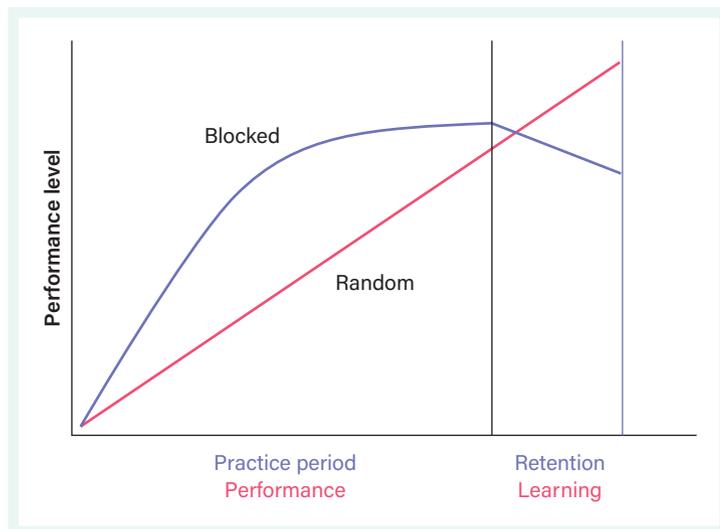
Practice of different skills where the learner doesn't practise the same skill twice in a row

### Random practice

**Random practice** is where the learner practices a number of different skills, without practising the same skill twice in a row. The learner is unable to predict what will come next with this type of practice. Lower predictability means the learner must have a range of possible movement responses and the learner switches between skills, so repetition is minimised.

In an example of random practice for netball, players might complete a lob pass, a chest pass, a right-handed pass, a lob, a chest pass, a left-handed pass, a lob, a chest pass, a right-handed pass, a left-handed pass, a chest pass, a lob etc.

There is some limited evidence that random practice is more beneficial for learners in the later stages of learning. Random practice has also been shown to result in greater retention of the skill and greater ability to translate the performance of the skill to a game situation.



**FIGURE 2.31** Why do you think blocked practice initially results in a more rapid increase in performance?

## 2.4 CHECK-IN QUESTIONS

- 1 Which one or more of the following statements are correct?
  - A Massed practice involves more work time than rest.
  - B Massed practice involves more rest time than work.
  - C Distributed practice involves more work time than rest.
  - D Distributed practice involves more rest time than work.
- 2 Complete this sentence: 'In general, to improve a continuous skill, \_\_\_\_\_ practice should be used. To improve discrete skills, \_\_\_\_\_ practice should be used.'
- 3 Compared with random practice, blocked practice is more likely to result in:
  - A performance of the skill.
  - B learning of the skill.
  - C retention of the skill.
  - D transfer of the skill.
- 4 What are the advantages of massed practice?
- 5 Why shouldn't a coach use massed practice within a vaulting practice session?
- 6 Many junior sports have practice once a week. How could a coach structure a 60-minute session to maximise the children's learning?
- 7 At the start of every training session, Greg, the coach of the under-13 soccer team, tells the players to complete the following skill drills:
  - 50 ball juggles – left foot (use your left foot to keep the ball up)
  - 50 ball juggles – right foot (use your right foot to keep the ball up).
 If the ball hits the ground, the player needs to start again and keep practising until they complete 50 in a row. With reference to the distribution of practice, **evaluate** the pros and cons of this training drill.

### 🚩 SIGNPOST

#### Smart Practice

Listen to the 'Smart Practice' podcast with AIS skill acquisition expert, Dr Daniel Greenwood, and AIS pathways expert, Dr Juanita Weissensteiner.



**Assessment**  
2.4 Check-in questions

### Command term

#### evaluate

Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information



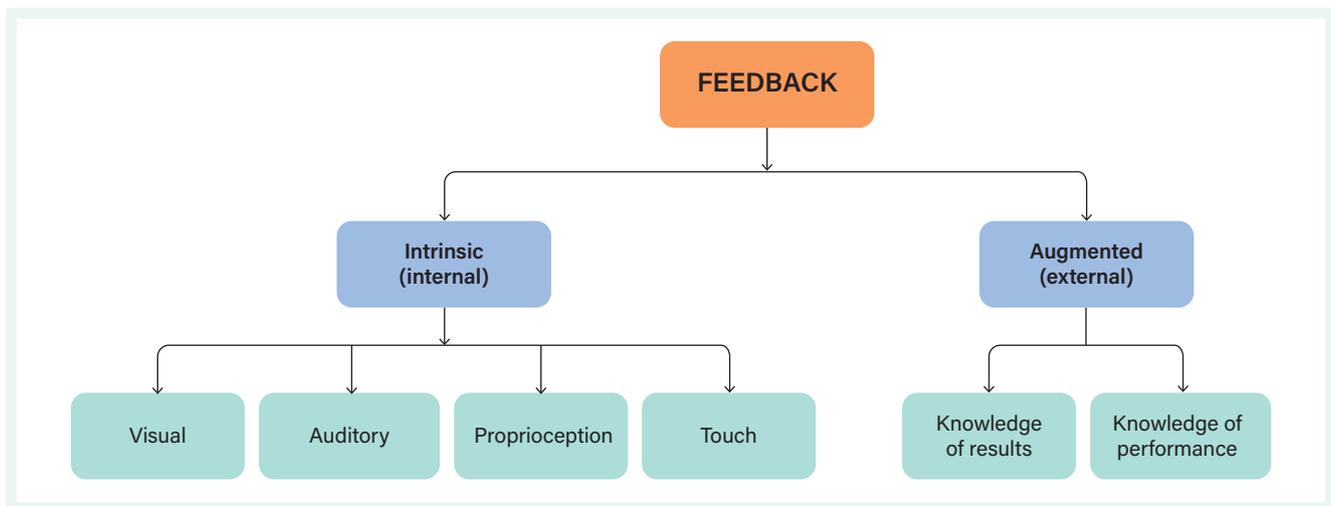
**Weblink**  
Smart Practice

## 2.5 FEEDBACK

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- frequency and type of feedback, including intrinsic and augmented (knowledge of results and knowledge of performance) and learn to:
- participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

It is generally accepted that, after practice, **feedback** is the most important factor in learning a motor skill (Spittle, 2013). Feedback is any information that the learner receives about their performance. Feedback may be **intrinsic feedback**, which comes from internal sources, or **augmented feedback**, which comes from external sources.



**FIGURE 2.32** Types and sources of feedback

#### feedback

Information a learner receives about their performance

#### intrinsic feedback

Feedback from the performer's own senses; the internal information an athlete receives, based on the outcome of a particular movement or series of actions

#### augmented feedback

Information about the performance that comes from an external source

#### proprioception

Sensory information that comes from within the body about the body's movement and position in space

## LOOKING FORWARD

### Analysing movement

#### Chapter 4

Chapter 4 will look at the four stages involved in performing a qualitative movement analysis. The final stage in this process, known as error correction, involves coaches or teachers providing feedback to the learner and/or addressing errors through strategies implemented in practice sessions.

Coaches need to deliver accurate feedback in a way that does not demoralise the learner or ruin an athlete's confidence, motivation or passion for the activity. See Module 2.6 for more information on psychological strategies.

## Types of feedback

### Intrinsic feedback

Intrinsic feedback is information the learner gets through their sensory system, directly from their performance. Our sensory system gathers and processes information through the senses to inform our understanding of the environment around us. Our senses influence both voluntary and involuntary movement – for example, if you touch something very hot or sharp, the reflex action (involuntary movement) is to draw your hand away quickly. Our senses can detect touch, pain, temperature, movement and position (**proprioception**), vibration and pressure, as well as vision (sight), sound (auditory), taste and smell. In motor learning we are most interested in the information that is received through touch, proprioception and vision.



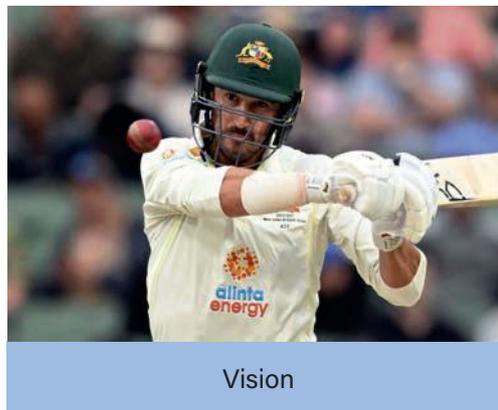
iStock.com/E+/German Adrasti

Touch



dpa picture alliance/Alamy Stock Photo

Proprioception



WILLIAM WEST/AFP/Getty Images

Vision

**FIGURE 2.33** Senses influencing movement performance and learning

When we perform a motor skill, the sensory system provides information about the movement. For example, when hitting a golf ball, our sense of touch provides information on how the club feels in the hand, our muscles and joints let us know how the movement felt (proprioception) and our sight allows us to see where the ball goes (vision).

- Touch is important in skills that have contact with external objects.
- Proprioception is important in skills that require equilibrium and balance and knowing the body's position in space.
- Vision is important for planning, performing and evaluation of movement skills.

Performers can also use the sound of the ball being struck to provide information about their performance. In some situations, auditory information can be highly valuable, such as in a game of goalball.

Australian Matildas goalkeeper Mackenzie Arnold suffers from bilateral sensorineural hearing loss, which affects her ability to hear certain frequencies and sounds. This has not stopped her from reaching the highest level in her sport, representing Australia, playing with the Matildas in the World Cup and playing for West Ham in the Women's Super League in England.



#### Weblink

Mackenzie Arnold shares her hearing loss journey with the world

## SIGNPOST

To read more about Mackenzie Arnold, go to the Optus Sport website and read the article, 'West Ham goalkeeper Mackenzie Arnold shares her hearing loss journey with the world.'



NurPhoto/NurPhoto/Getty Images

**FIGURE 2.34** Mackenzie Arnold in goal

## DID YOU KNOW?

NBA players who spend more time touching each other with fist bumps, high fives, chest bumps, leaping shoulder bumps, chest punches, head slaps, head grabs, low fives, high tens, full hugs, half hugs and team huddles are more successful as individuals and as a team. It appears that the most cooperative teams are also the most touchy-feely (Kraus et al., 2010). It could also be that this type of behaviour increases the arousal levels of the players, resulting in improved performance. (We will look at arousal level in detail in Module 2.6.)



**FIGURE 2.35** NBA players celebrating

Ezra Shaw/Getty Images Sport/Getty Images

## COLLABORATIVE TASK

## Prac activity

## Goalball



**FIGURE 2.36** Saving a goal in goalball

Goalball is a team sport that is played indoors and is specifically designed for athletes with vision impairment. The primary objective of the game is to score goals by rolling a ball into the opponent's net, while the opposing players use their bodies to block and defend against the ball. Bells inside the ball help the players by indicating the position and direction of the oncoming ball. The court has tactile line markings to allow players to orient themselves. The game is played in complete silence to allow the players to hear the bells inside the ball.

More information about goalball can be found on the Goalball Australia website.

Your school may have blindfolds and a goalball so that you can play a game of goalball.

Consider the role of each of your senses in this game. Without being able to see the ball, how did you work out where you were on the court in relation to the goals and other players? How did you determine where the ball was? How difficult was it to score? How difficult was it to defend the goals?



Alex Pantling/Getty Images Sport/Getty Images



**Weblink**  
Goalball Australia

## Augmented feedback

Augmented (external or extrinsic) feedback is information about performance that comes from an external source such as a coach or teacher. Augmented feedback can be auditory, and either verbal or non-verbal. It may come from a piece of equipment such as a smart watch or fitness tracker. It may be visual (see Chapter 3 for the types of images that biomechanists use to provide feedback to athletes) – for example, from a video/digital recording of the performance.

Augmented feedback supplements intrinsic feedback and can be provided during or after the performance:

- **Concurrent feedback** is provided during the performance of a skill. For example, a runner may check their fitness tracker or watch throughout a run to monitor their pace, intensity level (heart rate) or distance. The athlete can use this information as they are running to adjust their performance.



**FIGURE 2.37** A rowing coach calling out instructions to the crew while riding alongside the rowers is a form of concurrent augmented feedback.

- **Terminal feedback** is provided after the performance of a skill. A tennis coach at training telling an athlete to follow through more after hitting a forehand is an example of terminal augmented feedback. The athlete can use the information to adjust their technique before hitting the next forehand. A coach's address at quarter time in Australian Rules football (AFL) is also an example of terminal feedback. The coach provides the team with feedback on the things that they did well and then things to focus on going into the next quarter.

#### Knowledge of results

Augmented feedback about the outcome of skill performance

### Knowledge of results

**Knowledge of results** is information about the outcome or the results of a performance. For example, automated line-calling systems such as Hawkeye in tennis provide information to the learner on how far out a serve was. Other examples include the netball going through the ring or the coach telling the athlete they jumped 5.5 metres in the long jump. Knowledge of results provides information that lets the learner know if they have been successful and have achieved the goal of the skill.

#### Knowledge of performance

Augmented feedback about the technique of skill performance

### Knowledge of performance

**Knowledge of performance** is information that is provided by the coach, or through video analysis, about the process of the performance that led to the outcome (either successful or not). Learners can use this information to improve the quality of their performance by making changes to their technique. Knowledge of performance can reinforce teaching cues. A tennis coach may say to the learner, 'Bend your knees deeper to initiate the serve'. After the serve, this is reinforced through feedback on the performance – for example: 'The deep knee bend was great, and it resulted in the added power in that serve.'

Knowledge of performance is more beneficial to motor skill learners than knowledge of results: the learner can usually see the result, but they may need more information on why the ball hit the crossbar, or why the serve went into the net.

Good coaches know when to give feedback, how often to do so and how much detail to provide. Feedback is primarily used to improve performance, but it can also motivate a learner and provide encouragement to keep trying and to work towards their goals. Positive feedback can help when players are frustrated or disappointed in their performance as well as when they have done something right or tried really hard. Feedback can be used to reinforce positive behaviours and decrease or eliminate negative behaviours.

## Frequency of feedback

Giving the right feedback at the right time is critical to getting the best out of any performance, and good coaches determine the type, amount and frequency of the feedback given based on the skill level of the learner, the skill complexity and the experience of the learner. Frequency of feedback should be reduced as the learner progresses through the stages of learning (cognitive, associative, autonomous).

For learners in the cognitive stage, more feedback is better than less because they do not have error detection or correction capabilities. To ensure learners in this stage of learning are not overwhelmed, simple feedback in the form of demonstrations and key learning points, reinforced regularly, is best. As the learner develops, they become more proficient at identifying errors and can recognise and interpret intrinsic feedback, so the frequency of the augmented feedback can decrease. There is a risk of dependency if feedback is provided too frequently to learners in the early stages of learning; therefore, as the learner begins to understand the skill, the amount of feedback provided by the coach should be reduced.

### COLLABORATIVE TASK

#### Lab activity

#### Feedback - knowledge of results

##### AIM

To investigate the influence of feedback on performance

##### EQUIPMENT

- blindfolds
- bean bags
- poly dots
- tape measure

##### METHOD

- 1 Students work in pairs.
- 2 Place a poly dot 3 metres from the throwing line (as shown below).





- 3 Each student has five attempts to land the bean bag on the poly dot for each trial.
- 4 Trial 1: the blindfolded student stands behind the throwing line and attempts to land the bean bag on the poly dot.
- 5 After each attempt, their partner can provide only the following feedback:
  - The bean bag landed on the poly dot
  - The bean bag did not land on the poly dot.
 After each trial, record the number of successful throws.
- 6 Trial 2: the blindfolded student stands behind the throwing line and attempts to land the bean bag on the poly dot.
- 7 After each attempt, their partner can provide feedback on:
  - whether the bean bag landed on the poly dot or not
  - whether the bean bag landed to the left, to the right, past or before the poly dot.
 After each trial, record the number of successful throws.
- 8 Trial 3: the student removes the blindfold, then stands behind the throwing line and attempts to land the bean bag on the poly dot.
- 9 After each attempt, the student can see if:
  - the bean bag landed on the poly dot
  - the bean bag did not land on the poly dot.
 After each trial, record the number of successful throws.

### RESULTS

Redraw the table below and indicate with a tick or a cross if the bean bag landed on the poly dot.

	Trial 1	Trial 2	Trial 3
Attempt 1			
Attempt 2			
Attempt 3			
Attempt 4			
Attempt 5			

### DISCUSSION

- 1 What type of feedback was:
  - a provided after trial 1?
  - b provided after trial 2?
  - c available after trial 3?
- 2 a Did the student become more successful at landing the bean bag on the poly dot after each attempt in trials 1 and 2? Why or why not?
  - b What would the learner need to do if they were to reach the autonomous stage of learning for this motor skill?

### CONCLUSION

What conclusions can you draw from the results of this activity?

## 2.5 CHECK-IN QUESTIONS

- 1 An elite netball player (goal attack) took a shot for goal in a game. After releasing the ball, the player turned around immediately and jogged back ready for the next centre pass. What type of feedback did this player use to determine that the shot was likely to be successful?
  - A intrinsic
  - B augmented
  - C knowledge of results
  - D knowledge of performance
- 2 A coach could be heard calling out split times for athletes training for a 10,000-metre race. Which type of feedback was the coach providing to the athlete?
  - A augmented, knowledge of performance
  - B augmented, knowledge of results
  - C intrinsic, knowledge of performance
  - D intrinsic, knowledge of results
- 3 Which one of the following is an example of augmented feedback?
  - A a hockey player seeing the ball go into the goal
  - B a tennis player hearing the ball connect with the racquet
  - C a coach telling a player to fully extend their leg when kicking
  - D a soccer player feeling the ball make contact with their feet while dribbling
- 4 **Identify** the correct option from the words in bold in the following sentence:  
As the learner becomes more proficient, the coach should provide **more/less** augmented feedback.
- 5 Athletes receive information from their senses. Provide a suitable example of the type of intrinsic feedback an athlete may receive through each of the following senses:
  - touch
  - proprioception
  - vision (sight)
  - auditory (sound)
- 6 During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200 metres and 400 metres freestyle swimming events. **Explain** why the frequency and use of intrinsic and augmented feedback should have changed as Titmus progressed through the stages of learning.



**Assessment**  
2.5 Check-in questions

## 2.6 PSYCHOLOGICAL SKILLS

In this module you will learn about:

- considerations when coaching to enhance participation and performance
- psychological skills (confidence, motivation, optimal arousal and concentration) and accompanying strategies and learn to:
  - participate in, describe and develop coaching strategies to enhance participation and performance considering the needs of the learner and the performance requirements of the skill.

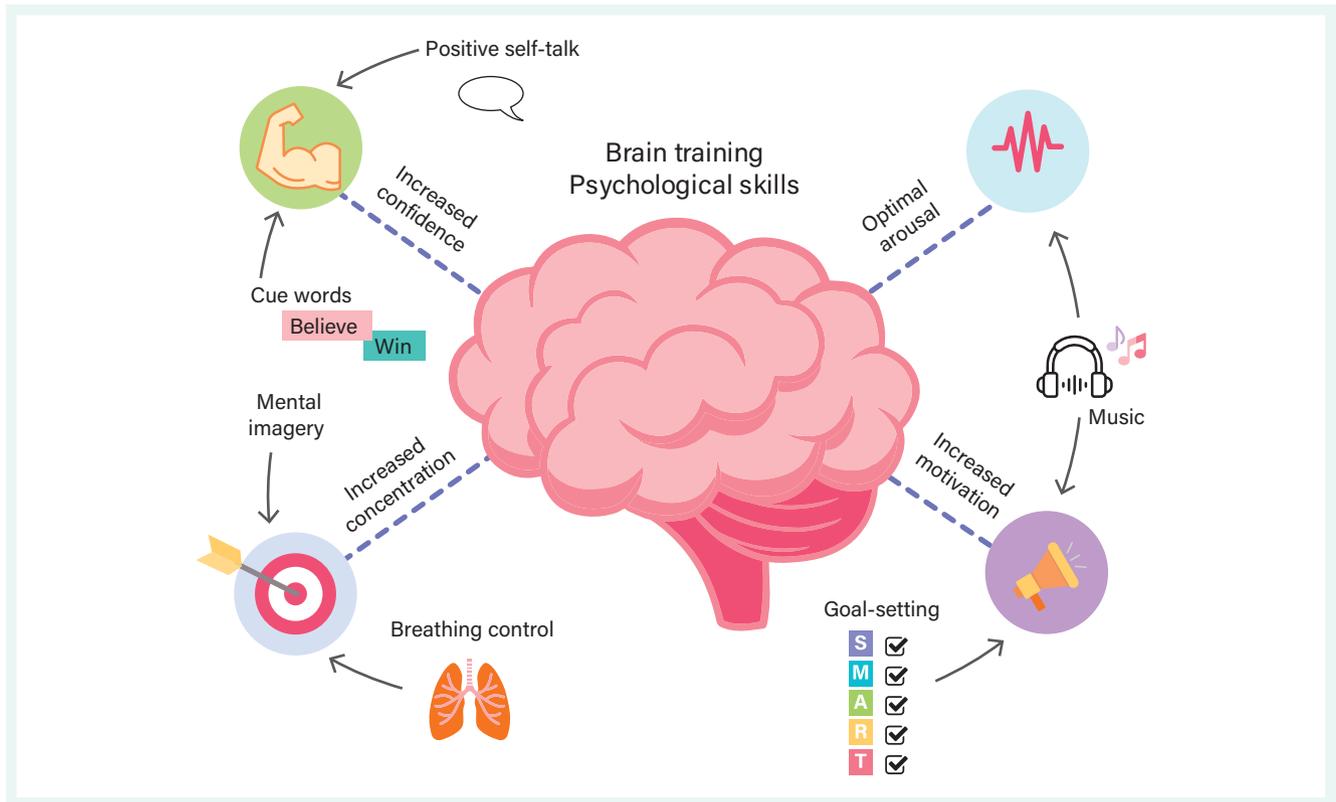
**psychology**

The study of the mind and behaviour

Sports **psychology** looks at the psychological factors that influence, and are influenced by, participation in physical activity, sport and exercise. Individuals (athletes, students, learners), coaches and teams use psychological skills to enhance, and at times restore, performance, and to maintain and promote the mental health and wellbeing of the individual. Psychological skills, like motor skills, need to be learnt and practised.

In this module we will look specifically at the following as key psychological skills and strategies to enhance participation and performance:

- confidence
- motivation
- optimal arousal
- concentration.



**FIGURE 2.38** Brain training: psychological skills



**Weblink**  
Let's Talk, Ash Barty

**🚩 SIGNPOST**

Listen to the podcast 'Let's Talk, Ash Barty', in which tennis champion Ash Barty discusses the psychological strategies she used throughout her career to overcome her fears and to succeed at the highest level.

## Confidence

**confidence**

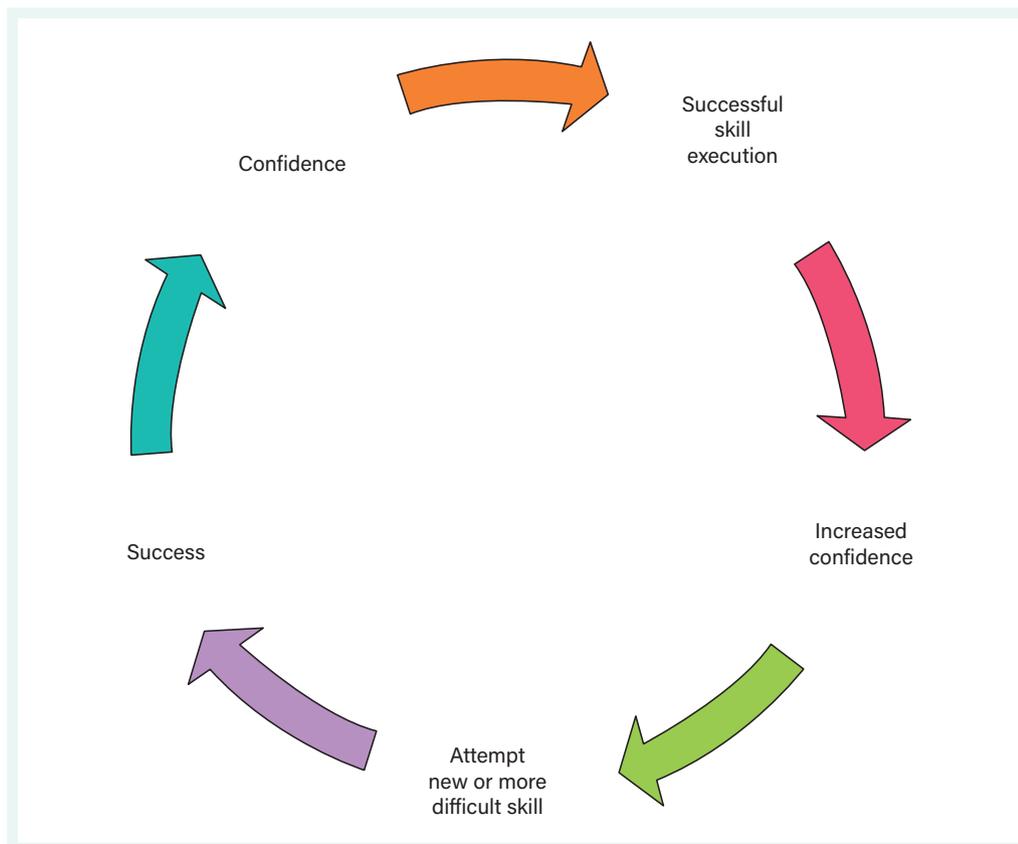
The belief or degree of certainty that an individual possesses about their ability

**Confidence** is the belief or degree of certainty that athletes possess about their ability to improve and achieve success in physical activity, sport and exercise. Recent research (Durand-Bush, 2023) suggests that confidence is fundamental to an individual's ability to perform consistently at a high level. We also know that children who are competent and confident in their ability are more likely to be physically active.

Confidence is:

- showing a degree of certainty and assuredness
- being willing to try new movements or physical activities
- showing resilience and maintaining a sense of self-belief after experiencing a setback – for example, returning from injury or losing a game.

Confidence is a self-fulfilling cycle – that is, confidence increases with success, and successful skill execution builds confidence, so the athlete becomes more confident to try new skills, learn skills faster or progress to a more difficult skill.



**FIGURE 2.39** The confidence cycle

## Building confidence

Coaches, teachers, parents and role models all play an important role in building confidence, especially in young learners, and need to provide experiences that allow the child to be successful. High expectations can increase self-efficacy, and young learners need to experience some situations that require persistence so they can build resilience and learn to bounce back from a setback.

**Self-efficacy** is the belief or confidence in your ability to be active within specific circumstances. For example, in practice, an athlete may be capable of successfully clearing the high jump bar at every height up to, and including, their personal best. However, their self-efficacy at replicating this in competition – where the conditions are different, the crowd is loud, they are feeling nervous and they are feeling the pressure to perform – may differ. Self-efficacy, like confidence, is fluid and can fluctuate. Self-efficacy theory (Bandura, 1986, 1997) helps us to understand the sources of information on which a learner or athlete bases their expectations.

### self-efficacy

Confidence in one's own ability to perform a target behaviour (a movement skill)

## REAL WORLD APPLICATIONS

### Confidence

'The 25-year-old has visibly struggled with his confidence in front of goal ...'

Chris De Silva, Wide World of Sports website, 14 May 2023

Player confidence is crucial to success, and yet it is incredibly fragile. Athletes can't just turn their confidence on and off; it fluctuates and can be the difference between an athlete's best performance and their worst. AFL player Harry McKay's confidence took a hit during the 2023 season, when his accuracy in front of goal all but disappeared. When asked how one gets their confidence back, McKay answered, 'I'd love to know.' Sports psychologists know that the ability of a coach to build a player's confidence is one of the secrets to success.



**FIGURE 2.40** Harry McKay

Darrian Traynor/Getty Images Sport/Getty Images

## Motivation

### motivation

The direction and intensity of effort

**Motivation** and confidence are closely connected. For movement skills to be learnt, the learner must be motivated – that is, they need to engage in, and put effort into, the learning process. Motivation to participate in physical activity, sport and exercise and to learn movement skills will vary. We looked at some of the factors that influence participation and skill development in Module 2.1, and you may recall that children are often motivated to participate for fun, to be with their friends or part of a team, to improve or learn new skills, to get fit, for the challenge or excitement of competition and to have success (and win!). Adults are also motivated by social interaction, competition, health benefits and a sense of achievement.

### intrinsic motivation

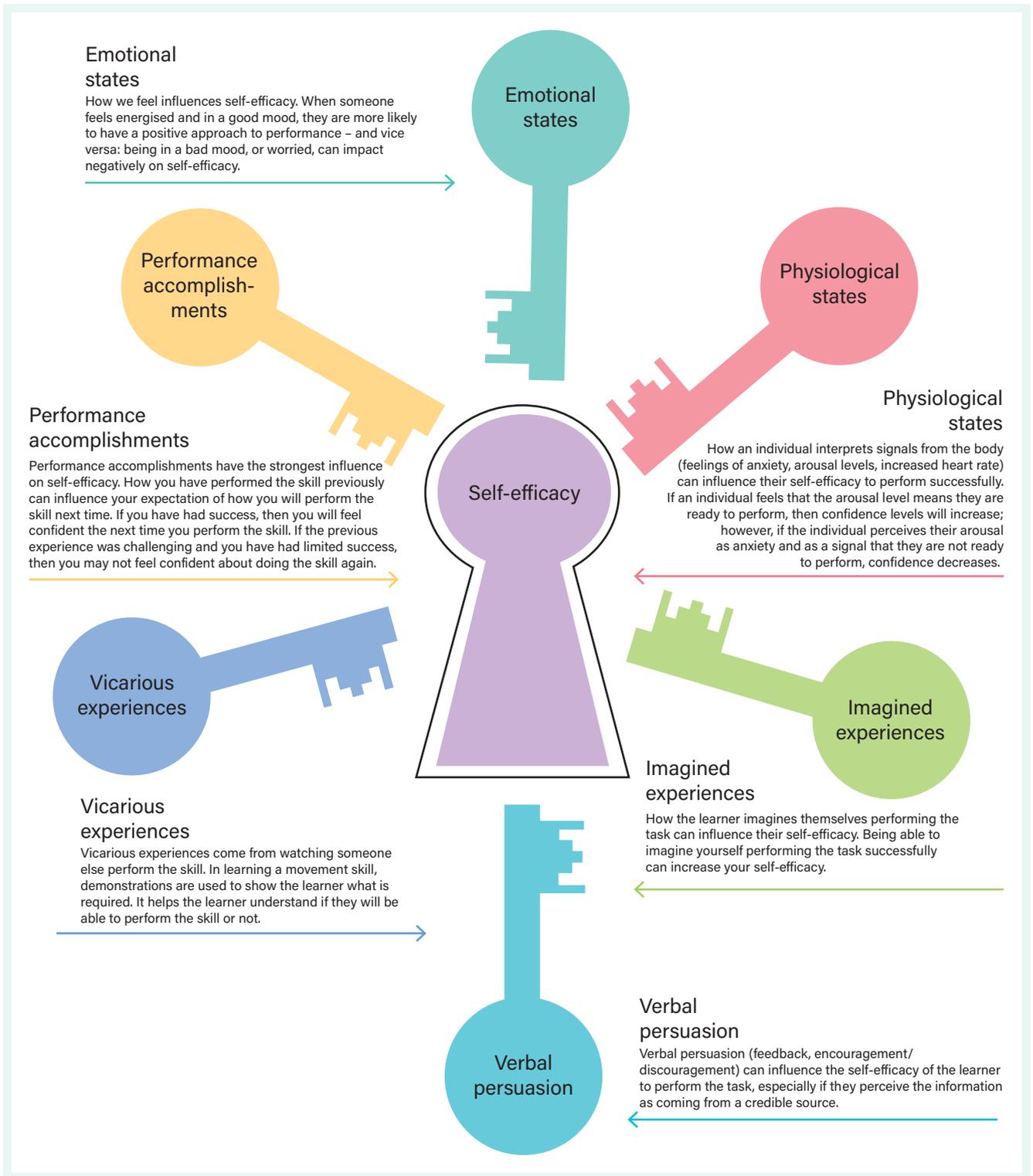
Motivation to participate in an activity for its own sake

**Intrinsic motivation** is motivation that comes from participating in the activity itself and the enjoyment that comes from it. Individuals who are continually trying to beat their personal best, or an athlete who is motivated by playing well, are intrinsically motivated, and are more likely to produce long-term results and maintain their interest and participation in the activity.

### extrinsic motivation

Participating in an activity for an external reason such as a reward, and not for the activity itself

**Extrinsic motivation** comes from an external source – for example, through rewards and recognition. Junior sporting clubs often use extrinsic rewards such as medals, trophies, certificates and vouchers to encourage and reward players. Some athletes are motivated by fame and recognition, but at junior levels this form of extrinsic motivation can come from praise or social approval and/or acceptance.



**FIGURE 2.41** Factors determining self-efficacy



**FIGURE 2.42** Extrinsic motivation can come from praise or social approval and acceptance.

What motivates one individual may not motivate another, so the learning environment needs to take into account the diverse reasons that motivate learners to participate. As shown in Figure 2.43, there are a number of ways in which the coach can tailor the learning environment to increase the motivation and self-efficacy of the learner.

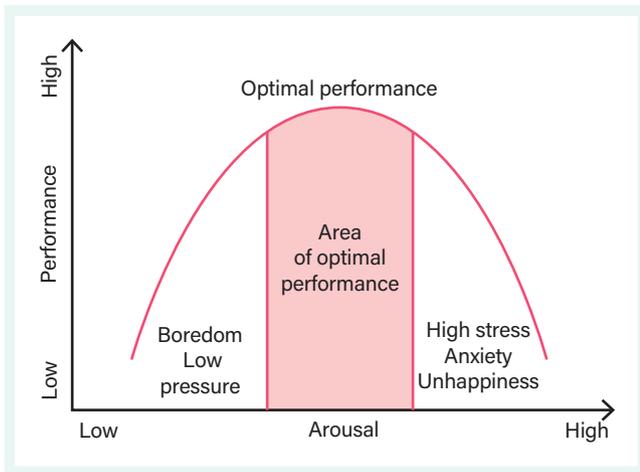
	Provide the learner with choice in how they learn		Set goals and encourage mastery of the task
	Listen to the learner to understand their needs		Encourage and reinforce effort; provide positive feedback
	Allow for social interaction		Use competition wisely
	Explain the purpose of the task; give clear instructions		Optimally challenge learners; allow for success and progression
	Use rewards carefully		Design, plan, structure and organise relevant and meaningful practice sessions

**FIGURE 2.43** Ways in which a coach can tailor the learning environment to increase motivation and self-efficacy

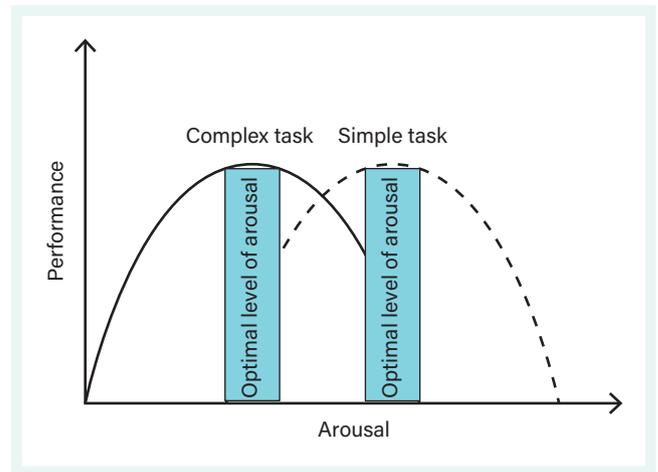
## Optimal arousal

Arousal refers to the physiological and psychological state of the learner. Are they ready to perform? Are the body and mind ready for action? Arousal can be identified by an increase in heart rate and is often accompanied by an increase in respiratory rate and blood pressure as well as heightened neural activity. Being in the optimal state of arousal is referred to as being 'in the zone' or in a 'state of flow'.

The impact of an individual's arousal level on performance can be represented by the 'inverted U' hypothesis. The inverted U hypothesis states that, at low and high levels of arousal, performance is poor. At the optimal level of arousal, performance is at its best.



**FIGURE 2.44** The inverted U hypothesis relates performance to the learner's state of arousal.

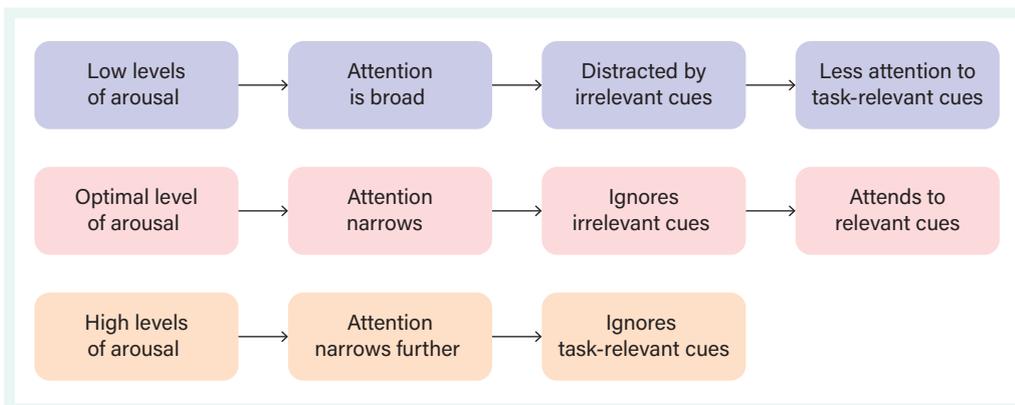


**FIGURE 2.45** The optimal level of arousal will vary with the complexity of the task.

The optimal level of arousal is not the same for all movement skills and tasks. Consider a sprinter: their best performance is going to come at a medium to high level of arousal. An archer, on the other hand, will perform best at a lower level of arousal. The optimal level for the two athletes is quite different, but each is appropriate for the activity they are undertaking.

On the inverted U, the archer is still in their optimal zone, but the curve has shifted further to the left of the axis, and for the sprinter, the curve has shifted further to the right (see Figure 2.45).

The inverted U hypothesis can explain the relationship between the level of attention that a learner or performer gives to cues in the environment and their arousal levels.



**FIGURE 2.46** Arousal level affects a performer's level of attention.

If the level of arousal is too high or too low, performance is affected negatively. The optimal arousal level for any movement skill is specific to the sport. In general, as the complexity of the skill increases, the optimal level of arousal for peak performance decreases and as the complexity of the skill decreases, the optimal level of arousal for peak performance increases.

In summary:

- Optimal arousal is higher for gross motor skills, simpler tasks and individuals in the autonomous stage of learning.
- Optimal arousal is lower for fine motor skills, more complex tasks and learners in the cognitive stage of learning.

# Concentration

**concentration**

The action of focusing all of one's attention

**Concentration**, which is the action of focusing attention, is important for the learning of movement skills and successful performance.

Concentrating on a task means that you are:

- ready to respond (alertness)
- attending only to the instructions or demonstration from the coach and not being distracted by other things (limited capacity)
- selecting the relevant cues from the environment to pay attention to (selective attention).

As a learner progresses through the stages of learning (see Module 2.2), what they need to concentrate on for a successful performance changes. Learners in the cognitive stage of learning need to concentrate on the movement skill, whereas those in the autonomous stage can concentrate on other factors because the skill has become almost automatic. This is why a coach may use part practice with a learner so that they do not need to concentrate on as many components of the skill.



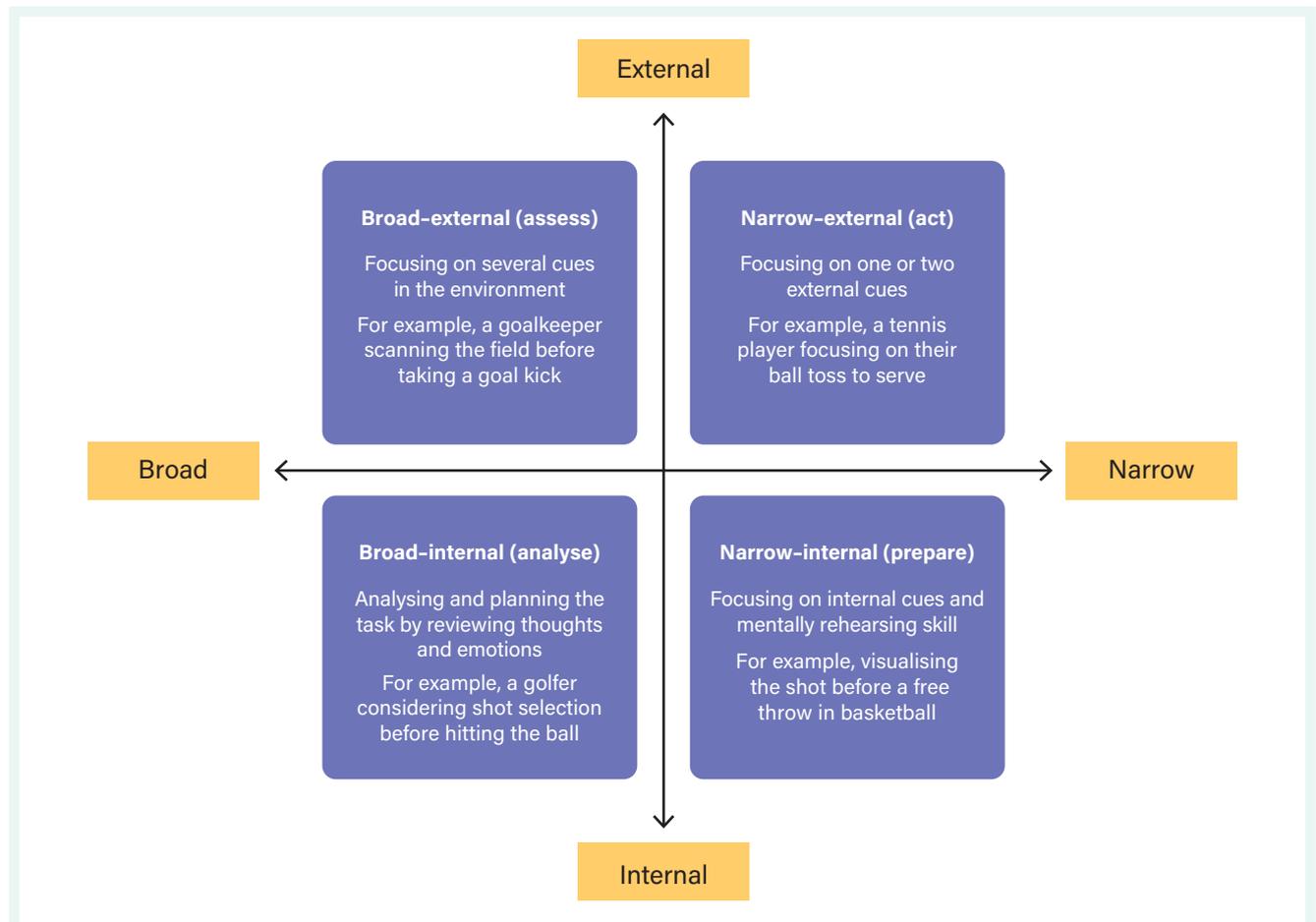
iStock.com/technotr

**FIGURE 2.47** Athletes concentrate by focusing their attention on the task.

Focusing on and selecting relevant cues can be represented through the model (Nideffer, 1976) shown in Figure 2.48, where attention is categorised as having direction (internal or external) and width (broad or narrow).

Factors affecting concentration may be internal or external distractors:

- External distractors can be visual or auditory, and may include other competitors, spectators and media.
- Internal distractors may include negative self-talk, fatigue and emotional arousal.



**FIGURE 2.48** The four types of attentional focus

### 🚩 SIGNPOST

To learn more about Nideffer's model of attentional styles, watch the video *Nideffer's Model of Attentional Styles* on the Show Me website.



**Weblink**  
Nideffer's Model of  
Attentional Styles

## Psychological strategies

Athletes use many different strategies to develop their psychological skills. Like all skills, psychological skills and strategies need to be learnt and practised. The following section will look at strategies that relate specifically to confidence, motivation, optimal arousal and concentration.

## Mental practice and imagery

Mental practice and imagery can be used to rehearse a skill without actually performing it. Just thinking about the skill and recreating the movement patterns in your mind can aid performance. Mental practice and imagery can benefit both the learning of a skill and the preparation for successful performance at the elite level.



iStock.com/Wavebreakmedia

**FIGURE 2.49** Visualising the successful shot can help an athlete perform the movement skill.

### imagery

Using all of the senses to create/recreate a movement skill in the mind

### mental practice

Rehearsal of a skill, without movement, to learn the skill

**Imagery** involves the learner using their senses to imagine themselves performing the skill. They see and feel themselves moving in their mind.

**Mental practice** is the rehearsal of the skill without movement, and is used to learn a skill. Mental practice can include verbalising the movement sequence, thinking through movement, problem-solving or imagining performing the skill.

Imagery has been shown to be an effective tool for developing sport-specific motor skills and enhance performance, and also to influence levels of anxiety, motivation and confidence. Imagery can also:

- improve your technique by imaging good technique between training sessions
- allow you to practise when you are too tired to physically train or when you are unable to train (e.g. if you have an injury)
- increase your competition confidence by running through your performance in your head before competing
- increase your activation levels if you are feeling lethargic
- calm you down if you are feeling nervous, anxious or stressed
- help you get to sleep.

Effective mental practice and imagery:

- is used regularly and systematically
- uses vivid and controllable images using all the senses to create a realistic image of the skill or performance
- is practised in real time and imagines successful performance using correct technique
- uses internal (first-person perspective) and external (third-person perspective) imagery to provide different information on the skill
- is used for learning and performing movement skills.

## COLLABORATIVE TASK

### Activity



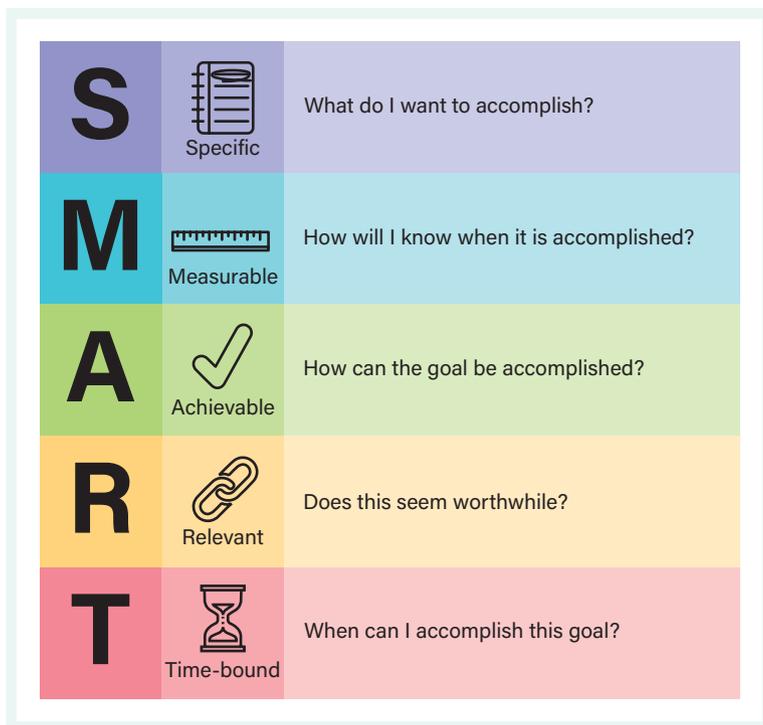
### Mental practice and imagery

Follow the steps below to complete a self-guided mental practice session using imagery. Throughout the session, ask yourself specific questions:

- What do you see?
- What do you hear?
- What do you taste?
- What do you feel?
- What do you smell?

#### METHOD

- 1 Sit in a comfortable, quiet place where you won't be interrupted.
- 2 Relax your body and take several long, slow breaths.
- 3 Close your eyes and create a vivid and convincing image of a skill or performance. This image can be one you've previously experienced or simply one you desire.
- 4 If you become distracted or find you are thinking about something else, acknowledge it and let it go.
- 5 Focus on your breathing if you lose the image.
- 6 Maintain a positive attitude.
- 7 Imagine the sights, sounds, tastes, feelings and even smells of the experience.
- 8 Take note of as much detail of the scene as possible. What are you wearing, who is there, what are you hearing, and how do you feel?
- 9 If your imagery session is not going the way you want it to, simply open your eyes and start over with your breathing.
- 10 End the session with a positive image.



**FIGURE 2.50** SMART goal-setting

## Goal-setting

Goal-setting is a powerful psychological strategy that is effective for enhancing performance by providing a focus for training and performing, and directing effort. Goals can assist in maintaining and increasing an athlete's motivation.

For goal-setting to be effective, goals need to be SMART: Specific, Measurable, Achievable, Relevant and Time-bound (see Figure 2.50).

Goals may relate to an outcome, to performance or to a process:

- Outcome goals are goals related to a result.
- Performance goals are goals related to individual performance.
- Process goals are goals related to the actions an individual must engage in to perform well. Goals can be short-term, medium-term or long-term:
  - Short-term goals are smaller, manageable chunks of the long-term goal.
  - Medium-term goals help monitor progress and provide benchmarks.
  - Long-term goals give purpose to training and performance.

**TABLE 2.06** Outcome, performance and process goals

	Focus	Features	Example
<b>Outcome goals</b>	End results, times, finishing places, rankings or medals	Can be difficult to achieve because they are linked to factors the athlete cannot control, such as performance of others	Finishing in the top five in a triathlon
<b>Performance goals</b>	Comparison of past and present performance, independent of other competitors	Lead to less anxiety and greater self-confidence because the athlete has control over their behaviour; will lead to improvement if realistic	Improving the first-serve percentage in tennis
<b>Process goals</b>	Actions (such as physical movement and game strategies) that athletes must perform during a competition to reach peak performance	Effective at improving performance levels because they positively influence other factors such as self-efficacy and confidence	Executing a defensive set play

## WORKED EXAMPLE

### Question

Eleassa is a fit 40-year-old who currently trains three times per week, plus doing a Parkrun (5 kilometres) on the weekend. Eleassa wants to complete the 42-kilometre Melbourne Marathon in 12 months' time. Her short-term, medium-term and long-term goals are set out below:

- Short-term goals (3 months): to run 10 kilometres
- Medium-term goals (6 months): to be running 30–40 kilometres per week in training (including one 90-minute run per week)
- Long-term goals (12 months): to complete the Melbourne Marathon in under 5 hours.

Use the SMART framework to **evaluate** Eleassa's goal-setting. Are the goals specific, measurable, achievable, realistic and time-bound?



Anadolu/Getty Images

### Steps to answering the question

In responding to this question, firstly, look at the command term: evaluate. To evaluate means to 'ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information.' So it is important that you make a decision, and give justification for it, on whether Eleassa's goals are SMART.

**TIP:** Your response will need to include a comment about each aspect of the framework and provide a specific example from the stimulus to support the comments.

### Sample response

*Eleassa's medium-term goal is a specific performance goal and her long-term goal is a specific outcome goal. There is a clear intention for what she wants to achieve in the medium and long term. However, her short-term goal ('to run 10 km') is not clear. It is not clear if her goal is to run 10 kilometres once, or if that is the total distance she wishes to cover in the 3-month period.*

*To make this goal more specific, Eleassa should be clearer of her intention – for example: 'In 3 months' time I want to be able to complete a 10-kilometre run in under 55 minutes.'*

## Arousal regulation techniques

Optimal arousal is important for successful performance (see page 78). There are many strategies that can be used to increase or reduce arousal levels. Athletes select appropriate strategies based on the desired outcome, the time, the location and the suitability of the strategy for the situation.

### Progressive muscle relaxation (PMR)

Progressive muscle relaxation is a process in which the individual progressively contracts and relaxes their muscles in a specific order. Usually it is done from head to toe, but it can be done in the reverse order. Progressive muscle relaxation relieves anxiety (and the associated physiological responses – increased blood pressure and heart rate) and can decrease arousal levels. PMR can also improve sleep.

PMR should be performed in a quiet environment, in a comfortable sitting or lying position. The strategy involves breathing in as the individual muscle group is contracted and tightened for 5–10 seconds, and then breathing out as you slowly release it. This helps to release tension in the muscles.



fizes/Shutterstock.com

**FIGURE 2.51** Performing PMR helps to release tension in the muscles.



## COLLABORATIVE TASK

### Activity

#### Progressive muscle relaxation

##### AIM

To participate in a PMR session

##### EQUIPMENT

- quiet space
- yoga or gym mat
- script (see below)

##### METHOD

Progressive muscle relaxation can be performed by following a guided script that is read out – either a recording or in person. You may perform the following individually or your teacher may guide you through this process.

Tense the muscles on both sides of your body at the same time for 5 seconds, then relax them fully, in the following sequence:

- Squeeze the muscles in your forehead.
- Clench your teeth.
- Push your tongue against the roof of your mouth.
- Press your lips together.
- Shrug your shoulders.





- Tense the muscles in your upper arms.
- Clench your fists and tighten the muscles in your forearms.
- Tighten your abdominal muscles.
- Arch your back.
- Squeeze your buttocks together.
- Tighten the muscles on the front and back of your thighs.
- Pull your toes up toward your head.
- Point your toes down.
- Curl your toes.

Repeat tightening and relaxing the muscles as needed in any areas of the body where you still feel tension after completing the sequence.

### CONCLUSION

How did you feel after the session?

## Breath control

There are a number of breathing techniques that can reduce arousal levels. Deep breathing involves controlling your breathing by breathing in slowly through your nose, allowing your chest and lower stomach to rise as you fill your lungs, and then breathing out slowly through your mouth.

Deep breathing slows the heart rate and lowers blood pressure, which reduces arousal levels and helps athletes to focus and concentrate as they disengage from distractions. Deep breathing is recommended before, during and after exercise (Migliaccio et al., 2023) as it can help increase the oxygen level in the body, regulate heart rate, promote relaxation, improve concentration and improve posture.

Elevated breathing, where an athlete breathes rapidly, can increase arousal. Recent research (Buchanan & Janelle, 2021) found that fast breathing reduced reaction time and movement time, and increased ratings of arousal. By taking short, sharp breaths, the athlete activates the central nervous system and increases its state of awareness. Elevated breathing before exercise can be beneficial if the athlete has to create greater physiological and psychological activation.

The connection between breathing and sports performance is still unclear (Migliaccio et al., 2023), but we do know that athletes can increase focus and concentration using slow breathing strategies.

## Music

Music can be used to regulate arousal and mood. Teachers, coaches, exercise instructors and athletes all use music in their work. Music can be used to relax and calm the athlete, as well as to psych them up – that is, to increase their arousal levels.

Music has motivational qualities that include arousal control, as previously discussed, but also improved mood and reduced rating of perceived exertion (RPE). The selection of music in exercise



NurPhoto SRL/Alamy Stock Photo

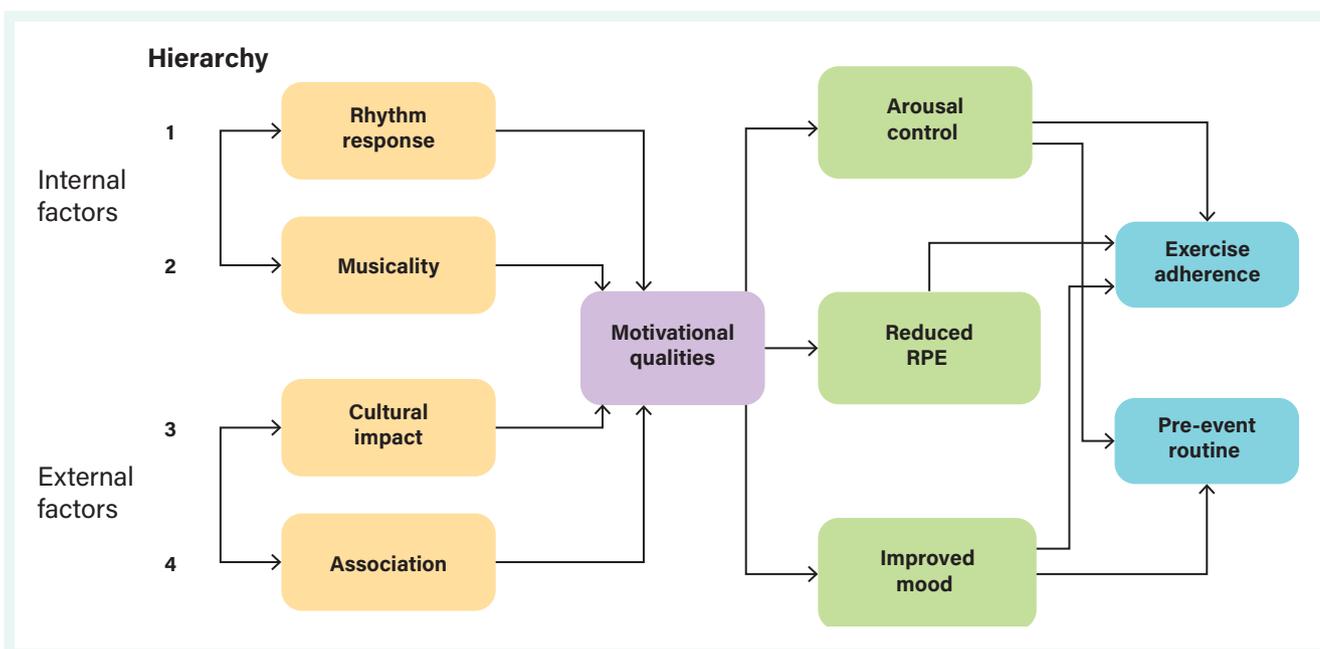
**FIGURE 2.52** Breathing techniques play an important part in an athlete's preparation before a race.

AAP Images/REUTERS/Issei Kato



**FIGURE 2.53** Naomi Osaka uses headphones to listen to music and block out distractions.

classes is often upbeat. A coach may also use a piece of music that exploits cultural and personal associations, as they are more likely to elicit the desired response. Music has been shown to help individuals adhere to exercise regimes. (Consider why group fitness classes are set to music. Why do people run with headphones?) In addition to the benefits of listening to music while learning or performing movement skills, research suggests that it may also contribute to greater work output, improved skill acquisition, increased flow state and overall enhanced performance (Karageorghis & Priest, 2011). Music can also be equally effective in relaxing the athlete if an appropriate piece is selected.



**FIGURE 2.54** Conceptual framework for the prediction of response to motivational asynchronous music in exercise and sport

Used with permission of Taylor & Francis Group from Karageorghis, Terry & Lane (1999), 'Development and initial validation of an instrument to assess the motivational qualities of music in exercise and sport: The Brunel Music Rating Inventory', in *Journal of Sports Sciences*, 17(9), pp. 713–724; permission conveyed through Copyright Clearance Center, Inc.

## REAL WORLD APPLICATIONS

### Fantheims

The power of the music in the movie *Rocky* is an example of a cultural association with a piece of music. More recently, the Port Adelaide Football Club has adopted 'Never Tear Us Apart' as a 'fanthem' to increase the arousal levels and the mood of the crowd and players. This replicates Liverpool Football Club in the UK and its use of the song 'You'll Never Walk Alone', which is intended to be a message of hope and has given Liverpool fans hope through some very tough times.

## LOOKING FORWARD

### Measuring intensity

#### Chapter 12

Exercise intensity is a measure of how hard an exercise is. Intensity can be measured through heart-rate monitoring, percentage of  $VO_2$  max, digital tracking tools, subjective terms such as low-, medium- and high-intensity, and the 'rating of perceived exertion' scale (RPE). RPE expresses the performer's perception of how hard they think they are working. It is a numeric rating that is used to describe the level of intensity of the exercise period. You will learn more about intensity and how it can be measured in Chapter 12.

## Other psychological strategies

### Self-talk

Talking (to yourself or others) and the use of emotive words such as 'tough', 'aggressive', 'hard-hitting', 'dependable', 'forceful', 'strong' and 'commitment' has been found to increase arousal levels.

Australian tennis player Lleyton Hewitt famously used 'C'mon!' as his positive self-talk.



PA Images/Alamy Stock Photo

### Cue words

Cue words can help athletes to focus, can be motivational, and can aid resilience. The cue word needs to be in places where it will be regularly seen, such as in a locker, on a piece of equipment, or even on a body part (like the hands).

In the fictional TV series about an English soccer team that found success, coach Ted Lasso used the term 'Believe' as the team's cue word.



27th Annual SAG Awards/Getty Images Entertainment/Getty Images

### Mindfulness

Mindfulness can be regarded as a type of psychological training to optimise performance as it can promote concentration and improve focus, decrease anxiety, help with emotion regulation and increase state of flow.



Hyoung Chang/Denver Post/Getty Images

### Meditation

Meditation trains the individual to relax by controlling the nervous system through reducing 'noise' or stimulation to the brain. This can result in lower blood pressure, heart rate and breathing rate, and relaxed muscles.

Meditation skills take some time and plenty of practice to acquire and they are most easily learned by younger individuals.



GLYN KIRK/AFP/Getty Images

**FIGURE 2.55** Athletes use self-talk, cue words, mindfulness and meditation.

**CASE STUDY****PSYCHOLOGICAL STRATEGIES**

DPP/Icon SMI 547/DPP/Icon SMI/Newscom

**FIGURE 2.56** Leanne Guinea in competition

Canoeist Leanne Guinea, former Australian National Open Age C1 Champion and World Champion, used a range of psychological strategies to enhance her performance through training and competition. In the text below, Leanne recounts her use of imagery, goal-setting and arousal regulation techniques.

### Imagery

In slalom canoeing, we use mental imagery extensively as a performance-enhancing technique, both in training and competition, as we are unable to practise the actual course before racing. Learning the course is probably one of the main purposes of imagery in slalom, which I do multiple times, from hours before, right up to the final few seconds before the race starts. This enables me to start my race run feeling confident and as though I have already paddled this particular sequence of gates numerous times before.

### Goal-setting

Each year I set a range of short-term goals including technical, physical, mental and performance goals, each with a specific strategy and a date by which I plan to achieve them. An example of one of my short-term physical goals for next season was to reach level 12.0 on the beep test and to achieve 17 chin-ups. One of my long-term goals was to decrease the ratio of gates that I hit during a race run: down to one per 100 gates by next World Championships. I find these kind of goals effective as they are measurable in training and competition, and I can use benchmarks to assess my improvements for motivation.





## Arousal regulation

In the past I have used both arousal reduction and arousal promotion techniques to help me be in the correct mental state for optimal performance. Techniques I use to get in the zone depend on how over- or under-aroused I am. Generally I am pretty quiet and get focused mentally prior to a race. But if I am over-aroused, techniques that I employ may include performing tasks that are familiar, such as going for a long warm-up paddle and doing specific drills and skills that I have done multiple times before in training. This allows me to have higher concentration on the skills that I will be using and the tasks that need to be completed to achieve success. If it is a big competition, I will also try to find a quiet place away from the crowd and other competitors and listen to music or read a book.

Less frequently, I find that I am under-aroused prior to racing and need to find some aggressiveness. On these occasions I try to listen to up-tempo music, watch videos of past races in which I have had a high level of aggressiveness, or (just prior to racing) speak with my coach, who tries to get me fired up with some words of inspiration.

### QUESTIONS

- 1 **Identify** three techniques Leanne Guinea uses to regulate her arousal levels.
- 2 **List** one short-term and one long-term goal Leanne set for herself.
- 3 **Explain** how goal-setting can help motivate athletes.
- 4 Why would sports such as slalom canoeing rely heavily on imagery as a strategy to enhance performance?
- 5 With reference to the inverted U hypothesis and the examples provided in the case study, **discuss** the importance of arousal regulation, how optimal arousal can be achieved and the impact it can have on performance.

### Command term

#### list

Provide a series of related words, names, numbers or items that are arranged consecutively

## WORKED EXAMPLE

©VCAA Exam 2018, Section B, Q8 a, b and c

Pita Taufatofua is an athlete from Tonga who has competed in both the summer and winter Olympic Games. He competed in taekwondo in the 2016 Summer Olympic Games in Rio and in cross-country skiing in the 2018 Winter Olympic Games in Pyeongchang.

Taufatofua is only the second athlete from a Pacific nation to compete in a Winter Olympic Games. As there is no snow in Tonga or near his base in Brisbane, Australia, Taufatofua initially trained by running on sand dunes with wooden planks strapped to his feet to simulate being on snow. He then trained on roller skis. These two training techniques assisted with developing balance, fitness and the glide technique required for cross-country skiing. Taufatofua learnt to ski in the snow in three months. He competed in the men's 15 km free cross-country event with a time of 56:41.10 and finished 114th out of the 118 competitors. His time was just under 23 minutes slower than that of the gold medallist for the event.

- a When Taufatofua first began to learn to ski, what stage of learning was he in?

**Sample response:** *Cognitive stage*

**Rationale:** Like all learners, Taufatofua progressed through the three stages of learning, but when he first started to learn he was in the cognitive stage.

- b Before the 2018 Winter Olympic Games in Pyeongchang, Taufatofua stated that he wanted to 'finish before they turn the lights off' and 'not ski into a tree.' Identify the psychological strategy that Taufatofua may have used to prepare for the event and outline how this psychological strategy may have improved his performance.





**Sample response:** *Goal setting – improving intrinsic motivation, improving self-efficacy and hence improving performance.*

**Rationale:** There are many strategies that Taufatofua could use, but the question asks for a strategy specifically used in preparing for the event, which limits the number of appropriate choices. Naming the strategy was the 'identify' aspect of the question and how the strategy could improve performance addressed the 'outline' component of the question.

Select a different strategy and outline how this strategy may have improved Taufatofua's performance.

- c** Select one sociocultural factor and explain how it may have affected the development of Taufatofua's skiing skills.

**Tip:** With an explanation, any of the sociocultural factors that we looked at in this chapter are appropriate answers to this question. 1 mark is awarded for identifying the factor and 1 mark for the explanation.

**Sample response:** *Skiing is not part of the cultural traditions (1 mark) or background of the country/ community where Taufatofua grew up, therefore he had less exposure to the activity and less access to the facilities or equipment, which would have limited his learning of the skill (1 mark).*

Select a different factor and formulate a response to this question.



#### Assessment

#### 2.6 Check-in questions

#### Command term

#### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

## 2.6 CHECK-IN QUESTIONS

- The most reliable source of information that a learner can base their expectations on is:
  - emotional state
  - physiological state
  - vicarious experiences
  - performance accomplishments
- Imagery that is related to a specific goal is called:
  - cognitive specific imagery
  - motivational specific imagery
  - motivational general – arousal imagery
  - motivational general – mastery imagery
- After 6 weeks of following her program, Jalena started to lose motivation and developed sore shins. **Outline** one psychological strategy that Jalena could use to stay committed to her program.
- Novak Djokovic found motivation in his desire to become the record holder for the most Grand Slam singles tennis titles. Is this an example of intrinsic or extrinsic motivation? **Justify** your response.
- Rachael runs three or four times a week. After each run, she checks the data on her fitness tracker to see if she has achieved her goals in terms of the distance travelled, kilometre split times and the average speed for her run. **Identify** the type of motivation the data provides and explain how the data motivates her.
- Discuss** how music can be used to achieve optimal arousal for an athlete. In your response, explain the inverted U hypothesis in relation to arousal and performance.

# CHAPTER SUMMARY

- In this chapter we looked at:
  - sociocultural factors that affect skill development
  - characteristics of the three stages of learning
  - theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches
  - in session and scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)
  - frequency and type of feedback including intrinsic and augmented (knowledge of results and knowledge of performance)
  - psychological skills (confidence, motivation, optimal arousal and concentration) and accompanying strategies from a coaching perspective, where the focus is to enhance participation and performance.



**Resource**  
Self-assessment checklist

**Video**  
Masterclass: Chapter 2

## 2.1 Sociocultural factors that affect skill development

- Sociocultural factors that affect physical activity, sport and exercise include family, peers, community, gender, socioeconomic status, and cultural beliefs and traditions.
- Sociocultural factors can impact skill development across all stages of the lifespan.

## 2.2 Stages of learning

- Learners progress through three stages of learning: the cognitive, associative and autonomous stages.

## 2.3 Theories of skill acquisition

- Linear approaches to learning movement skills are characterised by expected movement form, high volume of practice trials, lots of drills and repetition, and the absence of a simulated game environment.
- Linear approaches are applied through direct instruction, where the coach controls and directs the learning process and passes the knowledge on to the learner.
- Non-linear approaches to learning movement skills emphasise exploratory behaviours to find movement solutions and develop movement skills, and are learner-centred.
- Constraint-based approaches are non-linear and learner-centred, where the coach facilitates, and learners question, explore and generate knowledge.
- There are three types of constraints that influence movement capabilities: individual, environmental and task constraints.

## 2.4 Practice strategies

- Practice and feedback are the most important factors in learning a motor skill.
- Practice strategies need to meet the needs of the learner and the skill.
- Practice can be whole or part, blocked or random, and massed or distributed.

## 2.5 Feedback

- Feedback may come from internal sources (intrinsic feedback) or from external sources (augmented feedback).
- Intrinsic feedback comes to the learner from the sensory system through touch, proprioception and vision.
- Augmented (external or extrinsic) feedback comes from an external source such as a coach or teacher, supplements intrinsic feedback, and can be provided during or after the performance.
- Knowledge of results is information about the outcome or results of a performance, and knowledge of performance is information that is provided to the learner about the process of the performance that led to the outcome (either successful or not).
- Good coaches know the right type and the optimal amount and frequency of feedback to give to the learner.
- Frequency of feedback should be reduced as the learner progresses through the stages of learning (cognitive, associative, autonomous).

## 2.6 Psychological skills

- Confidence is the belief or degree of certainty that athletes possess about their ability to improve and achieve success.
- Motivation may come from intrinsic sources (from participating in the activity itself) or extrinsic or external sources (through rewards and recognition).
- The impact of arousal levels on performance is described by the inverted U hypothesis, which states that performance is poor at low and high levels of arousal. Performance is at its best at the optimal level of arousal.
- Concentration is the action of focusing attention, and is important for the learning of movement skills and successful performance.
- There are many psychological skills and strategies that can be learnt and practised to enhance participation and performance in physical activity, sport and exercise.
- Goal-setting, mental imagery, breath control, progressive muscle relaxation, music, self-talk, cue words, mindfulness and meditation are psychological strategies that athletes use.

# CHAPTER REVIEW



**Assessment**  
Chapter 2 Review

- 1 Before the final of the under-16 netball final, Stephanie, who is a goal shooter, was starting to feel nervous. Her palms were sweaty, her heart was racing, and she was getting distracted by the noise of the crowd.
  - a Select the most appropriate psychological strategy that may help Stephanie perform at her best when she steps onto the court.
    - A goal-setting
    - B mental imagery
    - C controlled breathing
    - D progressive muscle relaxation
  - b The noise in the stadium that was distracting Stephanie can be classified as:
    - A a task constraint.
    - B an indirect constraint.
    - C an individual constraint.
    - D an environmental constraint.
  - c Before the game, Stephanie was practising her goal shooting. She has 10 shots from under the post with a defender. After 10 shots, she repeats the exercise from further out from goal. This is an example of:
    - A massed practice.
    - B blocked practice.
    - C random practice.
    - D distributed practice.
  - d Provide one example of augmented feedback and one example of intrinsic feedback that Stephanie could use to improve her goal shooting.
- 2 Yusef sets up a task for the under-14 hockey team where, in groups of four, the players pass the ball, in a 6 m × 6 m space, with one defender. The aim of the drill is for three players to maintain possession and one player to try to intercept the ball (3v1).
  - a **Name** the approach that Yusef is using to develop the movement skills of the players.
  - b Using specific examples from the scenario, **identify** the constraints that have been manipulated in this situation and explain how this can improve skill development for the players.
  - c **Suggest** a change to the activity that results in the defensive play being less constrained.
- 3 Poppy is 6 years old and is learning to swim. Her lessons take place once a week for 30 minutes, and she is in a class with four other children, one of whom is her best friend. The teacher provides demonstrations and instructions to the children before they practise. In between their turns, the children sit on the side of the pool.
  - a Based on the considerations covered in this chapter, **discuss** the likely impact of this situation on Poppy's swimming skill development.
  - b After a year of swimming lessons, Poppy's mum is finding it difficult to motivate her to get in the water at her lesson. **Discuss** one intrinsic and one extrinsic motivating factor that might encourage Poppy to keep attending her swimming lessons.
  - c Poppy eventually finishes all the levels of the swim program and is now a squad swimmer. **Identify** the stage of learning Poppy is now in and discuss how the type and frequency of feedback changes as learners move along the learning continuum.

## CHAPTER

# 3

## BIOMECHANICAL ANALYSIS OF HUMAN MOVEMENT

UNIT 3 – AREA OF STUDY 1



zsolt\_luweges/Shutterstock.com

**FIGURE 3.01** Understanding biomechanical principles can help improve movement skills.

### Quizzes

Chapter 3 Pulse check

- 3.1** Check-in questions
- 3.2** Check-in questions
- 3.3** Check-in questions
- 3.4** Check-in questions
- 3.5** Check-in questions

Chapter 3 Review

### Videos

Masterclass: Chapter 3

- 3.2** In focus: Relationship between linear and angular velocity
- 3.2** In focus: Conservation of momentum
- 3.3** In focus: Newton's laws of motion

### Resources

Chapter 3 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



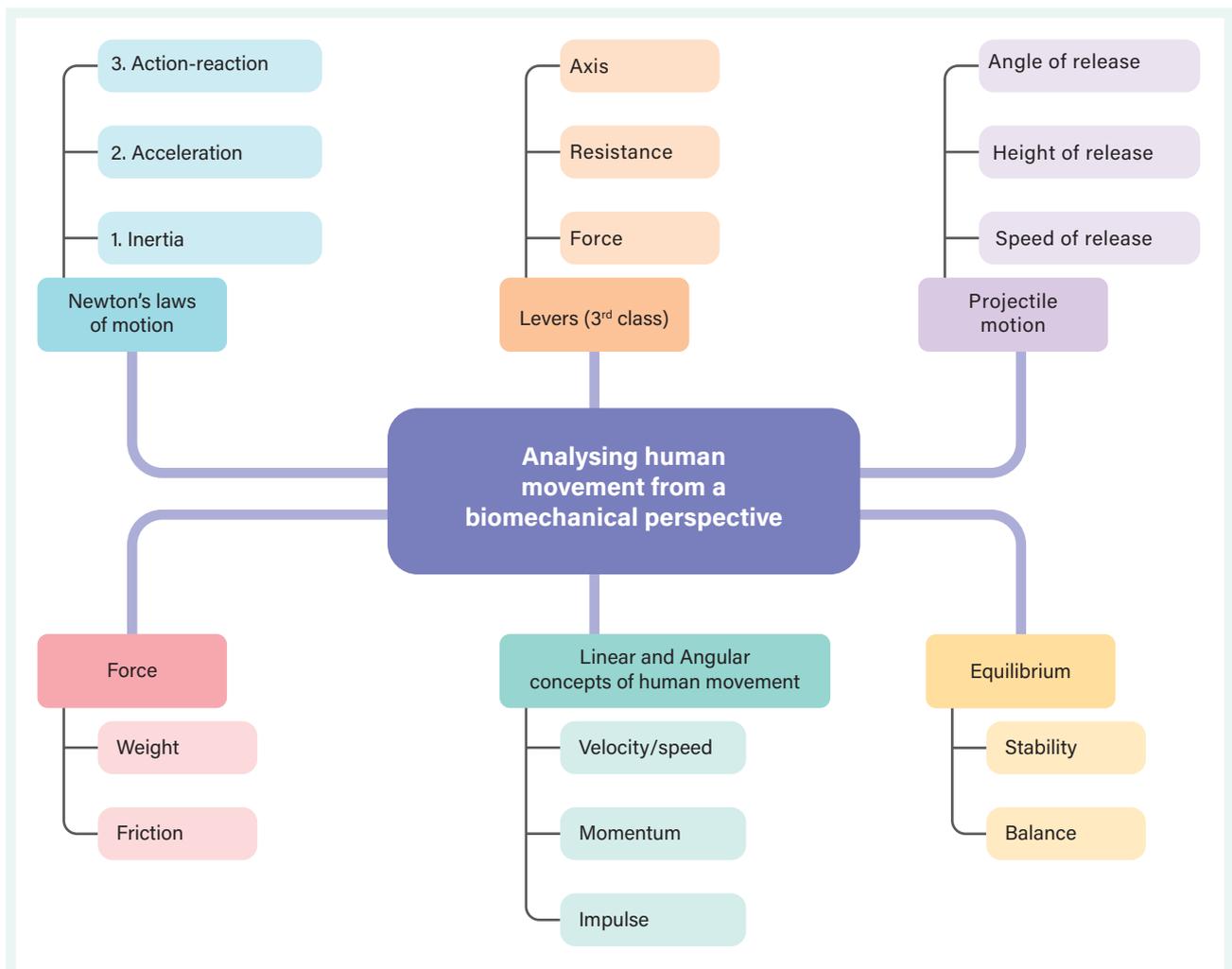
- » biomechanical principles for analysis of human movement:
  - linear and angular concepts of human movement including force/torque, momentum, impulse, speed/velocity
  - Newton's three laws of linear motion: inertia, acceleration and action–reaction
  - projectile motion (height, angle and speed of release)
  - equilibrium and human movement: anatomical third-class levers (axis, force, resistance and mechanical advantage) and stability (centre of gravity, base of support and line of gravity)

## KEY KNOWLEDGE

- » analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 3

Biomechanics is the study of human movement from a mechanical perspective. You may have come across many of the concepts we will look at in this chapter in your study of Science. In Physical Education we want to apply these same concepts to analyse human movement.

In Physical Education we are interested in the human body and how it moves. Biomechanics in this context is about analysing and understanding how forces affect movement and how we can apply biomechanical principles to improve movement skills in physical activity, sport and exercise. Throughout this chapter you will be introduced to biomechanical principles relevant to human movement, learn how to collect and analyse data, and apply these principles to improve and refine movement skills, and then to demonstrate how this can lead to improved performance outcomes.

**Assessment**

Pulse check

**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 **Define** the terms speed and velocity using an example from physical activity, sport or exercise.
- 2 What is Newton's second law of motion? Where do we see it in action in AFL football?
- 3 **Describe** the impact on the flight path of the ball when the height of release is changed.
- 4 What three factors influence the stability of rider on a skateboard?
- 5 Draw and label the three components of a lever.

## 3.1 BIOMECHANICAL ANALYSIS OF HUMAN MOVEMENT

In this module you will learn about:

- what a biomechanist does and the tools that they use and learn to:
- identify the most suitable analysis for a given sport or activity.

Biomechanics is the study of forces and their effect on living things. The study of biomechanics can:

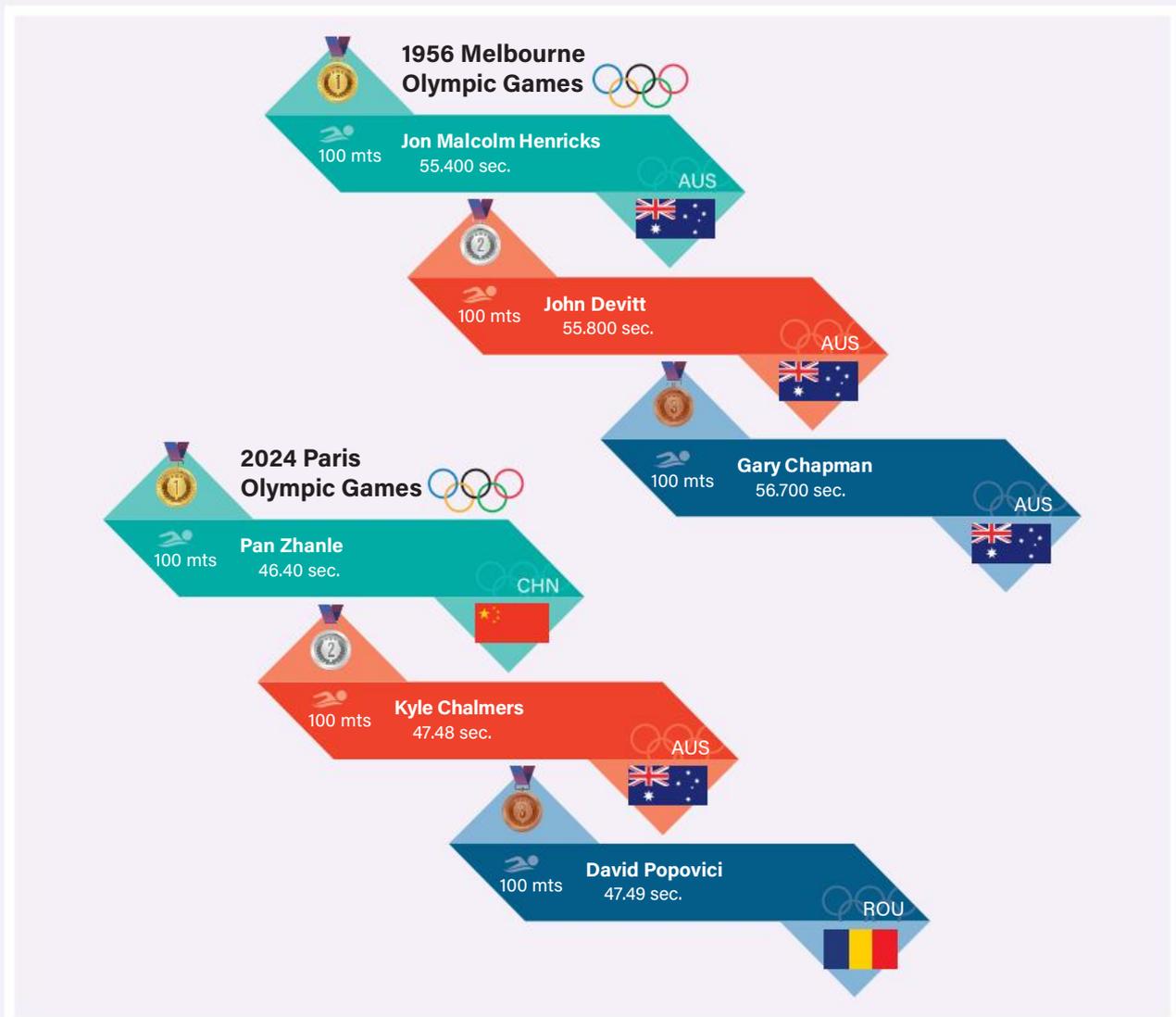
- help to develop and refine movement patterns and techniques
- improve the structure and design of equipment used in sport
- identify the causes of overuse injuries and impaired mobility in the elderly
- improve movement in people with disabilities such as cerebral palsy and lower-limb amputations.

## REAL WORLD APPLICATIONS

### Improved technique leads to improved performance

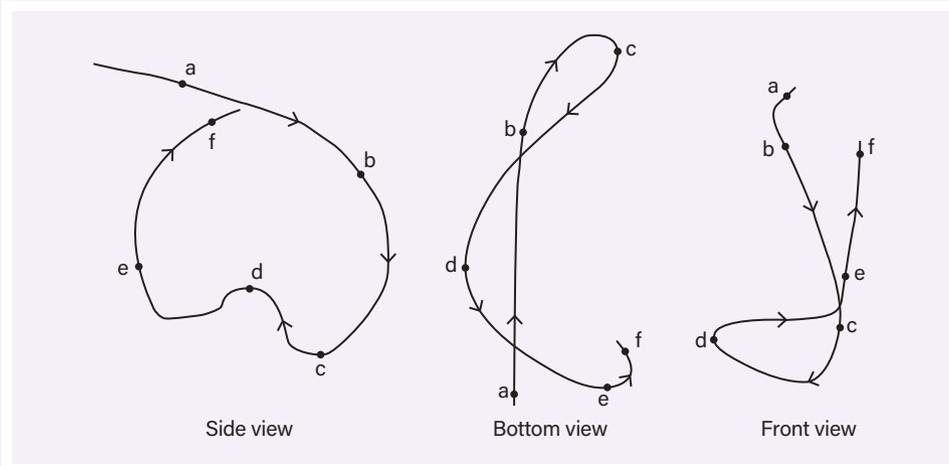
Until the late 1960s, freestyle swimmers would pull their hand backwards in a straight line through the water, like an oar, to produce a propulsive force. Based on a simplistic understanding of Newton's Third Law (action–reaction), the (drag) forces generated by moving the hand backwards through the water would propel the swimmer forwards. Biomechanical research done by Counsilman (1971) found that if the hand follows a curving path (see Figure 3.03) and finds still water to push against, a greater propulsive force is produced, allowing the swimmer to travel faster in the forward direction. Elite swimmers continuously adapt the angle of their hand through the pull phase by bending their elbow (see Figure 3.04), finding the optimal propulsive force through the ability to 'feel' for water. This sweeping action is now the technique taught by coaches and swim teachers across the world.

The 1956 Olympic Games in Melbourne is still the Australian swim team's most successful games. Australia won gold, silver and bronze medals in the men's 100 metres freestyle. In 2024, Kyle Chalmers took the silver medal with a time of 47.48 seconds, 7.92 seconds faster than the gold-medal time in 1956. While there are many factors that have led to the improved times, the change in technique described above has contributed significantly.



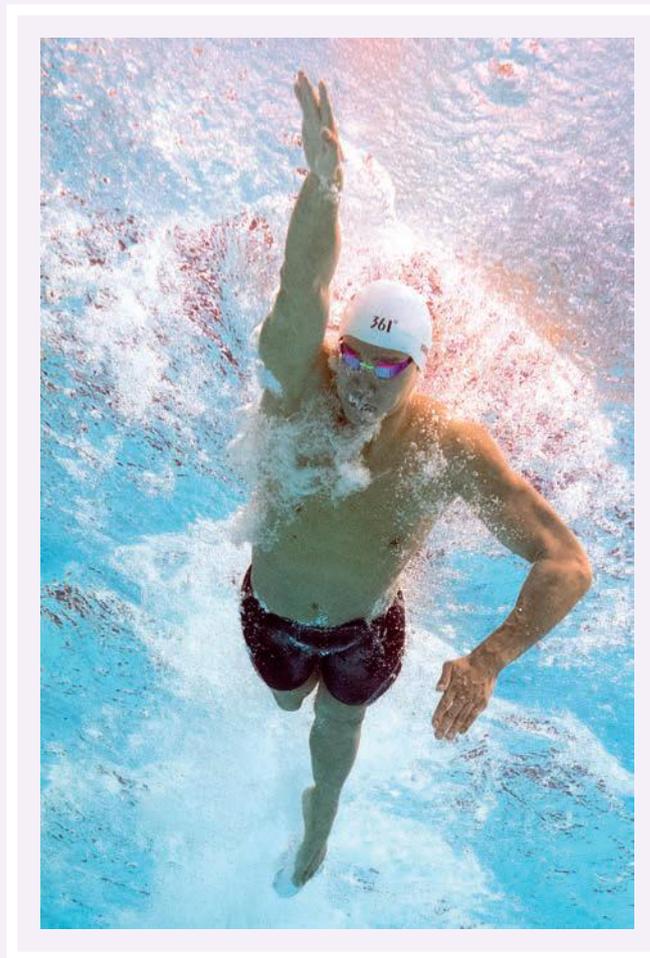
**FIGURE 3.02** Biomechanical analysis has helped to improve race times in the 100 metres freestyle event.

Source of data: <https://olympics.com/en>



**FIGURE 3.03** Front crawl (freestyle) stroke pattern of the right hand in three dimensions: a-b: entry; b-c: entry scull; c-d: inward pull or insweep; d-e: outward pull; e-f: exit or upsweep

Source: Toussaint, H.M., Hollander, A.P., Van den Berg, C. & Vorontsov, A. (2000), 'Biomechanics of swimming', in *Exercise and Sport Science*



FRANCOIS XAVIER MARIT/Getty Images

**FIGURE 3.04** Biomechanical analysis of swimming has resulted in changes to technique and faster times.

To analyse movement skills, biomechanists collect data – visual, numerical, digital and graphical. This can be done by simply observing the athlete in action in the field or in a lab. There are a range of tools that can be used to accurately measure things like joint angles, speed/velocity, acceleration, distance, height and force. These tools include the following:

- **3D analysis** is applicable to a variety of sports, especially those with complex body movements and a need for precise and detailed information, such as gymnastics. It is typically performed in laboratory settings using high-speed 3D motion analysis systems.
- **Force plate analysis** is commonly employed for activities such as walking, running and landing, often in combination with 3D motion analysis systems. It is particularly useful in assessing impact, braking and propulsive forces, calculating joint kinetics and evaluating weight transfer during dynamic activities.
- **Electromyography (EMG)** is employed to measure muscle activity and is frequently combined with 3D motion analysis and force plate testing. It is typically used for more advanced analysis purposes.
- **High-speed video analysis** involves the use of high-speed cameras, such as Photron, capable of operating at speeds up to 1000 Hz. This technique is particularly effective for conducting qualitative analysis of high-speed movements and impacts.
- **Competition analysis** involves evaluating relevant performance variables, such as split times, stride rate/length in athletics, and splits and stroke length/rate in rowing/kayaking.
- **Accelerometers, gyroscopes and lasers** are used to assess the technical characteristics of an athlete's motion.

**Systematic observation** of movement skills can be conducted directly (watching live) or indirectly (watching a recording). Video analysis in its simplest format can be viewed repeatedly, viewed in slow motion, paused and saved for comparison at a later date. Through the observation, information is gathered for the individual or coach to analyse and evaluate in order to provide the athlete with feedback on their performance. This process allows the individual or coach to identify errors and refine the movement skill.

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#### systematic observation

A method of collecting data by watching and/or listening to the subject and recording their observations

## LOOKING FORWARD

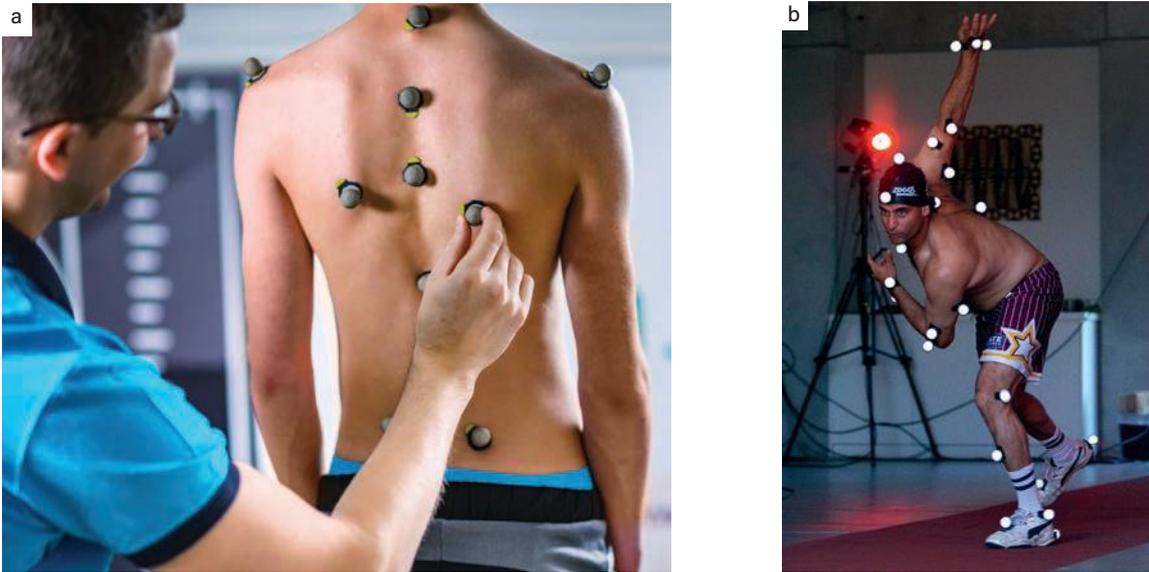
### Qualitative movement analysis

#### Chapter 4

In Chapter 4 we will look more closely at how to perform a qualitative movement analysis. You will perform the analysis using video footage and systematic observation to analyse and improve movement skills.

A more complex use of video footage would be the digitisation of the footage (converting body landmarks to computer coordinates) so a quantitative analysis can be conducted to calculate distances, speeds, forces and momentum.

Optoelectronic motion analysis (see Figure 3.05) uses cameras that project infrared light onto reflective spheres, called targets, placed on the body. For a whole-body analysis, 16 targets are placed on the joints. The targets reflect an 'image' that can be captured by the camera, transmitted to a computer as digital information, and analysed.



**FIGURE 3.05** Optoelectronic motion analysis: **a** placing the reflective spheres on the body; **b** capturing the 'image' under infrared light



#### Weblink

AIS Biomechanics Adapting Methods for Para Swimming



#### Assessment

3.1 Check-in questions

#### Command terms

##### summarise

Retell concisely the relevant and major details of one or more arguments, text, narratives, methodologies, processes, outcomes and/or sequences of events

##### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

## SIGNPOST

### AIS Biomechanics adapting methods for para swimming

Biomechanics is important to understanding the movement of individual athletes and bringing out their best. Watch the video *AIS Biomechanics Adapting Methods for Para Swimming*, which shows AIS Senior Biomechanist Marc Elipot working with Paralympic swimmer Jesse Aungles to deliver real performance gains, via the Australian Institute of Sport's YouTube channel.

## 3.1 CHECK-IN QUESTIONS

- 1 **Define** the role of a biomechanist.
- 2 **Discuss** how a coach of a junior sports team might benefit from knowledge of biomechanics.
- 3 Watch the video of Marc Elipot, the biomechanist at the AIS. **Summarise** the information presented in the video and then **outline** the key points to a family member or friend.

## 3.2 LINEAR AND ANGULAR CONCEPTS OF HUMAN MOVEMENT

In this module you will learn about:

- linear and angular concepts of human movement including force/torque, momentum, impulse and speed/velocity and learn to:
- analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills.

To understand how forces affect human movement, we first need to understand what a **force** is.

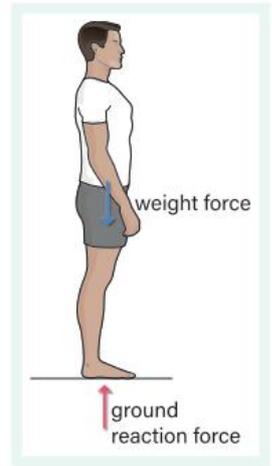
### Force

A **force** is defined as a push or a pull. Forces come in pairs: the force exerted by one object on another is matched by an equal and opposite force applied by the second object on the first. This is Newton's third law of motion. We will look at Newton's laws of motion in more detail in Module 3.3.

When we are standing still, our body weight exerts a force downwards onto the ground and the ground pushes back. This force is called the ground reaction force or 'normal' force. The weight force and ground reaction force are equal in size but opposite in direction. No movement occurs because the resultant force acting on the body is zero.

Forces cause objects to:

- change shape (stretch, squash or twist)
- accelerate (start moving, speed up, slow down, stop or change direction).



**FIGURE 3.06** Forces acting on the human body when standing

#### force

A push or a pull



Chris Hyde – FIFA/FIFA/Getty Images

**FIGURE 3.07** The force applied will change the motion of the ball.

Forces can produce movement or change the motion of an object. In Figure 3.07 a, the force that is applied to a stationary ball when it is kicked in soccer starts the ball moving; in Figure 3.07 b, when a player heads the ball, the force changes the direction the ball is travelling in; and in Figure 3.07 c, when the goalie catches the ball and saves a goal, the motion of the ball is stopped.

All forces produce or change the movement of an object, but this effect is not always obvious. When you jump, the effect of the reaction force between your feet and the ground cannot be seen because the object to which the force is being applied – in this case the Earth – is so massive the movement cannot be seen.

Forces cause objects to accelerate. Force can be calculated by multiplying the mass of the object by the acceleration:

$$F \text{ (force)} = m \text{ (mass)} \times a \text{ (acceleration)}$$

The equation  $F = ma$  is Newton's second law of motion. We will look at Newton's laws of motion in more detail in Module 3.3.

In physical activity, sport and exercise, the mass of an object is usually constant; therefore, to increase the acceleration of the object, a larger force needs to be applied.

### acceleration

The rate of change in velocity, measured in metres per second per second, or metres per second squared ( $\text{m/s}^2$ )

## DID YOU KNOW?

The unit of force is the newton (N), which is the amount of force required to accelerate 1 kg of mass at  $1 \text{ m/s}^2$ . The unit of force is named after Sir Isaac Newton, an English physicist who formulated the laws of motion.

## Types of forces

There are three main types of external forces that act on the human body:

- applied
- gravitational (weight)
- frictional.

In a situation that involves movement, these three types of forces can start, stop, speed up, slow down or change the direction of a ball, bat or body.

There are other forces (tension, spring, electric, buoyant and magnetic forces) and these can be seen in action sports such as gymnastics, trampolining and water sports, but they are less relevant to the analysis of human movement.

## Applied forces

Applied forces are forces that one object exerts on another object. In sporting situations, every time a ball is kicked or thrown, the movement is a result of an applied force. There are many examples of applied forces. Gripping a tennis racquet is an applied force. Jumping, putting a shot and running all require an applied force.

## LOOKING BACK

### The musculoskeletal system

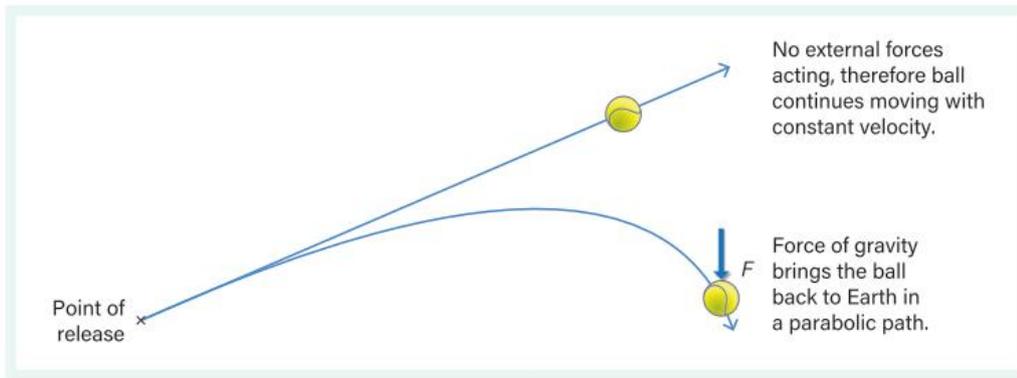
#### Unit 1, Chapter 1

The musculoskeletal system is studied in Unit 1 of VCE Physical Education. The bones, muscles, tendons, ligaments and other tissues all exert forces on one another. These are internal forces and, while they still come in pairs, they don't actually produce a change in motion of the whole body, only of body parts. To change the motion of the whole body, an external force is needed. Internal forces are important if a biomechanist is looking at the causes of injuries but, when we are looking to analyse human movement, it is the external forces that we are interested in.

## Gravitational force

A gravitational force is the force of attraction between two bodies or objects. On Earth, the gravitational force is the force (gravity) that keeps us on the ground and causes airborne objects, including the human body, to fall downwards – towards the centre of the Earth. The acceleration due to gravity is equal to  $9.8 \text{ m/s}^2$ .

All objects that are hurled, thrown or projected into the air are affected by the force of gravity (see Module 3.4 for more detail about projectile motion). For example, without gravity, a ball thrown into the air would just keep going. It is the force of gravity that brings the ball back down to the ground and creates its parabolic path.



**FIGURE 3.08** Gravitational force brings a projectile back to Earth.

Weight is the force that is exerted on an object or a body by gravity. It is directly proportional to the mass of an object. The weight force can be calculated by multiplying the object's mass by the acceleration due to gravity. Because weight is a force, the units used are newtons.

$$W \text{ (weight)} = m \text{ (mass)} \times g \text{ (gravity)}$$

## DID YOU KNOW?

**Mass** and **weight** are often used interchangeably, although they are two different quantities. Mass is a measure of the amount of matter an object is made up of. The units of mass are kilograms. Because body 'weight' is often given in kilograms, the two terms are often used to mean the same thing.

### mass

The amount of matter that makes up an object, measured in kilograms (kg)

### weight

The measure of gravitational force acting on a body ( $W = mg$ )

### friction

A force that acts in the opposite direction to motion when two surfaces are in contact with one another

## Friction

**Friction** occurs when two surfaces come in contact with each other. The two surfaces might be the body and air or water, a bicycle wheel and the road, a ball and the ground, or the hand and a bat. Friction opposes the motion of an object. In everyday living, friction between feet and floor is needed to walk, friction between wheels and path enables us to ride a bike, and friction between hand and object lets us pick things up. In sporting situations, there are times when it is beneficial to decrease the friction between two surfaces, such as in downhill skiing. In other examples, it may be important to increase the friction between the surfaces, such as between the track and the runner in sprinting.



**FIGURE 3.09** Are the athletes in each of these images trying to increase or decrease the friction?

Manipulating the amount of friction between surfaces is common in physical activity, sport and exercise. Rock climbers use chalk to dry sweaty palms, as do gymnasts, who also want to increase the friction and ensure they have a strong grip and don't slip off the apparatus. Sports shoes are designed to use friction. For example, shoes worn in volleyball, squash and badminton have rubber soles, while sports played on grass pitches often have studs. In some sports, the surface on which the activity is conducted is polished or oiled to make it as smooth as possible, reducing friction.

For an object to start moving, a large enough force must be applied to overcome friction. This is an application of Newton's first law of motion, which we will look at in detail in Module 3.3. As the applied force increases, so does the friction – to a certain point. The maximum amount of friction that can be generated between two non-moving surfaces is called maximum static friction. If the applied force increases beyond the maximum static friction value, then the object will begin to move.

When an object or body moves through air or water (or any other gas or fluid) it will experience a drag force. Drag is the frictional force between an object and the air or water. Drag forces oppose the direction of motion of the object, slowing it down. Drag is affected by factors such as air density, the cross-sectional area of the body and the speed at which the object is travelling. Any increase in speed results in an increase in drag.

To maximise speed, athletes try to reduce the impact of the other factors. In sports that require high speed, drag is often minimised through technique (body position) and clothing (fabric and design).



Francis Bompard/Agence Zoom/Getty Images

**FIGURE 3.10** Downhill skiers try to minimise drag by reducing the cross-sectional area of their body while going as fast as they can. Can you think of any other examples where athletes change their body position, clothing or equipment to minimise drag force?

## COLLABORATIVE TASK

### Prac activity

#### Investigating friction

##### AIM

To investigate the effect of friction on sprint times

##### EQUIPMENT

- tape measure
- stopwatch

##### METHOD

- 1 In pairs, allocate a timer and a runner.
- 2 Select four different conditions to sprint 25 metres. These may include:
  - shoes on – indoor surface
  - shoes off – indoor surface
  - school shoes – grass
  - runners – grass
  - runners – running track
  - running spikes – running track.
- 3 On the timer's signal, the runner sprints as fast as they can over 25 metres.
- 4 Allow the runner to fully recover in between each sprint.
- 5 Repeat steps 3 and 4 for each of the four conditions selected.
- 6 Record the time for each sprint.

##### OBSERVATIONS

Timer to record anything they observe for each sprint (such as slipping/sliding).

Runner to record their thoughts after each sprint.

##### DISCUSSION

Discuss the role of friction in sprinting. Refer to the data collected (both the times recorded and the observations from both the timer and the runner). In your discussion, consider the two contact surfaces, and the impact of the friction present in each situation on the sprint time.



## Torque

When a force causes an object to rotate or turn, this effect is called a **torque**.

Torques cause changes in **angular motion**. Angular motion involves rotation around a central axis or a fixed point. The axis can be:

- real
- imaginary
- internal
- external.

The joints of the body are real, internal axes. In Figure 3.11 a, an imaginary, external axis is the centre of gravity; in Figure 3.11 b, a real, external axis is the bar when performing a rotation on a high bar; and In Figure 3.11 c, when spinning in figure skating, the axis is an imaginary, internal, vertical axis.

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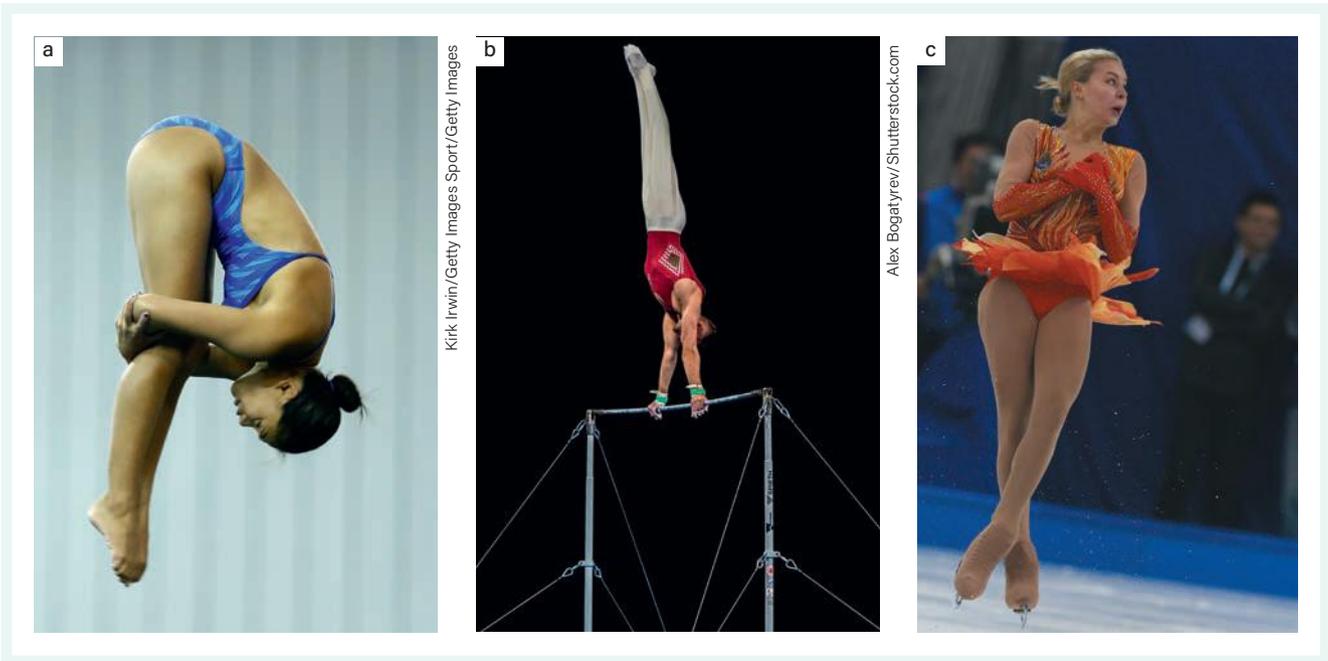
##### torque

The turning effect produced by a force

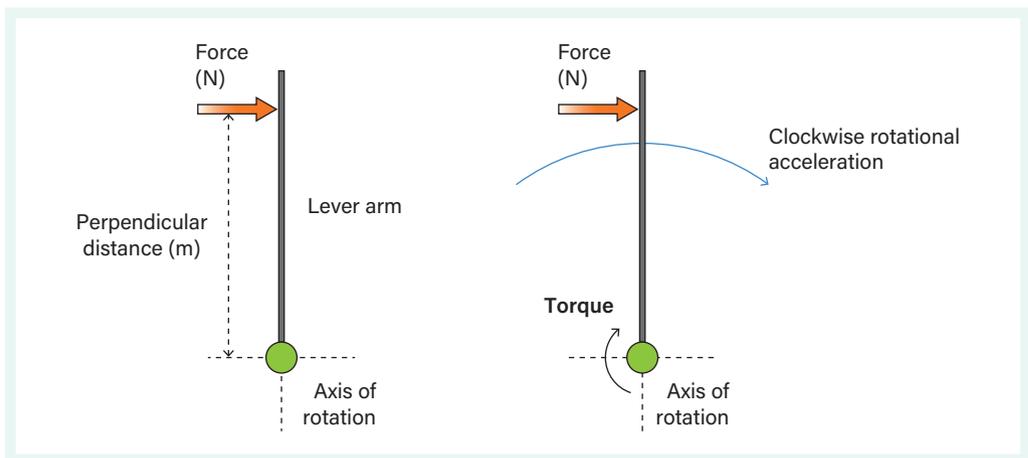
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##### angular motion

Movement of a body part around an axis of rotation



**FIGURE 3.11** Angular motion: **a** rotation around an imaginary external axis; **b** rotation around a real external axis; **c** rotation around an imaginary internal vertical axis



**FIGURE 3.12** Torque: the force applied at a distance from the axis causes a turning effect.

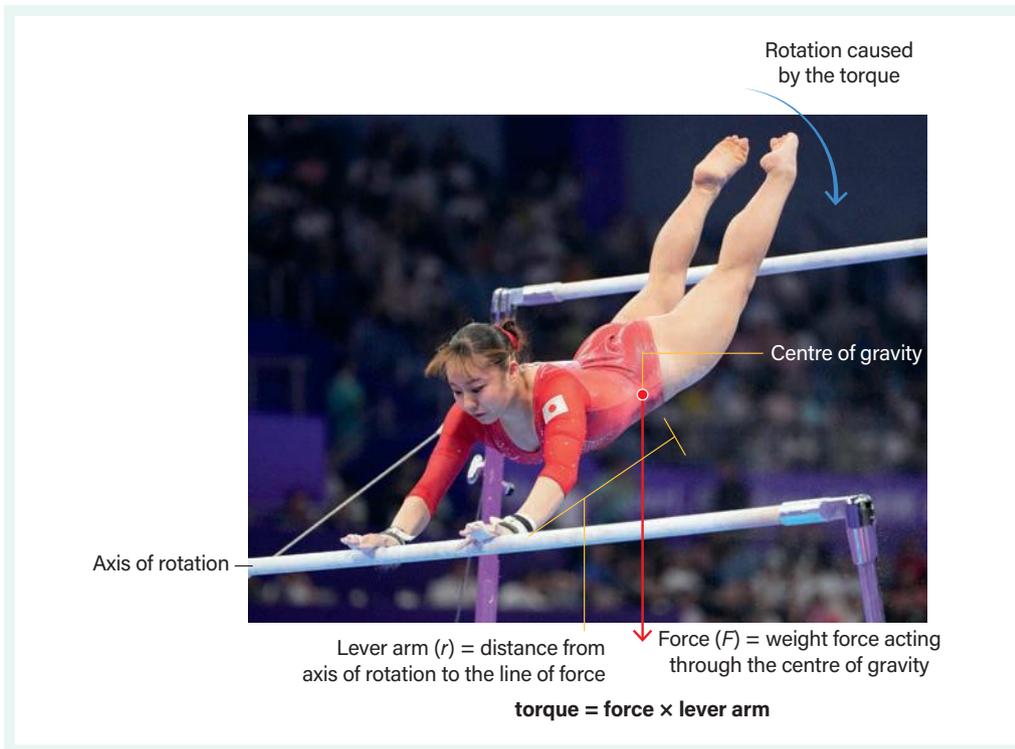
**eccentric force**

A force that does not act through an object's centre of gravity

The application of an **eccentric force** on an object can cause the object to rotate and move forwards.

Torque, sometimes called 'moment of force', can be calculated by multiplying the force by the lever arm of the force. The lever arm is the perpendicular distance from the axis of rotation to the line of action of the force. Torques cause rotation about an axis and cause angular acceleration; the greater the torque, the greater the angular acceleration.

The size of the torque is determined by two factors: the length of the lever arm and the size of the applied force.



Newscom/Alamy Stock Photo

**FIGURE 3.13** Torque will cause the gymnast to rotate around the bar.

## Increasing rotation

Increasing the rotation of an object or the body can be beneficial in sport:

- In sports such as tennis, badminton, golf, baseball and cricket, the athlete applies torque to swing the racquet, club or bat.
- Spin is created by an athlete applying an eccentric force to a ball, causing the ball to rotate in sports such as cricket, squash and table tennis.
- Torque is needed to rotate the oar or paddle in rowing, canoeing and kayaking.



amanaimages/Adobe Stock

**FIGURE 3.14** Gymnastics, diving, ice-skating and dance all involve many movements that require the body to rotate around an axis.

## Angular velocity

Angular velocity is the rate of change of the angular displacement (change in absolute angular position) of a body over time. Angular velocity is measured in degrees per second.

Angular velocity is important in sports such as diving, gymnastics, aerial skiing, snowboarding, skateboarding and dance, where athletes need to complete rotations before they land or hit the water, snow or ice.

Studies have shown that an ice-skater performing a triple axel (three-and-a-half rotations), will increase their angular velocity to more than 1800 degrees per second. Angular velocities increase with the difficulty of the skill being performed. The angular velocity required to complete a single rotation is not as great as the angular velocity required to complete a triple rotation.



PA Images/Alamy Stock Photo

**FIGURE 3.15** Aerial skiers often need to slow their rotation before landing. They do this by increasing their moment of inertia (see page 119), which they achieve by spreading out their arms or legs to slow the rotation.

When you swing your leg to kick a ball, or swing a racquet to hit a ball, the rotational movement of your limb results in the linear movement of the ball. Often, we want to increase the linear velocity of a ball that is being hit, kicked or thrown.

The relationship between linear and angular velocity is given by:

$$\text{linear velocity} = \text{radius of rotation} \times \text{angular velocity}$$

To increase linear velocity, we can increase the radius of rotation of the implement being used. The most practical way to do this is to increase the length of the implement. If all other aspects are equal, the greater the radius of rotation, the greater is the linear velocity of the ball and the further it will travel.

This explains why drivers in golf are longer than nine-irons, why elite players prefer longer baseball bats and why a tennis racquet can hit a ball further than a bat used to play bat tennis. However, if the longer bat or racquet is too heavy and cannot be swung as quickly as a shorter bat or racquet, the angular velocity will be compromised by the increase in radius of rotation.



In focus: Relationship between linear and angular velocity



Travis Kirkland/Shutterstock.com

**FIGURE 3.16** Junior sports equipment is modified to make it easier for young players to use.

## LOOKING BACK

### Modified sporting equipment

#### Chapter 2

In Chapter 2 we looked at task constraints that can be manipulated to enhance participation and performance in physical activity, sport and exercise. Children and junior athletes often use modified equipment because it is easier for them to manipulate and then they are more likely to successfully hit a ball. The rationale for modifying equipment for children is underpinned by biomechanical principles like the one we have just looked at: radius of rotation. Later in this chapter (Module 3.5) we will look at levers and lever length, which will build further on your understanding of the biomechanical principles that influence the selection of equipment in many different sports and activities. However, as we discuss in Chapter 3, there are also sociocultural reasons why children use modified equipment. Modified sporting equipment makes participating in physical activity, sport and exercise more engaging and enjoyable for children as they are able to be successful, which leads to greater enjoyment and builds confidence to try new things.

# Momentum

## momentum

The quantity of motion a body has; it is the product of a body's mass and its velocity ( $p = mv$ )

**Momentum** is a measure of the amount of motion an object has and its resistance to changing that motion. Momentum is equal to the mass of the object multiplied by its velocity. The symbol for momentum is  $p$  and the units of measurement are kg m/s:

$$\text{momentum } (p) = \text{mass } (m) \times \text{velocity } (v)$$

Therefore, the faster an object moves, the more momentum it will have. For two objects of the same mass, the one with the higher velocity will have greater momentum. The more momentum an object has, the harder it is to stop. In which of the situations in Table 3.01 is the momentum of the object or body greater?

**TABLE 3.01** In which situation will momentum be greater?

Situation A	Situation B
65 kg athlete running at 10 m/s	65 kg athlete running at 12 m/s
60 g tennis ball served at 220 km/h	160 g cricket ball travelling at 90 km/h
95 kg AFL full-forward standing still	70 kg AFL small forward sprinting towards goal

An object or body that is not moving has zero momentum because it has no velocity. However, if two objects have the same mass but different velocities, the object with the greater velocity will have the greater momentum. Similarly, if two objects have the same velocity but different masses, the object with the greater mass will have the greater momentum.

A change in momentum can be achieved by a change in mass or in velocity. In most of the situations where momentum changes in physical activity, sport and exercise, it is a change in the object or body's velocity that results in the change in momentum.

Consider a cricket ball that has been struck forcefully by the batsman. Even though the ball does not have a very high mass, its velocity is very high, which means it has a large amount of momentum. A cricket ball travelling at high speed is harder to stop than a cricket ball that has just been padded away by the batsman, because objects with greater momentum are harder to stop.

## Collisions

Momentum is important when objects collide, and collisions are very common in sport and physical activity. When a bat, club or racquet hits a ball, when a player tackles another player in football or when a soccer ball contacts a player's head, there is a change in the momentum of each object. The mass of the object remains the same in these situations, so the change in momentum is a result of a change in the objects' velocity.

When two objects collide, the player or object with the greater momentum will dominate the collision. This may be a smaller, lighter player moving with greater velocity, or a larger, heavier player moving with the same velocity, as their opponent. When two players collide and stay in contact with one another (see Figure 3.17 a) both will usually continue moving in the direction of the object with the greater momentum. But when a ball is hit with a bat or a player kicks a ball, the direction of the ball will be the same as the direction of the applied force (see Figure 3.17 b).

## Conservation of momentum

Momentum is conserved in an isolated system where there are no external forces acting. The principle of conservation of momentum states that the total momentum of the system before the collision is equal to the total momentum after the collision. In sporting collisions, for example, the effects of external forces such as air resistance and friction would be present, but they can be ignored in order to qualitatively determine changes in momentum.

Mark Brake/Getty Images Sport/Getty Images



Emily Barker/Getty Images Sport/Getty Images

**FIGURE 3.17** Momentum is conserved in all collisions: **a** when two players collide; and **b** when an object (ball) and a person collide (kick).

In conservation of momentum, we need to look at the objects involved in the collision before and after impact. If we use the example of the player kicking the ball in Figure 3.17 b, then the momentum of the player before they kick the ball will be equal to the momentum of the ball after it is kicked. To explain conservation of momentum in this situation, we are making a couple of assumptions:

- 1 The ball has a zero velocity before the collision.
- 2 The player has zero velocity after the collision.

Let's say that the player has a mass of 75 kilograms and is running at 5 metres per second. The ball has a mass of 0.5 kilograms.



**Video**

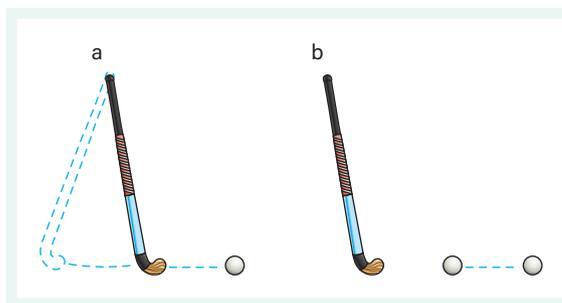
In focus: Conservation of momentum

Total momentum before collision	=	Total momentum after collision
Momentum of player = mass × velocity $p = 75 \times 5 = 375 \text{ kg m/s}$		Momentum of player = mass × velocity $p = 75 \times 0 = 0$
Momentum of ball = mass × velocity $p = 0.5 \times 0 = 0$		Momentum of ball = mass × velocity $p = 0.5 \times v$
Total momentum before = momentum of player + momentum of ball = 375 kg m/s		Total momentum must equal 375, therefore: $375 = 0.5 \times v$ $375 \div 0.5 = 750$ Velocity of the ball after being kicked is 750 m/s

After the collision, the ball moves off very quickly, with a high velocity ( $v$ ), and the player slows to zero velocity. The total momentum after the collision is equal to the momentum of the ball. The principle of conservation of momentum states that the momentum before the collision will equal the momentum after the collision.

**LEARNING HACK**

In many sporting collisions, there is one object that has a greater mass than the other and one that has a much higher velocity than the other. This means that, when we are looking at conservation of momentum, we can think of mass and velocity of each object as big or small.



**FIGURE 3.18** The momentum of the stick before the collision is equal to the momentum of the ball after the collision.

momentum of stick + momentum of ball = momentum of stick + momentum of ball

$$M \times v + m \times 0 \text{ (ball not moving)} = M \times 0 \text{ (stick not moving)} + m \times V$$

total momentum before collision = total momentum after collision

$$\therefore Mv = mV$$

where  $M$  = mass of stick

$m$  = mass of ball

$V$  = velocity of ball

$v$  = velocity of stick

So, when a ball is hit or kicked, conservation of momentum can be represented as:

$$(M \times v) + (m \times 0) = (M \times 0) + (m \times V)$$

Mass is constant in sporting collisions, and in most collisions between bat and ball, or body and ball, the mass of the ball is less than the mass of the body or bat that strikes it. This means that the velocity of the ball after impact will be greater than the velocity of the implement that hit or kicked it.

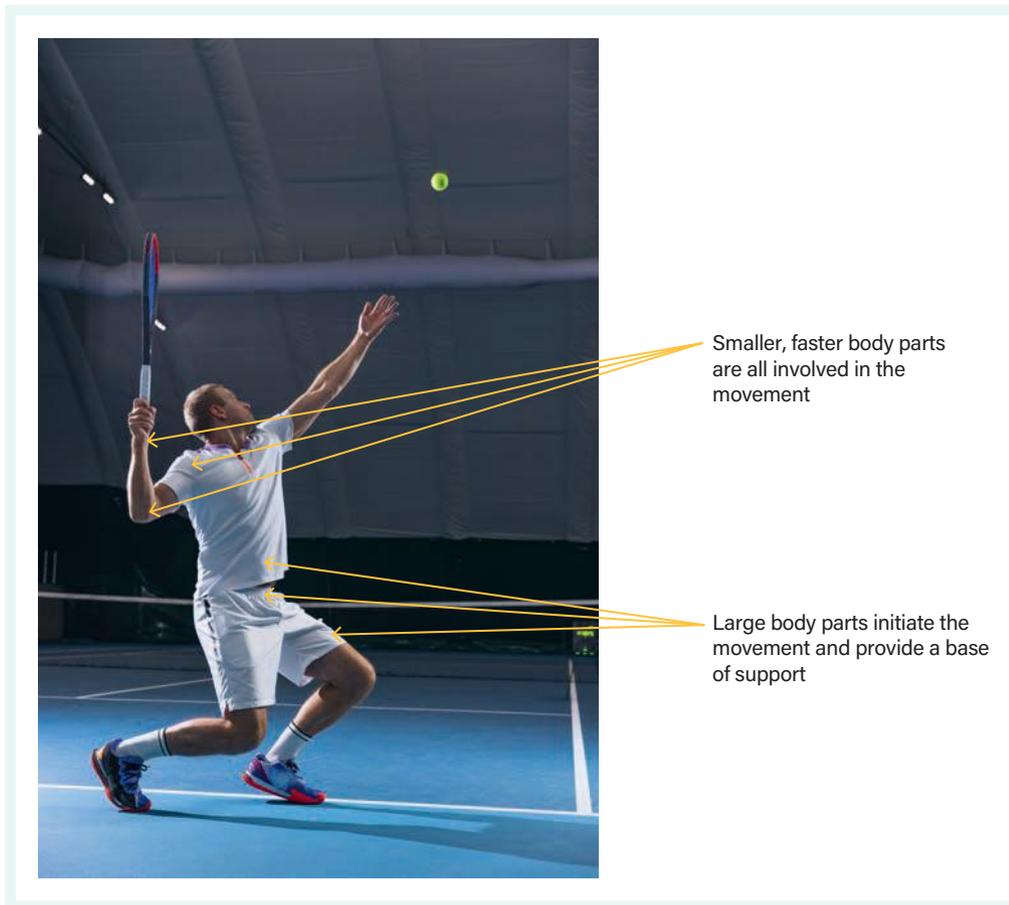
The principle of conservation of momentum can be applied when refining movement skills. If the main objective of the skill is to hit, kick or throw an object or ball as far as possible, it is important that the object is released or struck with maximum velocity, and this can only occur when the momentum that is generated throughout the movement is transferred smoothly from each of the body parts that are involved.

The coordination of all the body segments involved in the movement allows athletes to generate maximum velocity. This is referred to as **summation of momentum**, summation of forces, summation of speed, or the kinetic link principle. Maximum velocity results from momentum being generated in a sequential manner, from the body parts closest to the centre of gravity to those further away.

This momentum is conserved, so the larger body parts move more slowly (large mass, smaller velocity) and the lighter body parts more quickly (small mass, larger velocity). Highly skilled performance is characterised by well-timed, coordinated movements that result in optimal velocity of the object at impact or release.

**summation of momentum**

The sequential and coordinated movement of each body segment to produce maximum velocity



iStock.com/Anton Vierlein

**FIGURE 3.19** The speed of a tennis serve starts with the lower body movement.

In the example of the tennis serve (see Figure 3.19) the whole body is used to generate the force needed to serve at high speeds. The large, powerful muscles of the legs and trunk start the process, generating the initial momentum that is then transferred to the sequential body parts (shoulder, elbow, wrist). The smoother the motion, the more efficient the movement, which in turn maximises the momentum transferred and results in the ball being served at the highest possible velocity. Elite athletes continually refine their movements, not only by practising their serving technique but also by building strength in all the muscles involved and by increasing flexibility across their joints to allow for smooth rotation throughout the movement.

## LOOKING FORWARD

### Refining movement skills

#### Chapter 13

Refining a movement skill requires an athlete to address multiple components of the skill, not just the technique. In this section we are looking at the biomechanical aspects of the skill. In Chapter 2 we looked at skill acquisition principles affecting skill development. Later in the text, in Chapter 13, we will look at the physiological aspects, including different training methods, that lead to increases in factors, such as strength and flexibility, that contribute to the skill. Coaches need to consider all aspects of skill development when working to get the very best results with athletes.

## A BAN ON CHILDREN HEADING IN FOOTBALL (SOCCER), NOT THE BEST APPROACH

24 AUGUST 2023

Sports Medicine Australia is anticipating a surge in children playing football in the wake of Australia and New Zealand hosting the FIFA Women's World Cup.

While concerns about concussion may inspire calls in Australia for a ban on children heading the ball, as is the case in England and America, a ban would likely not produce the hoped-for outcomes, a world-leading researcher in concussion in football says.

'[A] heading ban in young players – a strategy endorsed in heading guidelines in the US and England – might appear to be a sensible option to protect the developing brains of young players,' world-leading researcher in concussion in football Dr Kerry Peek – who is a member of Sports Medicine Australia's NSW Council – said.

However, 'banning heading during an important skill development phase may impede young players from developing safer heading technique in the future,' Dr Peek said.

'If we expect players to head the ball at any age, we must teach them the skills of heading, much of which, like ball tracking and body positioning, require no ball-head impacts at all,' Dr Peek said.

'If we do not teach players how to safely head the ball, then we could be exposing them to a higher risk of concussion.

'Acquiring the skills of heading can and should start with no ball-head contact at all.'

Dr Peek is the lead author of a research article published in *Sports Medicine Australia's Journal of Science and Medicine in Sport* titled 'The incidence and characteristics of purposeful heading in male and female youth football (soccer) within Australia'.

Sports Medicine Australia CEO Jamie Crain said: 'We expect that young people will be inspired to play soccer by the media coverage of the Women's World Cup, particularly coverage of the Matildas games.

'This expected surge in participation is not just fabulous for football but for individuals who try the sport.

'The physical activity will benefit individuals though improved fitness levels and will also bring mental health benefits and extra opportunities to interact with others, essential for socialisation.'

Dr Peek said: 'Recently football has received increased scrutiny, particularly the impact of purposeful heading on brain health and development.'

Purposeful heading is a skill integral to football where players deliberately use their heads to re-direct the ball. Between 20–25 per cent of goals are scored by a header across international tournaments.

'Whether purposeful heading is associated with neurodegenerative diseases in later life is the subject of much debate,' Dr Peek said.

'But considering the scientific and public concern around repetitive head impacts such as heading a ball, governing bodies should do what they can to retain all the positive benefits of playing a team sport while minimising the risks, especially in young players.'

Dr Peek was a member of UEFA's Heading Expert Group (chaired by Prof Tim Meyer) that drafted UEFA's Heading Guidelines in 2020.

Dr Peek's study of 110 football games was the first study to document heading incidence rates in Australia and found:

- Under-15 males and under-17 females demonstrate a higher heading incidence rate than any other age group.
- Midfielders completed the most headers in all female age groups.
- Defenders completed the most headers in under-15–20 males.
- Heading duels accounted for 16 per cent of total headers with most headers performed during free play.



- Only 57 head impacts (out of a total of 4672 recorded, or about 1 per cent) were unintentional, from being struck by the ball or an opponent's body part. Of these only four required medical attention.

'The study findings can be used to inform heading guidelines which would include teaching youth players heading technique based

on specific game scenarios for their position and age group while also limiting heading practice in players who consistently head the ball in matches to reduce the accumulative number of headers over their playing career.'

Source: 'A ban on children heading in football (soccer), not the best approach', *Sports Medicine Australia*, 24 August 2023



Cavan Images/Alamy Stock Photo

**FIGURE 3.20** Should heading the ball be banned to minimise the risk of injury from headers in junior soccer?

### QUESTIONS

- 1 What are the perceived risks associated with heading the ball in soccer?
- 2 What does Dr Peek see as the future problem if headers are banned in junior soccer?
- 3 Based on your understanding of force and momentum, **explain** biomechanically the impact of the ball on the head when the ball is headed in soccer. (The mass of a soccer ball is approximately 400 grams or 0.4 kilograms.)
- 4 What is the role and responsibility of the coach in refining the movement skill of heading in junior soccer players?

'What I want to see is a change in the messaging, hence no ban on heading in young ages, but we have consistent coach education to support the way children are taught the important foot-based skills of football (through small sided games, playing out from the back, short corners etc.) so that most heading is naturally minimised in children's football and heading is introduced in football as part of their skill development as players get older and transition to a full pitch (around 13–14 years of age).'

Dr Kerry Peek, quoted in 'A ban on children heading in football (soccer), not the best approach', *Sports Medicine Australia*, 24 August 2023

## COLLABORATIVE TASK

## Lab activity



## Summation of momentum

## AIM

To investigate how summation of momentum affects the distance a ball can be thrown

## EQUIPMENT

- tennis ball
- tape measure

## METHOD

With a partner, complete the following.

- Sit with your back against a wall, arm by your side, and throw the tennis ball using only your wrist.
- Sit with your back against the wall and throw the ball using your wrist and elbow.
- Kneel, then use your wrist, elbow and shoulder to throw the ball.
- Stand up, keeping your feet together, and use your trunk, shoulder, elbow and wrist to throw the ball.
- Stand, step forward and throw the ball using your trunk, shoulder, elbow and wrist.

## RESULTS

Record the distance of each throw.

## DISCUSSION

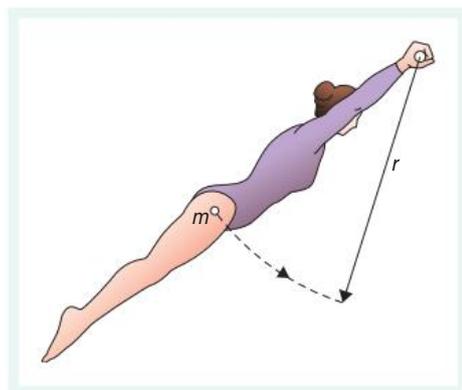
- 1 In which trial did the ball cover the greatest distance?
- 2 **Explain** your results in relation to summation of momentum.
- 3 How is momentum conserved when each body segment has a different mass and moves with a different velocity?
- 4 Young children often throw using only their arm. **Outline** three teaching points you could use when teaching them to throw correctly.

## CONCLUSION

What conclusion can be made about summation of momentum and the increased release velocity of a ball in an overarm throw?

**moment of inertia**

The product of the distribution of the mass ( $m$ ) of the object and the axis about which it rotates



**FIGURE 3.21** Moment of inertia = mass  $\times$  radius<sup>2</sup>

## Angular momentum

A rotating body also has momentum. Angular momentum is the amount of angular motion that a body possesses. It is the product of the **moment of inertia** and the angular velocity of an object rotating around an axis. Just as inertia is an object's resistance to a change in its linear motion, moment of inertia is an object's resistance to change its angular motion.

A rotating body will continue to rotate unless acted upon by an external torque. For example, young children will often swing a racquet or bat and continue turning in a full circle.

How do divers, gymnasts, skaters and trampolinists control the speed of their rotations in the air? Why is it easier to complete a double somersault in the tuck position than in the full layout position? The answer to both questions lies in the way athletes manipulate their moment of inertia and angular velocity.

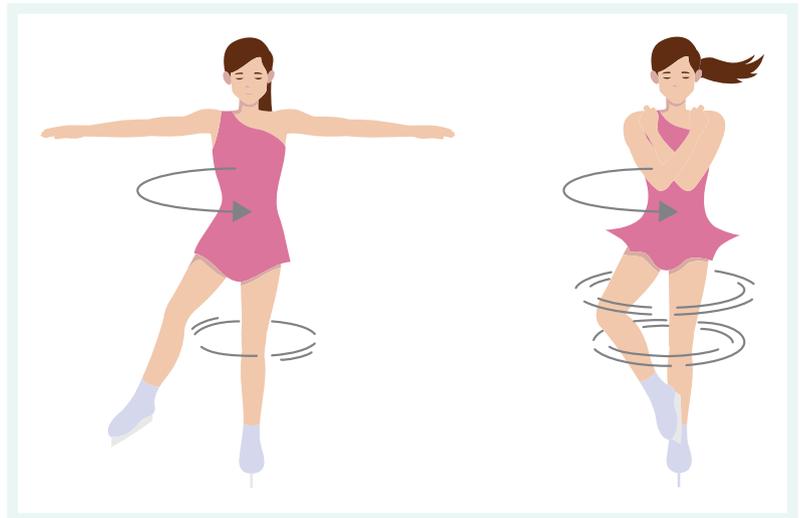
They are able to do this by moving their limbs away from the axis of rotation (see Figure 3.22 a) or by drawing them closer to the axis of rotation (see Figure 3.22 b) to control angular velocity when somersaulting, twisting or spinning.

For example, aerial skiers bring their arms in towards their body when performing a twist. This decreases the moment of inertia, as the mass is now concentrated closer to the radius of rotation. The result is an increase in the rate of rotation. Similarly, by pulling their bodies into a tight tuck position, they reduce their moment of inertia, meaning the rotation will be much faster than in a pike or layout position.

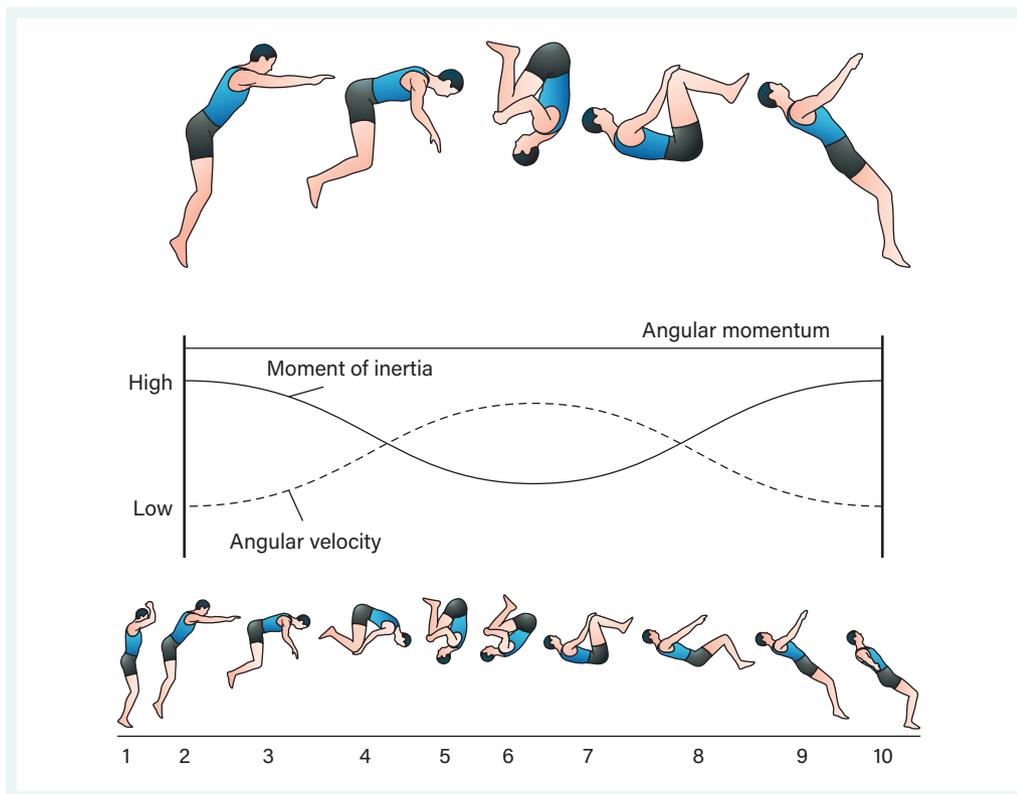
Angular momentum of an object remains constant, unless acted upon by an external torque.

- An increase in moment of inertia results in a decrease in angular velocity.
- A decrease in moment of inertia results in an increase in angular velocity.

This principle is known as conservation of angular momentum.



**FIGURE 3.22 a** Increased moment of inertia results in slower rotation. **b** Decreased moment of inertia results in faster rotation.



**FIGURE 3.23** The relationship between moment of inertia and angular velocity. The angular momentum is conserved, so it remains constant throughout the movement.

# Impulse

## impulse

The change in momentum of an object. It is the product of force and the time over which the force is applied ( $I = F \times t$ ).

**Impulse** is equal to the change in momentum of an object. To change the momentum of an object, a force must be applied over a period of time. Impulse is equal to the applied force multiplied by the length of time over which the force was applied:

$$\text{impulse } (I) = \text{force } (F) \times \text{time } (t)$$

Impulse is an important quantity in sporting situations. Because the mass of an object remains the same in most movement situations, any change in momentum must be the result of a change in velocity.

Remember that a force causes objects to accelerate – that is, to start moving, speed up (positive acceleration), slow down (negative acceleration), stop or change direction. Momentum is the product of mass and velocity, and impulse is a change in momentum. Therefore, a change in an object's momentum can result from:

- a large force being applied over a very short period of time
- a small force being applied over a longer period of time.

Consider a golf ball that is struck with a driver (see Figure 3.24 a). The ball is in contact with the club for a fraction of a second, but the force applied is very large. Compare this to the frictional force that is applied to a golf ball rolling over the putting green (see Figure 3.24 b), slowing it down until it comes to an eventual stop (hopefully, in or very near the hole!). This frictional force is a small force applied over a much greater period of time. In both examples, the ball will experience a change in momentum. In the first case, the ball goes from 0 kilometres per hour (km/h) to approximately 300 km/h; in the second example, the ball goes from approximately 2 km/h to 0 km/h.

In many sporting situations, the impulse applied to an object can be manipulated to either increase or decrease the velocity of an object.



**FIGURE 3.24 a** The driver applies a large force on the ball in a very short time. **b** The grass applies a small frictional force to the ball over an extended period of time.

There are many examples in sport of reducing impact forces by increasing the time over which the force is acting. Manipulating impulse can reduce the risk of injury, particularly when catching a fast-moving ball or landing after a dismount in gymnastics. Increasing the time over which the force is applied decreases the impact force and reduces the likelihood of injury. Athletes achieve this by 'giving' with the ball (starting with arms outstretched towards the ball and then moving them in the direction of the ball's movement) or through flexing in the ankles, knees and hips. Soccer players (see Figure 3.25) move with the direction of the ball when receiving a pass on the chest. This increases the time over which the force is applied, which in turn reduces the force. As a result, the ball will drop to the player's feet rather than bouncing away.



Jonathan Daniel/Getty Images

**FIGURE 3.25** A soccer player moving with the direction of the ball

## REAL WORLD APPLICATIONS

### Shot-put and discus

Shot-putters and discus throwers use the impulse–momentum relationship to increase the time over which the force is applied to the shot and discus. Compared to a standing technique, the rotational or glide technique used in shot-put increases the time over which the force is applied. This results in a greater impulse being applied and a change in momentum, which leads to a greater release velocity of the shot.

Watch videos on rotational technique and glide technique on Nelson MindTap.



#### Weblinks

Rotational technique for shot-put

Glide technique for shot-put



**FIGURE 3.26** The rotational technique used in: **a** shot-put; **b** discus



## COLLABORATIVE TASK

### Prac activity

#### Force–impulse–momentum relationship

##### Part 1

###### AIM

To throw a water balloon as far as possible

###### EQUIPMENT

- 3 water balloons filled so each is about the size of a softball

###### METHOD

Experiment with different techniques to throw the water balloon as far as possible without it first breaking in your hand!

###### DISCUSSION

What technique worked best, and why? (In your discussion, consider the size of the force and the time over which the force was applied.)

##### Part 2

###### AIM

To throw the water balloon as far as possible and catch it without breaking

###### EQUIPMENT

- 3 water balloons filled so each is about the size of a softball

###### METHOD

- 1 With a partner, devise a strategy for catching the water balloons without breaking them when they are thrown underarm from 5 metres and 10 metres away and overarm from 5 metres.
- 2 Perform one trial and then make any necessary adjustments to your strategy before completing the other trials.

###### DISCUSSION

- 1 Which two variables did you manipulate in devising your strategy?
- 2 If the water balloon did not break, how was this achieved?
- 3 Why does the balloon become more difficult to catch without breaking as the distance increases?
- 4 If the water balloon did break, what adjustments would need to be made to increase the chance of success?
- 5 How can your results be applied to injury prevention in sport?



Claudia Marx/Adobe Stock

## Speed and velocity

### Speed

Speed is used to describe how fast an object is travelling. It is the rate of motion. Because we usually calculate how long it takes to cover a certain distance, it is actually average speed that we are measuring. Average speed can be calculated by dividing the distance covered by the time taken.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$



dpa picture alliance archive/Alamy Stock Photo

**FIGURE 3.27** Light gates make timing sprints easier and more accurate.

## COLLABORATIVE TASK

### Prac activity – data collection

#### Measuring speed

##### EQUIPMENT

- 100-metre track
- stopwatch or timing gates

##### METHOD

- 1 In pairs, have one student time how long it takes their partner to:
  - run 100 metres
  - walk 100 metres.
- 2 Hypothesise as to the effect of manipulating stride length and/or stride frequency on speed. Test your hypothesis over 100 metres.

##### RESULTS

**Calculate** the average speed for each trial (remember, average speed = distance/time).

##### DISCUSSION

- 1 **Explain** why the average speed to complete the two trials in step 1 was different. Use data to support your response.
- 2 From your results, what was the effect of changing the stride length or frequency or both?

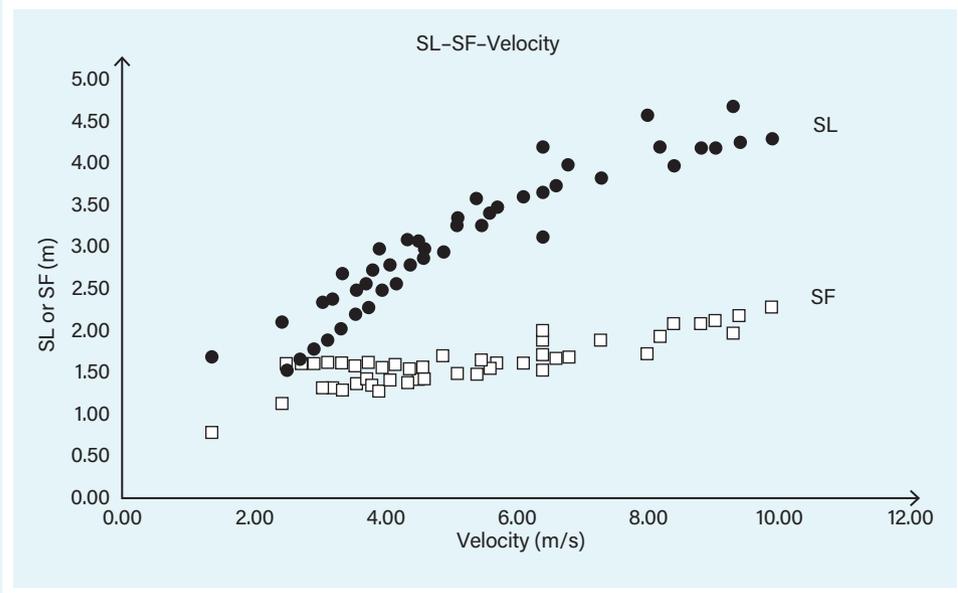


##### Command term

##### calculate

Determine from given facts, figures or information; obtain a numerical answer showing the relevant stages in the working; determine or find (e.g. a number, answer) by using mathematical processes





**FIGURE 3.28** Graph of the relationship between stride length (SL), stride frequency (SF) and velocity

Source: Bailey, J., Mata, T. & Mercer, J.A. (2017), 'Is the relationship between stride length, frequency, and velocity influenced by running on a treadmill or overground?', in *International Journal of Exercise Science*

**Command terms**

**describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

**discuss**

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

- 3 **Describe** the relationship between stride length and stride frequency and speed, as shown in Figure 3.28.
- 4 'Stride length increases as velocity increases across submaximal running velocities. Further increases in velocity towards maximal velocity are achieved by increases in SF while SL plateaus.' Use the data in Figure 3.28 to support or dispute this statement.
- 5 **Discuss** the following statement: 'The optimal ratio of stride length to stride frequency will result in maximal speed.'

**CONCLUSION**

What conclusions can be drawn from the data collected and the analysis of the results?

**LOOKING FORWARD**

**Measuring speed**

**Chapter 10**

In Chapter 10 we will look at the assessment of fitness. There are many tests that are used to measure and athletes speed, covering distances from 10 metres to 50 metres. Specificity is important, and a coach or exercise scientist will select the distance that replicates the distances covered in the sport. The data collected can be used to track progress and inform training program design, and in some instances is used as a selection criterion.

## Velocity

Velocity also describes the rate of motion. Unlike speed, however, velocity is measured in a specific direction. It is calculated by dividing the displacement, or change in position, by the time taken. Velocity has both a size (how fast an object is travelling) and a direction (which way the object is travelling).

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

The terms 'speed' and 'velocity' are often used interchangeably, and in some instances they will be the same. For example, the average speed of a 100-metre sprinter will be the same as their average velocity because the distance travelled is equal to the displacement of the runner. However, if we look at the diagram shown in Figure 3.29, the netball player doesn't travel in a straight line to receive the ball.

The distance they travel to reach the point where they receive the ball is greater than their displacement (how far they are from where they started).

An athlete can have a change in speed by slowing down or speeding up, but a change in velocity could result from a change in speed, a change in direction, or both.

Speed and velocity are both measured in metres per second or m/s.



**FIGURE 3.29** Distance and displacement both measure how far an athlete has travelled, either in total or from their starting point.



## DATA ANALYSIS

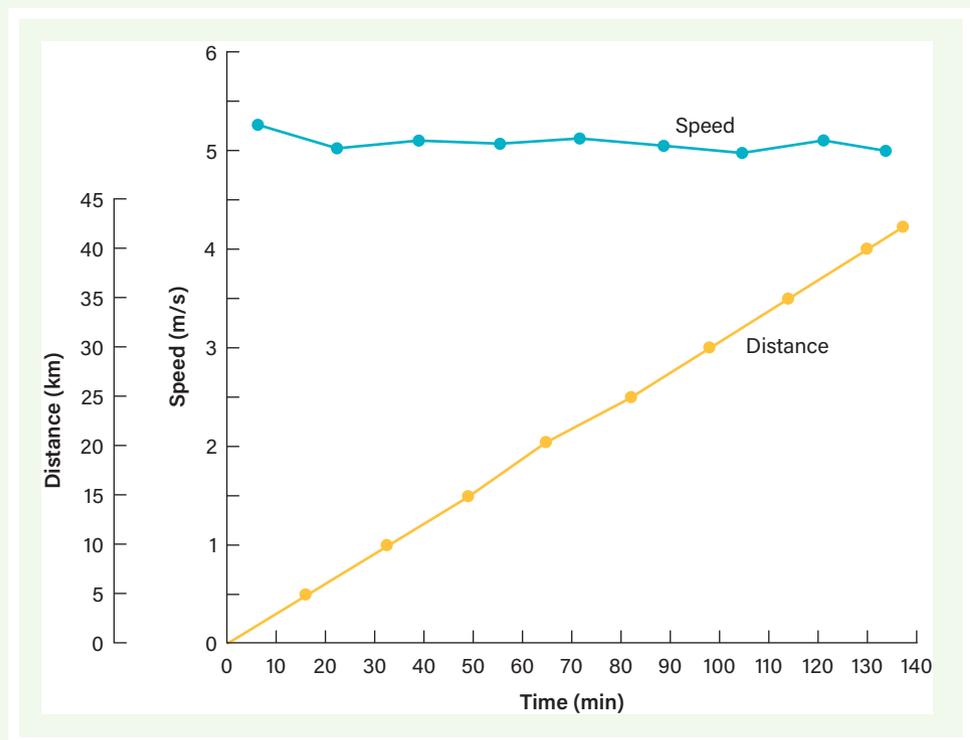
### Marathon

**TABLE 3.02** 5-kilometre split times and average speeds for each split for a female marathon runner

Distance (km)	Time (min:s)	5 km split time (min:s)	Average speed in each 5 km split (m/s)
5	15:47	15:47	5.28
10	32:17	16:30	5.05
15	48:34	16:17	5.12
20	65:55	16:21	5.10
25	81:03	16:08	5.17
30	97:27	16:24	5.08
35	114:07	16:40	5.00
40	130:26	16:19	5.11
42.195*	137:42*	7:16*	5.03*

\*The time for the final 2.195 km of the race was used to calculate the average speed of 5.03 m/s.

- Using the information in the table above, calculate the average speed for the whole race in m/s.
- What was the average speed of the race in km/h?
- What can be said about the running speed of the athlete throughout the race? Use data to support your answer.
- Figure 3.30 shows speed and distance vs time. How could a coach use this data to provide feedback to the athlete on their performance?



**FIGURE 3.30** Graph of speed and distance covered during a marathon

Source: Watkins, J. (ed.), *Fundamental Biomechanics of Sport and Exercise*, 2014, Routledge

## CASE STUDY THE FASTEST MAN ON EARTH

Usain St Leo Bolt was born in Jamaica in 1986. He is 195 centimetres tall, and from the age of 14 he started demonstrating his exceptional speed. Because of his height, Bolt also competed in the high jump and was a promising fast bowler in cricket. He was, however, encouraged to channel his energies on the track, which proved to be a good decision. Bolt's achievements in athletics, specifically the 100 metres, 200 metres and 4 × 100 metres relay, are unrivalled. He has a 'triple triple' – that is, three gold medals at each of three consecutive Olympic Games.

Perhaps most famously, Usain Bolt holds the record for being the fastest man on Earth. Fifteen years after he ran the 100-metre sprint in a world-record time of 9.58 seconds at the IAAF World Championships in 2009, the record still stands.



JOHN MACDOUGALL/AFP/Getty Images

**FIGURE 3.31** Usain Bolt celebrates running 100 metres in the fastest time ever recorded.

Analysis of speed variation during short sprints such as the 100-metre and 200-metre sprints can provide coaches with useful performance information.

Key performance indicators for sprints are:

- time taken to achieve maximum speed
- maximum speed
- length of time that maximum speed is maintained
- difference between maximum speed and speed at the finish.

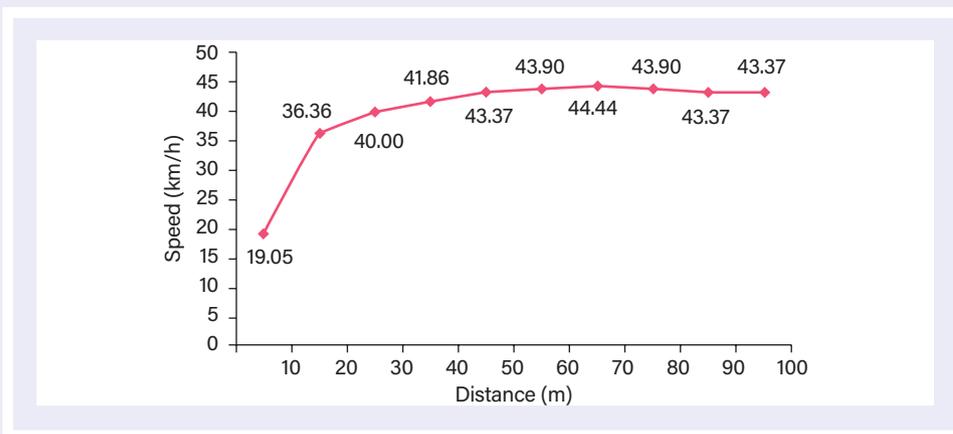
Table 3.03 shows the times for each 10-metre split in Bolt's world-record run. From this data, his average speeds (in kilometres per hour) were calculated and are graphed in Figure 3.31.





**TABLE 3.03** Usain Bolt's split times and speeds in the 100-metre sprint in 2009

Distance (m)	Time (s)	Split time (s)	Speed (m/s)
10	1.89	1.89	5.29
20	2.88	0.99	10.10
30	3.78	0.90	11.11
40	4.64	0.86	11.63
50	5.47	0.83	12.05
60	6.29	0.82	12.20
70	7.10	0.81	12.35
80	7.92	0.82	12.20
90	8.75	0.83	12.05
100	9.58	0.83	12.05



**FIGURE 3.32** Usain Bolt's average speeds in the 100-metre sprint in 2009 graphed against distance

Watch a video of Usain Bolt's world record in the 100 metres at the World Athletics Championships in Berlin, 2009.



**Weblink**  
Usain Bolt's 100 metres world record

**distance**

The path travelled by a body from point A to point B

**displacement**

A change in the position of a body

**speed**

The distance travelled divided by the change in time; the rate of motion or change in position

**velocity**

Speed of an object in a given direction ( $v = d/t$ )

**QUESTIONS**

Use the information in the case study, including the data in Table 3.03 and Figure 3.32, to answer the following questions.

- 1 Explain** why the **distance** and **displacement** of the runner are the same at the end of the race.
- 2** What was Bolt's maximum **speed**? How long did it take him to achieve this speed?
- 3 Calculate** the average speed for the race in m/s. Why is the average speed different from the individual split speeds?
- 4 Define** the term 'constant **velocity**'. Support your answer with data from the table or the graph. Which predictor of performance does this data provide information about?
- 5** What is the difference between Bolt's maximum speed and his final speed? Why is this difference a significant predictor of race performance?

The importance of speed in sports such as running, cycling, skiing, rowing and swimming is pretty clear – the faster the athlete can go, the greater the chance they have of winning the race, as the winner is determined by the fastest time to complete a set distance. But what about in other sports? Does the speed of the ball matter in soccer or hockey? The answer is yes. The faster the ball is travelling towards the goal in these sports, the less time the goalkeeper has to make a decision

and react to stop the goal. In sports such as cricket or baseball, the speed of the bowled ball or pitch determines the time the batter has in which to decide to play a shot, take a swing or leave the ball.

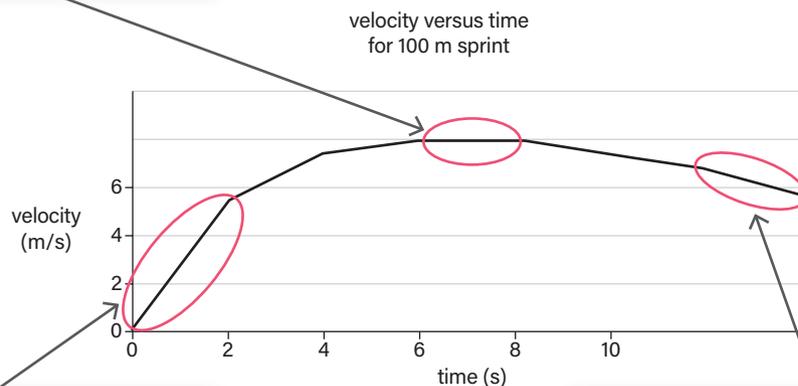
Speed plays an important role in many sports, and coaches and athletes analyse data and use the information to continuously refine movement skills to increase their speed, or the speed of the ball, and improve their performance.

## WORKED EXAMPLE

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A horizontal line on a velocity vs time graph indicates a period of constant velocity.

constant velocity = zero acceleration



A positive gradient on a velocity vs time graph shows a period of positive acceleration (speeding up).

increasing velocity = positive acceleration

A negative gradient on a velocity vs time graph shows a period of negative acceleration (slowing down).

decreasing velocity = negative acceleration

Based on the graph above, which one of the following statements best describes the student's sprint performance?

- A The student ran at a constant velocity for 100 m.
- B The student ran at their maximum velocity for 100 m.
- C The student accelerated positively throughout the sprint.
- D The student accelerated positively until they reached their maximum velocity.

**Response:** D

**Rationale:** A velocity vs time graph can provide information about the athlete's performance. In this example we can see that the athlete:

- accelerated at the start of the race until they reached maximum velocity at 6 seconds
- had a constant velocity between 6 and 8 seconds
- slowed down towards the end of the race (8–14 seconds).

We can also see that the total race time was 14 seconds.

**EXAM TIP:** In multiple-choice questions, if the answer is not obvious at first, use the information provided to eliminate some of the distractors. The three points above allow us to eliminate options A, B and C, leaving the correct answer, D.



**Assessment**  
3.2 Check-in questions

**Command terms**

**demonstrate**

Show ideas, how something can be done or that something is true by using examples or practical applications, or by applying algorithms or formulas

**apply**

Use; employ in a particular situation or context

## 3.2 CHECK-IN QUESTIONS

1 ©VCAA Exam 2021, Section A, Q12

The difference between the initial position and the final position of an object is known as:

- A force.
- B torque.
- C momentum.
- D displacement.

2 Complete the table below.

	Definition	Symbol	Unit
Speed			
Velocity			

3 A weightlifter is holding a 100-kilogram weight above their head. **Identify** the forces acting on the weightlifter. Mark and label the forces in the diagram.

4 In relation to torque, **explain** the importance to a bobsled team of applying the initial force in the direction of motion.

5 **Demonstrate** your understanding of distance and displacement using player movements in a game of rugby.

6 A coach is teaching a young child to throw a cricket ball. They tell the child to step forward with their opposite foot and stand side-on to the target before throwing the ball. **Apply** your understanding of summation of momentum to explain the importance of this feedback to the child.

7 Biomechanically, what is the child in Figure 3.33 trying to achieve by gripping the tennis racquet so far up the handle?

8 Young gymnasts are taught to 'ride your motorbike' on landing. **Explain** the biomechanical principle on which this feedback is based.



**FIGURE 3.33**

## 3.3 NEWTON'S LAWS OF LINEAR MOTION

In this module you will learn about:

- Newton's three laws of linear motion: inertia, acceleration and action–reaction and learn to:
- analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills.

### Newton's laws of motion

Sir Isaac Newton (1643–1727) was a mathematician and scientist. He is most famous for his three laws of motion and his law of gravitation, the basis for understanding mechanics. These laws help us to analyse motion. In this module we will look specifically at Newton's three laws of linear motion as they have many applications to human movement in physical activity, sport and exercise, and can be used to understand and analyse movement skills and techniques.

Newton's three laws of linear motion are the:

- law of inertia
- law of acceleration
- law of action–reaction.

### Newton's first law of motion

The law of **inertia** states:

A body will remain at rest or in uniform motion in a straight line unless acted upon by an external force.

A ball projected into the air would continue travelling in a straight line without gravity. Gravity is the external force that acts to bring the ball back to Earth, creating a parabolic path.

Inertia is the tendency for a body to resist a change in its state of motion, whether that state is at rest or moving with a constant velocity. It is much harder to move or change the motion of an object that has greater inertia, and inertia is directly related to the mass of the object. The greater the mass of an object, the greater its inertia, and the greater the force needed to change its state of motion. If the force applied to an object is not greater than the inertia of the object, there will be no change in the object's motion.

Newton's first law of motion can be seen in many sporting situations. A soccer ball won't move from the position it has been placed in until a player applies a force by kicking it. A tennis ball will continue travelling in the direction of the serve until the player at the other end applies a force and hits it back, changing the direction of motion of the ball.



**FIGURE 3.34** To raise the bar, the lifter must apply a force great enough to overcome the inertia of the weight.



In focus: Newton's laws of motion

#### **inertia**

The tendency for a body to resist a change in its state of motion



## ABOVE AND BEYOND THE STUDY DESIGN

The physics of ski jumping, page 164

## Newton's second law of motion

The law of acceleration states:

A force applied to an object will produce a change in motion (acceleration) in the direction of the applied force that is directly proportional to the size of the force.

The acceleration that occurs is proportional to the force and inversely proportional to the mass of the object. More simply:

- the greater the force, the greater the acceleration
- the greater the mass, the less the acceleration.

Remember that if an object starts to move, speeds up, slows down or changes direction, it is accelerating, and an external force has made this happen!

This law allows us to calculate force and acceleration. Newton's second law can be stated mathematically:

$$F \text{ (force)} = m \text{ (mass)} \times a \text{ (acceleration)}$$

where:

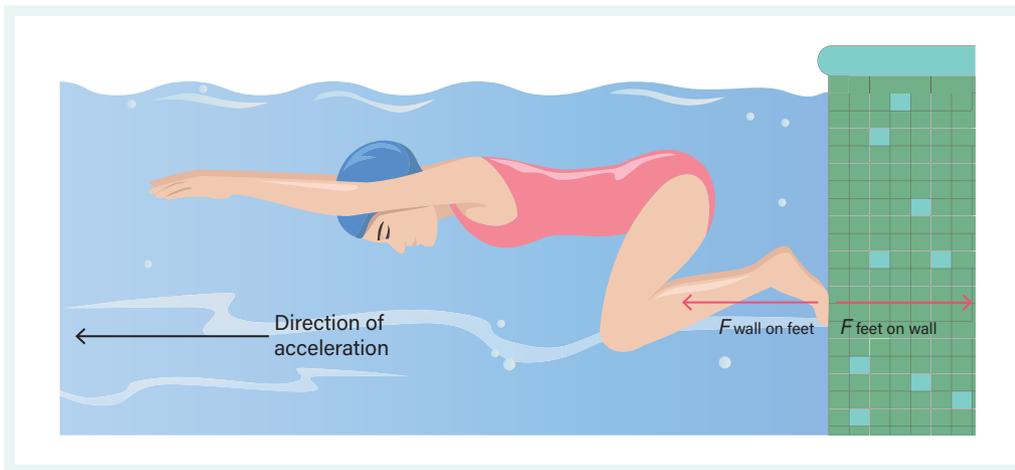
- force is measured in newtons (N)
- mass is measured in kilograms (kg)
- acceleration is measured in metres per second per second ( $\text{m/s}^2$ ).

Applying a greater force can be easily seen in many sporting situations. If we want to throw a ball further, or kick it a longer distance, a greater force needs to be applied. Earlier in the chapter it was stated that the mass of the object in many sporting situations does not change. Consider, however, a game of football (any code) being played in wet conditions. The ball can become waterlogged, making it heavier. The increase in the mass of the ball means that a greater force is required to kick the ball the same distance when compared to a dry ball.

Successful performance in sport isn't always determined by applying maximal force. Skilled performance is often about controlling the amount of force applied. For example, hitting a tennis ball as hard as possible won't necessarily win the point. Skilled athletes judge the force required for accuracy and efficiency in their movements.

Newton's second law allows for quantitative analysis of human movement. If the mass of an object and the force applied are both known, then the resulting acceleration can be calculated. Alternatively, if the mass and the acceleration are known, then the force can be calculated.

It is not always clear that a force has been applied. Sometimes, the only evidence is the resulting acceleration of the object. Let's consider what happens when swimmers turn and push off the wall at the end of a lap.



**FIGURE 3.35** Newton's second law helps to explain how a swimmer accelerates by pushing off the wall.

The swimmer applies a force to the wall and the wall applies an equal and opposite force on the feet of the swimmer (Newton's third law). If the acceleration of the swimmer off the wall is measured, then the force can be calculated using Newton's second law:  $F = ma$ .

Let the swimmer's mass be 70 kg and acceleration equal  $1.5 \text{ m/s}^2$ .

$$\therefore F = 70 \times 1.5 = 105 \text{ N}$$

It is the force that the wall applies to the feet of the swimmer that results in the acceleration.

## WORKED EXAMPLE

### APPLICATION OF NEWTON'S SECOND LAW

©VCAA Exam 2018, Section B, Q10





**a** Identify **two** forces acting on the cyclists in the image on page 133. (2 marks)

The cyclist ahead is accelerating away from the other cyclist.

**Sample response:** *Weight force, friction (ground, drag, air/wind resistance)*

**Rationale:** Force of gravity is acting on the cyclist, which is the weight force ( $W = mg$ ). The road is also applying a force (reaction force) back onto the rider and the bike.

The other force is a frictional force. Technically, the friction between the two contact surfaces of the road and the bike is not on the cyclist, so the other friction forces are between the two contact surfaces of the cyclist and the air. This force is the drag force (air/wind resistance).

A common error made by students was to write 'air' or 'wind'. These are not forces and were not awarded marks.

**b** Use Newton's second law of motion to explain how this is occurring if the net (overall) force acting on both cyclists is the same. (2 marks)

**Sample response:** *Acceleration is equal to the net force divided by mass. For acceleration to be greater when the net force is equal, the mass of the object must be different. Therefore, the rider behind must have a greater mass than the rider at the front.*

**Rationale:** An understanding of the relationship between the three variables in Newton's second law was needed to answer this question. The question stem said that the force acting on both cyclists was the same, but that one had a greater acceleration. Using  $F = ma$ , if the acceleration of the rider at the front is greater but force is the same for both riders, then the mass of the rider at the front must be less than the mass of the rider at the back.

## Newton's third law of motion

The law of action–reaction states:

**For every action there is an equal and opposite reaction.**

When two objects come into contact with one another, they exert forces that are equal in size but opposite in direction on each other.

In many sporting situations, as in the swimming example above, it can be difficult to see the reaction force. When a tennis ball is hit, it is easy to see the force the racquet applies to the ball because the ball changes direction and accelerates. The reaction force of the ball on the racquet is harder to see. This is because the racquet has a greater mass than the ball, and the change in its acceleration is very small.

It is important to remember that even though the two forces are equal in size and opposite in direction, they don't cancel each other out. The forces are acting on different objects, so the effect of each force will be different.

When running, we push down and back with our feet and the surface pushes up and forward (ground reaction force). Running on a track is easier than running on sand, because the sand dissipates the force applied by the foot, reducing the reaction force. If the ground reaction force is lower, then, according to Newton's second law, the acceleration will also be reduced. Running on sand results in lower acceleration, speed and stride length.

It is easier to observe Newton's third law when the surface is almost frictionless. For example, if you stand on a skateboard on a smooth surface holding a medicine ball and throw the ball to a partner (who is not on a skateboard) the action of throwing the ball in one direction will produce a reaction, causing the skateboard to move in the opposite direction.

### 3.3 CHECK-IN QUESTIONS

- List** Newton's three laws of motion and provide a sporting example of each law.
- ©VCAA** Exam 2022, Section A, Q15  
Which one of the following is an example of Newton's second law of motion?
  - when performing a somersault, rotating at the same angular velocity unless an external force acts to change the rotation
  - when performing a long jump, swinging the legs forward, which causes the upper body and arms to rotate forward
  - when performing bicep curls, putting more weight on the dumbbell, which requires more force to lift the dumbbell
  - when performing a throw in netball, the netball not travelling with the same acceleration as a tennis ball when thrown with the same force
- A medicine ball (mass = 10 kilograms) and kettle bell (mass = 5 kilograms) are both on the ground. Which has the greater inertia?
- A Year 7 student at the inter-house athletics carnival picked up the 3-kilogram shot (suitable for the under-13 age group). The student was only 12 and should have competed using the 2-kilogram shot. **Predict** the impact of using the heavier shot on the student's performance and **justify** your response using Newton's second law of motion.
- The goal attack in a netball game shoots for goal. The ball misses and hits the ring before rebounding to the ground and bouncing once, then is caught by the goal defence. **Identify** and describe at least three instances of Newton's third law in this scenario.



**Assessment**  
3.3 Check-in questions

#### Command terms

##### list

Provide a series of related words, names, numbers or items that are arranged consecutively

##### predict

Give an expected result of an upcoming action or event; suggest what may happen based on available information

##### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

## 3.4 PROJECTILE MOTION

In this module you will learn about:

- projectile motion (height, angle and speed of release) and learn to:
- analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills.

### Projectile motion

When an object is thrown or kicked into the air, or when the body leaves the ground, it is considered a projectile. More formally, an object or body that is launched into the air and is affected only by the forces of gravity and air resistance can be considered a **projectile**. In physical activity, sport and exercise there are hundreds of examples of projectiles. In this section, we will look at analysing the motion of these objects and identify how the factors affecting their motion can be manipulated to achieve the optimal outcome.

##### projectile

An airborne body that is only affected by the forces of gravity and air resistance



**FIGURE 3.36** Pole vaulters become projectiles once they have released the pole. The only forces acting on them are gravity and air resistance.

### projectile motion

The movement of an object through the air

**Projectile motion** looks at the factors that influence the flight path of the projectile.

In sport and physical activity, the human body is often a projectile – there are many examples where the aim of the activity is to move through the air. In athletics, diving and gymnastics, athletes must often project themselves into the air and then complete a movement or sequence of movements. Divers use the spring from the diving board, and gymnasts the beat board or mini-tramp, to gain extra height.

There are numerous other examples of projectiles in sport and physical activity. Balls, shuttlecocks, arrows, javelins and discs all act as projectiles when they are thrown, kicked, shot or hit. The goal is often to throw, kick or hit as far or as accurately as possible, to hit a target or pass the ball to another player.

‘What goes up must come down.’ You may have heard this famous quote, which is usually attributed to Sir Isaac Newton. In many sporting situations, this idea has important consequences. Consider a volleyball that has been set high in the air, above net height, ready to be hit by the spiker. At the highest point, the volleyball will, for a fraction of a second, stop moving before it begins to fall back down. For the spike to be successful, the player needs to hit the ball close to its highest point. This provides the greatest height to angle the ball down into the opposition’s court. If the player hits the ball after it has started to fall, it is less likely to be effective and, in the worst case, will be hit into the net.

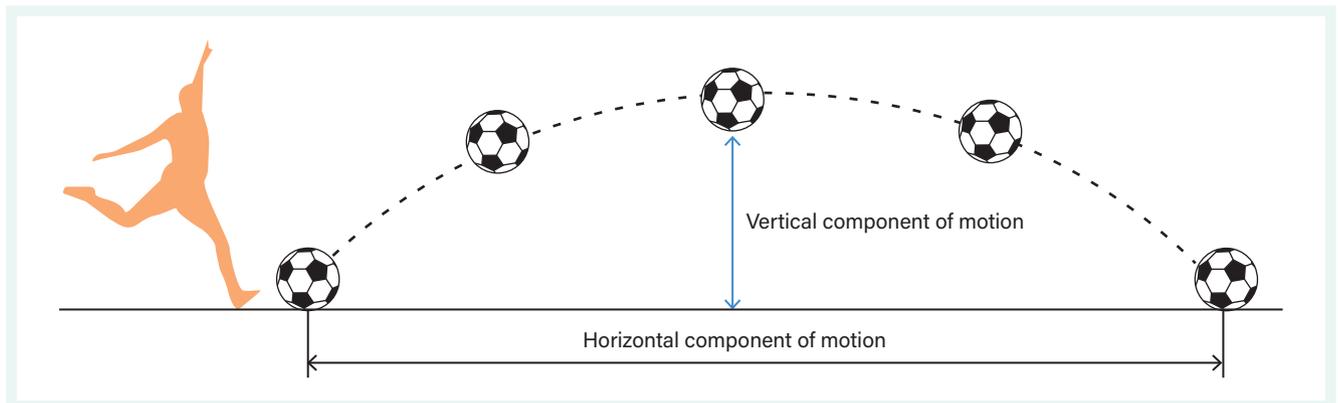
Can you think of other examples where hitting a ball at the top of its flight path is needed for the skill to be successful?



**FIGURE 3.37** Connecting with the ball at the top of its flight path gives the hitter the greatest chance of success.

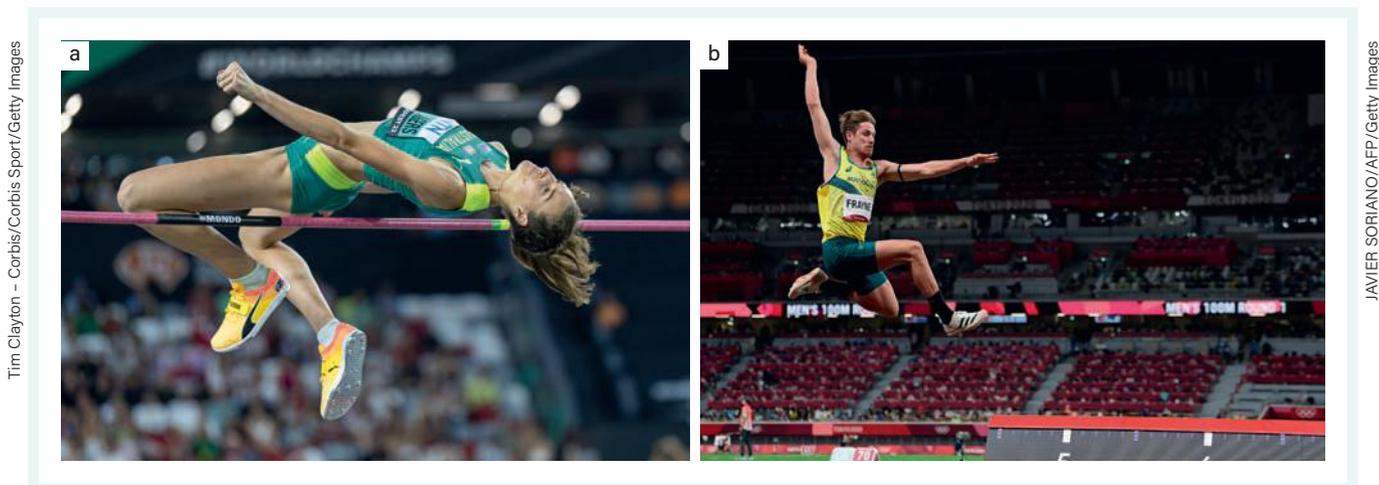
## Vertical and horizontal components

The volleyball player in Figure 3.37 has moved both vertically (they are off the ground) and horizontally (moving toward the net). Projectile motion has a horizontal and a vertical component and follows a parabolic path.



**FIGURE 3.38** Projectiles usually have both a horizontal and a vertical component of motion.

In some instances, maximising the horizontal component of the body or object's motion is important, whereas in other situations, maximising the vertical component of the motion is what matters more.



**FIGURE 3.39 a** Maximising the vertical component of the body's motion aids in completing a successful jump in high jump; **b** for long jump, the horizontal component needs to be maximised.

In events that are judged on accuracy or on a projectile that needs to hit a target, athletes need to manipulate both the vertical and horizontal components of parabolic motion to be successful. For example, an Australian Rules footballer taking a set shot for goal would need to consider the distance to the goals as well as the height required to clear the player on the mark. Netballers often use a lob pass, maximising the vertical component of a pass to get the ball over the head of a defender. To analyse motion biomechanically, it is easiest to break it down into its horizontal and vertical components.

## Vertical component

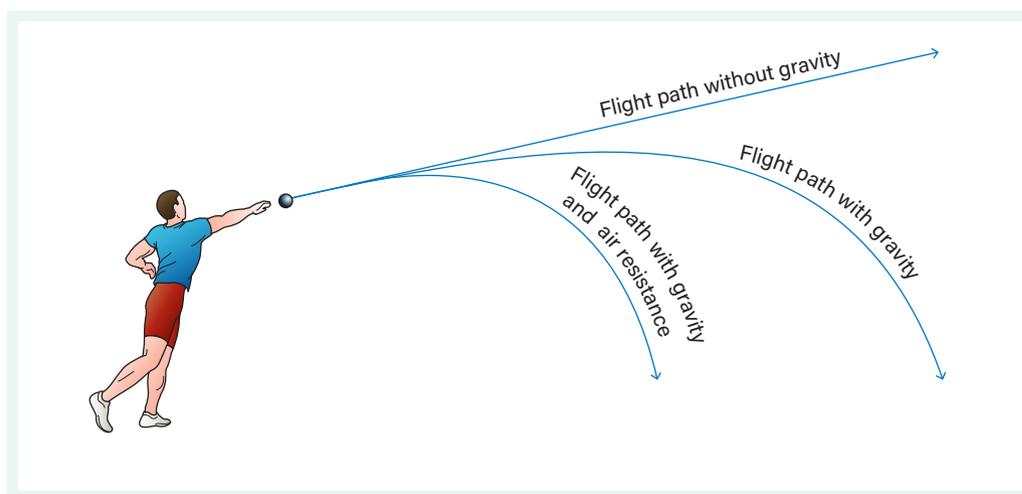
The vertical component of projectile motion is influenced by:

- gravity
- the vertical component of the initial projection velocity.

### DID YOU KNOW?

If you toss a ball in the air, the time taken to reach the highest point is the same time taken to return to its original height – the flight path of a projectile is symmetrical!

Gravity is a force that acts on all bodies close to the Earth's surface, causing objects to accelerate towards the Earth at a rate of  $9.81 \text{ m/s}^2$ . Gravity gives projectiles their parabolic flight path. Acceleration due to gravity is constant for any object, regardless of its size, shape or weight. This means that a medicine ball and a tennis ball dropped from the same height will reach the ground at the same time (ignoring the effects of air resistance).



**FIGURE 3.40** Projectile paths with and without gravity and air resistance

The vertical component of motion relates specifically to the height reached by the projectile. If there were no gravity, a projectile would just keep going, following the same path on which it was projected. The vertical speed of an object decreases as it goes up and then increases as it comes back down. If the object is thrown and caught at the same height, the final speed will be the same as the initial speed.

## Horizontal component

The horizontal component of projectile motion is affected by:

- air resistance
- the horizontal component of the initial projection velocity.

These factors will determine the horizontal distance the projectile covers. Without air resistance, the horizontal velocity of a projectile would remain the same.

Often, when analysing sports and activities quantitatively, air resistance is not taken into account or is considered negligible. If we neglect air resistance, the horizontal speed of the projectile will be constant throughout the motion of the object. In a number of sports, however, air resistance is very important, as it affects the horizontal component of the projectile's velocity and can become an external force that assists the athlete to gain extra horizontal distance or velocity.

## DID YOU KNOW?

For the 100-metre sprint, the maximum allowable tailwind is 2 metres per second. If a sprinter breaks a record with a tailwind greater than this, then the record may not be recognised because it is wind-assisted.

## Factors affecting the path of a projectile

The path of a projectile depends on three factors:

- angle of release
- speed of release
- height of release.

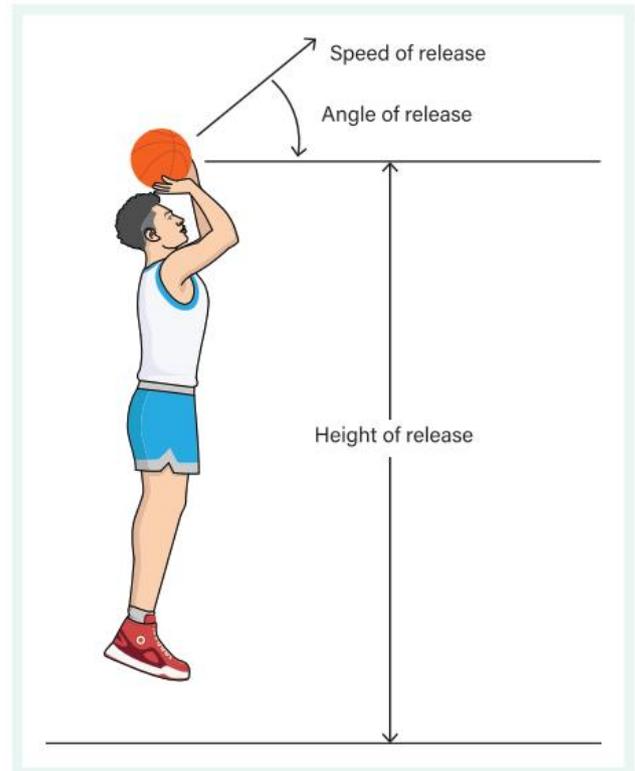
**TABLE 3.04** Factors influencing projectile motion

Variable	Factors of influence
Flight time	<ul style="list-style-type: none"> <li>• Initial vertical velocity</li> <li>• Height of release</li> </ul>
Distance (horizontal)	<ul style="list-style-type: none"> <li>• Horizontal velocity</li> <li>• Height of release</li> </ul>
Distance (vertical)	<ul style="list-style-type: none"> <li>• Initial vertical velocity</li> <li>• Height of release</li> </ul>
Flight path	<ul style="list-style-type: none"> <li>• Initial speed</li> <li>• Angle of release</li> <li>• Height of release</li> </ul>

### Angle of release

The **angle of release** is the angle (with respect to the horizontal) at which an object is projected into the air. This angle will determine the flight path of the projectile. There are three shapes that a flight path can form, depending on the angle of release:

- a vertical shape, where the object goes straight up and comes straight back down again – for example, performing a block in volleyball, where the performer jumps straight up and returns to the ground by the same path (see Figure 3.42 a)
- a parabolic shape, where the angle of release is between 0 and 90 degrees – for example, passing the ball in volleyball, where the ball travels in a parabolic path (see Figure 3.42 b)
- a half-parabola, where the angle of release is 0 degrees, or perfectly horizontal – for example, serving a flat serve in volleyball, where the ball travels in a horizontal trajectory (see Figure 3.42 c).



**FIGURE 3.41** Three factors affect the flight path of a projectile.

#### angle of release

The angle at which a body or object is projected into the air in relation to the horizontal



ESB Professional/Shutterstock.com



DANIEL GARCIA/AFP/Getty Images



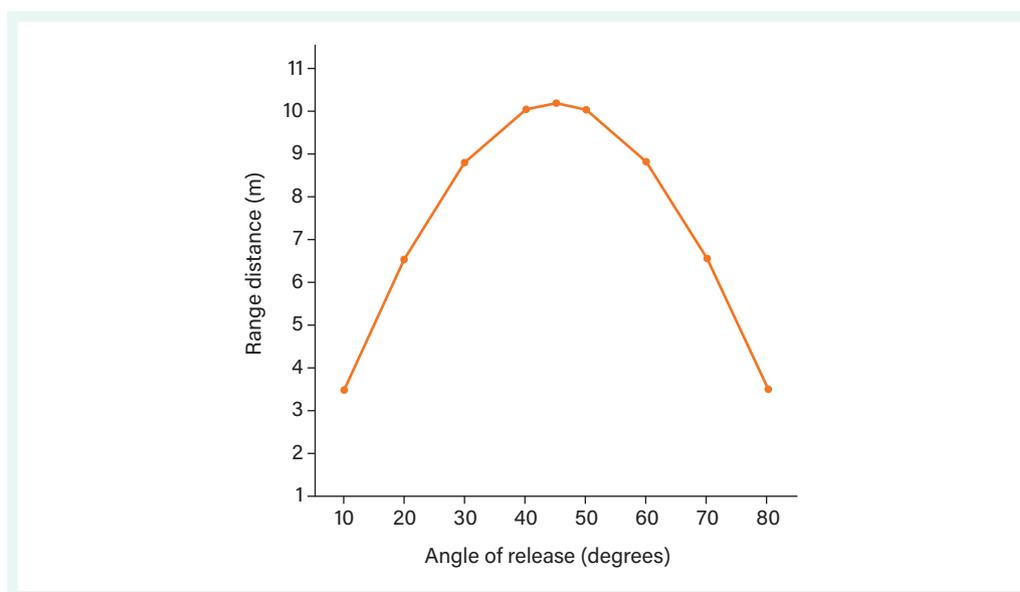
Voyager Images/Alamy Stock Photo

**FIGURE 3.42** a Vertical trajectory; b oblique trajectory; c horizontal trajectory

The angle of release of a projectile affects the horizontal distance it will cover. For any given release speed, where the projectile lands at the same height from which it was released, the best angle of release, to result in the greatest horizontal distance, is 45 degrees. Table 3.05 shows how varying the angle and speed of release changes the distance the projectile will travel.

**TABLE 3.05** The effect of angle of release and speed of release on the horizontal distance a projectile will travel

Angle of release (degrees)	Distance travelled (m) at different projection speeds		
	10 m/s	20 m/s	30 m/s
10	3.49	13.94	31.38
20	6.55	26.21	58.97
30	8.83	35.31	79.45
40	10.04	40.15	90.35
45	10.19	40.77	91.74
50	10.14	40.15	90.35
60	8.83	35.31	79.45
70	6.55	26.21	58.97
80	3.49	13.94	31.38



**FIGURE 3.43** The effect of angle of release on the distance covered by a projectile released at 10 m/s from a constant height

## Speed of release

### speed of release

The speed at which an object is thrown, kicked or propelled into the air

The **speed of release** is the speed at which an object is thrown, kicked or propelled into the air. The release speed of a projectile has both a vertical and a horizontal component.

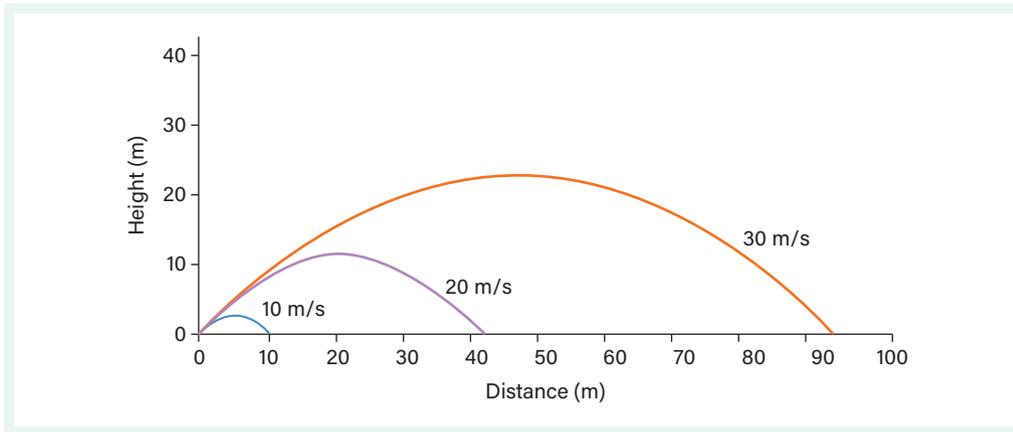
The vertical component of the release speed determines the:

- height reached
- flight time of the projectile

The horizontal component of the release speed determines the:

- horizontal distance the projectile will cover.

The greater the speed of release, the greater the horizontal range of the projectile.



**FIGURE 3.44** The effect of speed on the distance covered by a projectile released at 10, 20 and 30 m/s from a constant angle (45 degrees)

#### relative height of release

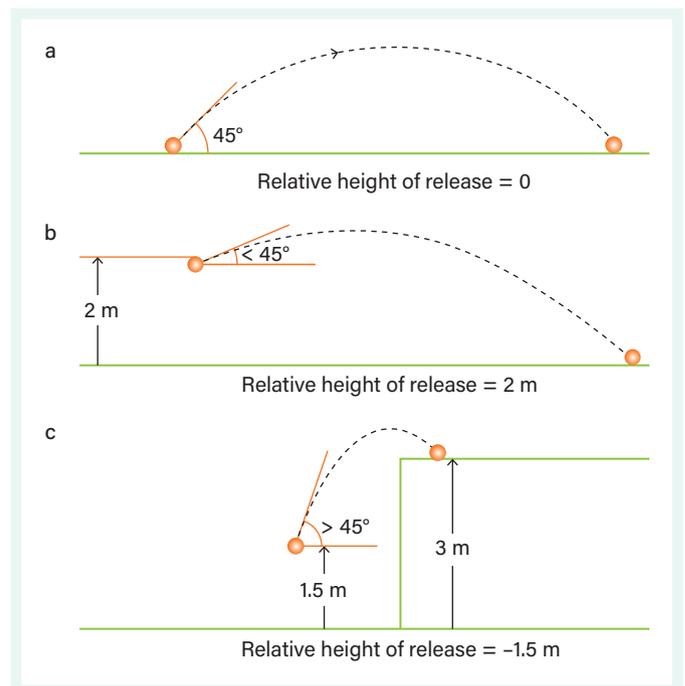
The difference between the height that a projectile is released from and the height at which it lands

## Height of release

The **relative height of release** is the difference between the height from which a projectile is released and the height at which it lands or stops.

When the height of release is zero (see Figure 3.45 a), the projection height equals the landing height and the optimal angle of release is 45 degrees. If the height of release is greater than zero (see Figure 3.45 b), the projection height is greater than the landing height and the optimal angle of release is less than 45 degrees. If the height of release is less than the landing height, the optimal angle of release is greater than 45 degrees (see Figure 3.45 c).

Table 3.06 shows the optimal release angles for different sporting events. The goal of high jump is to gain as much vertical height as possible and therefore a higher projection angle is required. In shot-put, where the height of release is greater than the landing height, the angle of projection decreases to about 36 degrees.



**FIGURE 3.45** The height of release affects the optimal angle of release for a projectile.

**TABLE 3.06** Optimal angle of release for different sporting events

Sport	Optimal angle of release (degrees)
Long jump	15–27
High jump	40–48
Shot-put	36–37
Discus	35–44
Javelin	36–40
Basketball (free throw shooting)	48–52

The optimal angle of release in any sporting situation is always athlete-specific. As a general rule, however:

- To maximise flight time or vertical height reached by a projectile, the angle of release should be greater than 45 degrees.
- To minimise flight time, the angle of release should be less than 45 degrees.
- To maximise horizontal distance of a projectile (speed of release should be increased and a higher release height is beneficial) the angle of release should be slightly below 45 degrees.

### centre of gravity

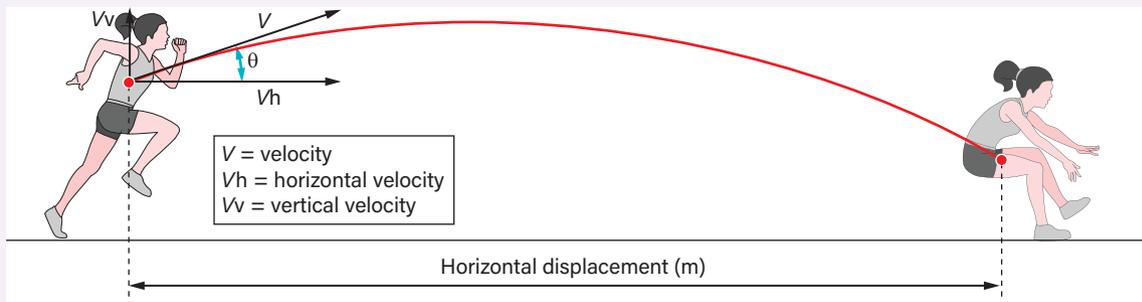
The point at which the whole weight of an object can be considered to act

## REAL WORLD APPLICATIONS

### Optimal angle of release - long jump

An analysis of men's long jump has shown that the theoretical optimal release angle (45 degrees) for maximal horizontal displacement (longest jump) is different from the actual best release angle (15–27 degrees). When we consider the human body to be a projectile, we consider the whole body to be moving in the same path as the **centre of gravity** (you will learn more about centre of gravity in Module 3.5). In long jump, the height of release is determined by the height of the centre of gravity, and the height of the centre of gravity is greater at take-off than on landing (see Figure 3.46).

A long and fast run-up is used to produce lower angles of release. If an athlete were to achieve the predicted optimal angle of 45 degrees, they would need to decrease their take-off velocity by half, which would then decrease the overall horizontal distance achieved in the jump. Through training, athletes optimise their height, leg length, strength and power to achieve the optimal combination of take-off velocity and take-off height. This has resulted in an optimal take-off angle of between 15 and 27 degrees.



**FIGURE 3.46** The height of release in long jump is determined by the height of the athlete's centre of gravity.



Westend61 GmbH/Alamy Stock Photo

**FIGURE 3.47** To maximise horizontal displacement, the optimal angle of release for long jump is between 15 and 27 degrees.

## COLLABORATIVE TASK

## Prac activity - data collection

## Projectile motion

## AIM

To investigate the variables that affect projectile motion

## EQUIPMENT

- garden hose, with nozzle, close to a grassed area
- tap (preferably connected to a water tank)
- large protractor
- measuring tape

## METHOD

- 1 Connect the hose to the tap and turn it on so that the spray lands on the grass.
- 2 With constant water pressure and the hose nozzle at ground level, measure the horizontal distance the water covers when the angle of the nozzle is at 15 degrees, 25 degrees, 45 degrees, 65 degrees and 75 degrees to the ground.
- 3 With constant water pressure, and keeping the angle of release the same, raise the hose nozzle 1 metre off the ground. Measure the horizontal distance covered by the water. Change the height of the hose nozzle to 50 centimetres and 2 metres off the ground.
- 4 Keeping the hose nozzle on the ground at a constant angle of 45 degrees, turn the tap on to vary the water pressure. Measure the horizontal distance covered by the water each time.

## RESULTS

- 1 Record the measurements.
- 2 Graph your results as:
  - distance vs angle of release
  - distance vs height of release
  - distance vs speed of release.

## DISCUSSION

- 1 Draw the flight path of the water in each of steps 2–4.
- 2 What is the relationship demonstrated between each of the variables and the horizontal distance covered?
- 3 How could you increase the vertical component of the projectile's motion? What would be the benefit of increasing the flight time (the vertical component) in activities such as diving, dancing or gymnastics?
- 4 As the coach of a junior baseball team, how could you **apply** the principles of projectile motion to instruct your batters to hit a line drive?
- 5 Select a sport or activity and **identify** when optimal performance would require a change in either angle of projection, height of release and/or projection velocity.
- 6 How could you modify this activity to **investigate** the effect of each of the variables on the vertical displacement of a projectile?



## Command term

**investigate**

Observe, study or carry out an examination in order to establish facts and reach new conclusions

CASE STUDY PROJECTILE MOTION ANALYSIS

### PROJECTILE MOTION

#### Introduction

A projectile is a body in free fall that is subject only to the forces of gravity ( $9.8 \text{ m/s}^2$ ) and air resistance. An object must be dropped from a height, thrown vertically upwards or thrown at an angle to be considered a projectile. The path followed by a projectile is known as a trajectory.

The factors that affect the projectile's trajectory are:

- angle of release
- speed of release
- relative height of release.

The horizontal and vertical components of motion are independent of each other. Horizontal motion of an object has no external forces acting upon it (with the exception of air resistance

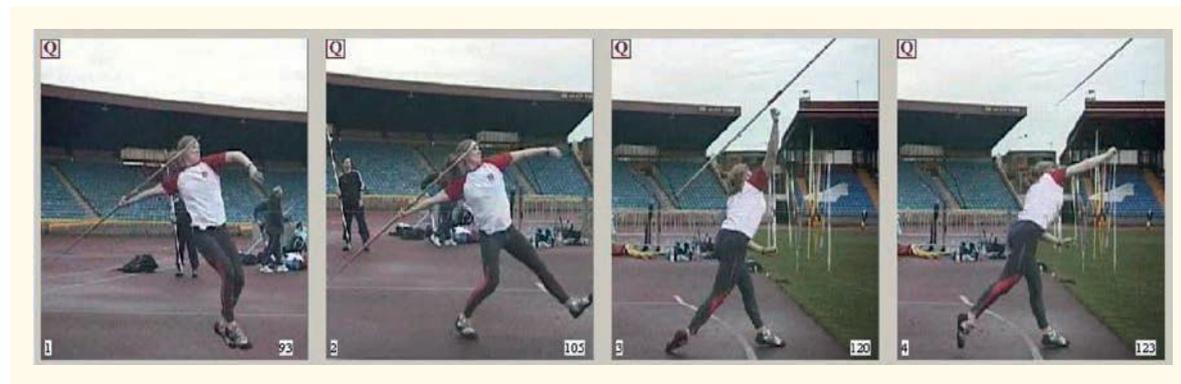
but this is generally not accounted for). Due to this absence of horizontal forces, a projectile remains in motion with a constant horizontal velocity, covering equal distances over equal periods in time. The vertical velocity, however, is reduced by the effect of gravity. Force of gravity acts on the initial vertical velocity of the javelin, reducing the velocity until it equals zero. A vertical velocity of zero represents the apex of the trajectory, meaning that the projectile has reached its maximum height. During the downward flight of the projectile, vertical velocity increases due to the effect of gravity.

Data from five different athletes is shown in Table 3.07.

**TABLE 3.07** Data from five different javelin throws

	Throw 1	Throw 2	Throw 3	Throw 4	Throw 5
Initial velocity (m/s)	21.48	28.13	19.70	22.11	20.87
Angle of release (degrees)	46.55	40.65	45.58	43.41	43.63
Height released (m)	1.80	2.38	1.96	2.02	1.68
Time (s)	3.29	3.86	3.00	3.22	3.05
Distance (m)	48.59	82.37	41.37	51.71	46.09
Maximum height (m)	14.19	19.49	12.05	13.78	12.25

Adapted from Quintic Sports, 'Case study 15: Projectile motion'



**FIGURE 3.48** Throwing technique of throw 3 in Table 3.07

#### Objectives

To compare the projectile motion of different javelin throws

Quintic Sports



**QUESTIONS**

- 1 **State** the three factors that impact on the distance the javelin was thrown.
- 2 Rank the throws from longest to shortest distance thrown.
- 3 Why is the height of release different for each throw? How would you measure height of release for a javelin throw?
- 4 **Explain** the relationships between height of release and distance thrown. Use data to support your explanation.
- 5 With reference to Figure 3.48, **evaluate** the technique of the thrower shown and provide feedback on how they may be able to increase the distance the javelin was thrown.

**Command terms****state**

Give a specific name or value or other brief answer without explanation or calculation

**evaluate**

Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information

**3.4 CHECK-IN QUESTIONS**

- 1 **List** and **explain** the three factors that influence the flight path of a projectile.
- 2 Using the data in Table 3.07, **explain** the relationship between angle of release, speed of release and distance travelled.
- 3 **Identify** three movement situations where different angles of release achieve the desired outcomes.
- 4 When is 45 degrees the optimal angle of projection? Using specific sporting examples, **explain** why 45 degrees is not always the optimal angle of projection.
- 5 In both springboard and platform diving, the height of release is greater than the landing height. **Compare** and **contrast** the way both forms of diving use the factors associated with projectile motion to maximise performance.
- 6 A young basketball player is consistently missing the basket. The ball hits the net, below the basket. Based on your understanding of projectile motion, what feedback would you give the young player to improve their shooting technique?



**Assessment**  
3.4 Check-in questions

**Command terms****compare**

Recognise similarities and differences and the significance of these similarities and differences

**contrast**

Show how things are different or opposite





7 ©VCAA Exam 2022, Section B, Q4 a

The images below show two types of serves in volleyball. Player A is performing a jump serve, tossing the ball up high and forward, and then jumping up and, while still in the air, striking the ball with the heel of their hand. Player B is performing a standing serve, tossing the ball up and then, with both feet on the ground, striking the ball with the heel of their hand.

Contrast how the height of release and the angle of release would help improve player A's serve compared to player B's serve when striking the ball with the heel of the hand. 4 marks

dotishock/Shutterstock.com



Boris Riaposov/Shutterstock.com

## 3.5 EQUILIBRIUM AND HUMAN MOVEMENT

In this module you will learn about:

- equilibrium and human movement: anatomical third-class levers (axis, force, resistance and mechanical advantage) and stability (centre of gravity, base of support and line of gravity) and learn to:
- analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills.

This module will look at how an understanding of the factors that affect equilibrium, stability and balance can be used to improve and refine performance in physical activity, sport and exercise.

The terms equilibrium, balance and stability are often used interchangeably, but in a biomechanical context, the three terms each have different meanings:

- Equilibrium is the state of motion, either rest or constant velocity during movement, where all forces and torques are balanced.
- Stability is a body's ability to resist a change in its current state.
- Balance is the ability to control equilibrium while stationary or moving.



Xinhua News Agency/Xinhua News Agency/Getty Images

**FIGURE 3.49** Skateboarders need exceptional balance to control their equilibrium as they perform different skills.

There are many activities where maintaining balance is important, such as performing a handstand on the beam in gymnastics or holding an arabesque in a floor routine, but many sports also require athletes to maintain their equilibrium while moving. Why is it easier to remain upright on a bike that is moving than on one that is stationary? How do footballers remain upright while dodging and weaving around opponents? Why do swimmers and sprinters crouch low in preparation for the starter's gun? How do snowboarders start moving down the mountain? They all manipulate or control their equilibrium!

## REAL WORLD APPLICATIONS

### Snowboarding

The most difficult aspect of snowboarding is maintaining the correct body balance which is dependent on the directions and magnitudes of external forces and their torques.

Staniszewski, 2019

Snowboarders need to maintain an upright posture when standing and moving, but they also need to disrupt their stability to start moving, to change direction and to come to a stop.



Xavier Laine/Getty Images Sport/Getty Images

**FIGURE 3.50** Snowboarders need to maintain balance while accelerating downhill and changing direction.



**Weblink**  
Australian Olympic Team:  
Snowboard

### DID YOU KNOW?

Snowboarding is a relatively new Winter Olympic sport, debuting in 1998 with the giant slalom and halfpipe competitions. In 2026, there will be 11 medal events, including the mixed team snowboard cross event. Each team has one female and one male competitor. The first male competitor over the line transfers his time advantage to his female teammate, and the women then begin their runs in a staggered format. The first female athlete to pass the line wins the race. To find out more about the Australian Olympic snowboard team, go to the 'Snowboard' page on the Australian Olympic Team website.

# Equilibrium

An object is said to be in **equilibrium** when there are no unbalanced forces or torques acting on it. An object in equilibrium is either motionless or moving with a constant velocity – that is, it is not accelerating.

There are two types of equilibrium:

- static equilibrium
- dynamic equilibrium.

## Static equilibrium

For the body or an object to be in static equilibrium, it must not be moving or rotating – that is, it must be completely motionless. All the forces and torques acting on the body or object must add up to zero:

- The sum of all the vertical forces acting on the body must be zero.
- The sum of all the horizontal forces acting on the body must be zero.
- The sum of all torques must be zero.



**FIGURE 3.51** Each of the athletes shown is in a state of static equilibrium.

## Dynamic equilibrium

When the body or an object is moving with a constant velocity – that is, with no change in speed or direction – it is said to be in dynamic equilibrium.

Examples include a distance runner or cyclist maintaining a constant speed on a straight track.

## Stability and balance

Equilibrium, stability and balance are closely related. **Stability** is the resistance to the disruption of equilibrium, and **balance** is the ability to control equilibrium.

When stability is increased, it is more difficult to unbalance an object; when stability is decreased, it is easier to unbalance the object or body. In some sports, the aim is to increase stability; in others it is beneficial to decrease stability. For example, swimmers use a stance on the blocks that minimises their stability, so that only a small movement is required to initiate the dive into the pool (see Figure 3.51 c). Wrestlers, on the other hand, use positions that increase their stability, making it more difficult for their opponents to disrupt their equilibrium.

Stability and balance are important for good performance in all sports. There are a number of factors that can be applied to enhance equilibrium, maximise the body's stability and therefore achieve balance.

### equilibrium

The state of motion the body is in when all forces and torques are balanced

### stability

The ability of a body to resist a change in its current state of equilibrium

### balance

The ability to control equilibrium while stationary or moving

## REAL WORLD APPLICATIONS

### Balance exercises

Older adults who have reduced balance are at higher risk of having a fall, which can result in serious injury, hospitalisation and even death. Balance exercise training has been shown to be important in allowing older adults to maintain their independence and reduce the risk of falls.

Monash University has developed a Balance Intensity Scale (BIS). The BIS can be used to measure how difficult a balance task is for the exerciser and to monitor the individual's progress in improving their balance.



MONASH  
PRIMARY  
AND ALLIED  
HEALTH CARE

### BALANCE EXERCISE INTENSITY – HOW HARD ARE YOUR BALANCE EXERCISES?

Balance exercise training is especially important as people age to maintain independence and reduce the risk of falls. Current recommendations for adults over the age of 65 is to participate in at least 2 hours per week of balance exercises at a moderate to high level of balance challenge, what we call balance exercise intensity.

#### What you might notice if you are exercising at higher balance training intensity

BEFORE YOU START		WHILE YOU EXERCISE		
				
You pause or hesitate before starting the exercise.	You need help from someone to get into position to start the exercise.	You notice your breathing changes as you do the exercise (rate increases, or hold your breath)	You need to take one or more steps to keep your balance during the exercise	You need to move your arms or grab and hold something to keep your balance during the exercise
				
You need to hold onto something to get into position to start the exercise	You need more than one try to get into position to start your exercise	You feel yourself holding any part of your body stiff or rigid to keep your balance during the exercise	You feel unsteady during the exercise	Someone else needed to help you regain your balance during the exercise

#### How you can rate the intensity of your balance exercises

Use this scale to rate the difficulty of your balance exercises. Choose the number that matches how hard you worked to keep your balance during exercise.

GLOBAL RATING SCALE OF BALANCE EFFORT	1	2	3	4	5
How hard did you have to work to keep your balance during this task? It was ...	No effort at all	A little effort	Some effort	A lot of effort	Maximal effort

Adapted from Open Access article: Farlie, M. K., Keating, J. L., Molloy, E., Bowles, K.-A., Neave, B., Yamin, J., ... Haines, T. P. (2019). The Balance Intensity Scales for Therapists and Exercisers Measure Balance Exercise Intensity in Older Adults: Initial Validation Using Rasch Analysis. *Physical Therapy*, 99(10), 1394-1404. doi:10.1093/ptj/pz2092/5531450. Oxford University Press.



For more information: [monash.edu/medicine/balance-intensity-scale](https://www.monash.edu/medicine/balance-intensity-scale)

**FIGURE 3.52** The Balance Intensity Scale is used to measure balance in older adults.

Adapted with permission from Balance Intensity Scale: How hard are your balance exercises? (2020), <https://www.monash.edu/medicine/balance-intensity-scale>

## Factors affecting stability

A body's ability to maintain equilibrium is affected by:

- base of support
- centre of gravity
- line of gravity
- mass
- friction between the body and the surface or surfaces contacted.

### Base of support

Generally, the larger the base of support, the greater the stability of an object. The base of support is the area bounded by the outside edges of the body parts in contact with the supporting surface. The diagrams below show how different positions of feet and hands can produce different areas for the base of support.



**FIGURE 3.53** **a** Baseball players use a wide stance to maximise stability while hitting. **b** The dancer will make continual minor adjustments to ensure her line of gravity remains inside the base of support to maintain balance while performing an arabesque. **c** Sprinters have four points of contact with the ground to maintain balance while waiting for the start of the race. **d** The gymnast's hands are usually shoulder width apart to provide a reasonable-sized base of support for a handstand.

Increasing the base of support can be as simple as moving your feet further apart. Moving one foot in front of the other increases your stability forwards and backwards. To increase side-to-side stability, move one foot further away from the midline of the body. As the area of the base of support increases, the degree of muscular effort required to maintain stability tends to decrease. Standing on one foot requires much more muscular effort to maintain balance than standing on two feet.

This principle can be applied to enhance sporting performance. Baseball and softball players will stand with one foot well in front of the other when hitting so that they can hit the ball hard without losing their balance.

Athletes will often compromise increased stability in favour of mobility, or mobility for increased stability. A tennis player waiting to receive the ball with an open stance has greater stability than the player who is standing with a staggered stance, but the player with the staggered stance will be able to initiate movement in the direction of the ball more easily. The swimmer on the blocks in Figure 3.51 c and the sprinter in the starting position in Figure 3.53 c are both trying to find the perfect combination of stability and instability!



## COLLABORATIVE TASK

### Activity

#### The four-stage balance test\*

##### AIM

To assess static balance

##### EQUIPMENT

- stopwatch

##### METHOD

There are four standing positions that get progressively harder to maintain (see Table 3.08).

- Try to stand in each position for 10 seconds.
- You can hold your arms out, or move your body to help keep your balance, but don't move your feet.
- For each position the person timing will say, 'Ready, begin!' Then they will start timing. After 10 seconds, they will say, 'Stop.'
- If you can hold a position for 10 seconds without moving your feet or needing support, go on to the next position. If not, *stop* the test.





**TABLE 3.08** The four-stage balance test

	1 Stand with your feet side by side.	Time: _____ seconds
	2 Place the instep of one foot so it is touching the big toe of the other foot.	Time: _____ seconds
	3 Tandem stand: Place one foot in front of the other, heel touching toe.	Time: _____ seconds
	4 Stand on one foot.	Time: _____ seconds

**DISCUSSION**

- 1 Which position was most difficult to maintain?
- 2 How does the position of your feet affect your ability to balance?
- 3 Based on your understanding of balance and stability, **explain** why positions 1–4 become more difficult to hold.

\* The test is intended to be performed on older adults to assess their risk of falls. Not being able to hold position 3 for 10 seconds is an indication of an increased risk of fall.

**Centre of gravity**

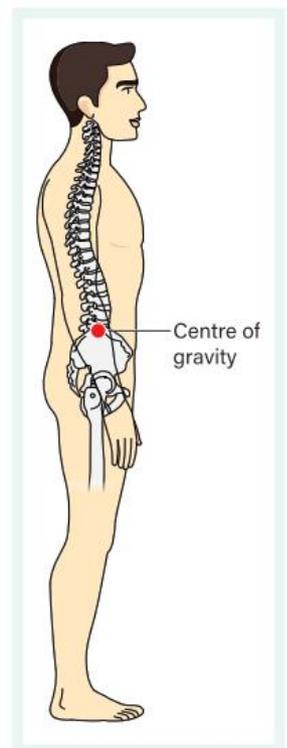
The body's centre of gravity is the point around which its weight is balanced, regardless of the position of the body.

Generally, the centre of gravity in people is found close to the navel (belly button).

The centre of gravity can be raised or lowered depending on the position of the body. Try standing on your toes and compare your stability to when you crouch down low. The higher the centre of gravity, the less stable a body will be, and the lower the centre of gravity, the more balanced and stable it will be (provided the line of gravity falls within the base of support). Flexing the hips, bending the knees and flexing the ankles are ways to lower the centre of gravity. These techniques are often used in sporting situations where the athlete requires greater stability.

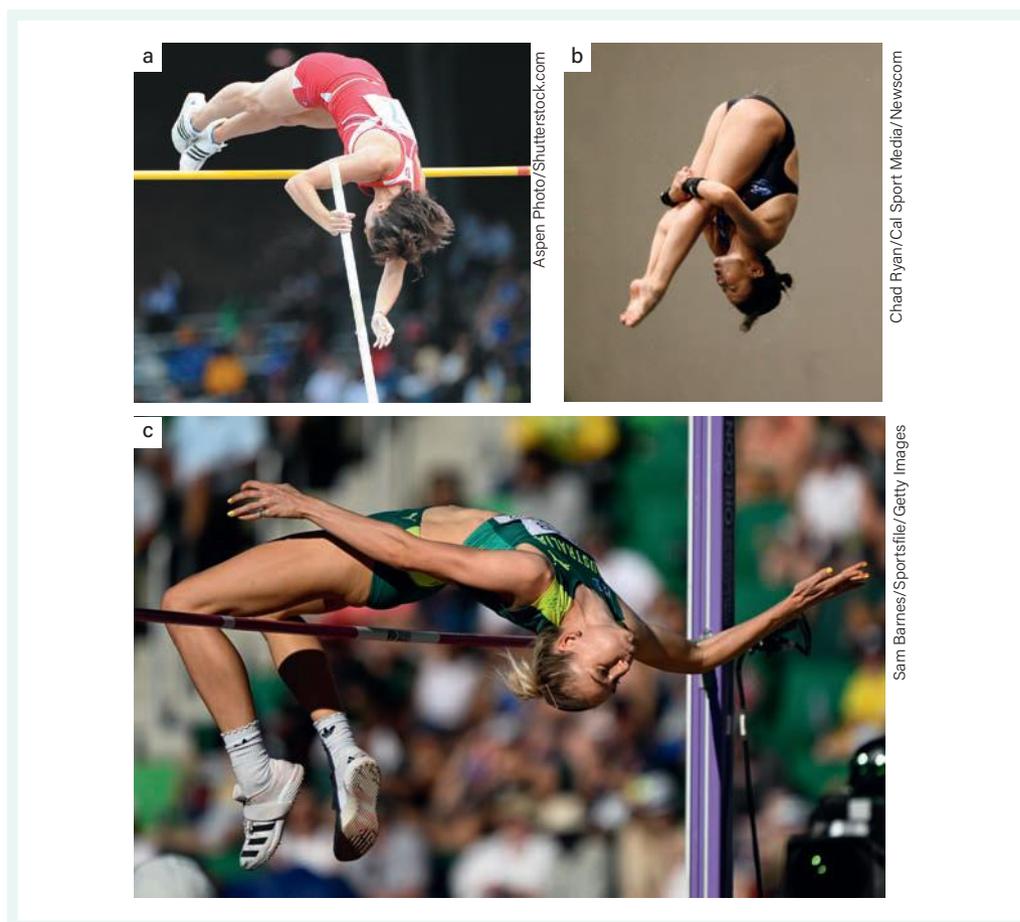
Stability is increased when the centre of gravity is lowered.

Stepping forward and extending both arms out in front, such as when performing a chest pass, moves the centre of gravity to just outside the body; similarly, putting your arms above your head raises your centre of gravity. Pregnant women often find that their balance is affected because, as their body grows to accommodate the baby, their centre of gravity moves towards the outer edge of their base of support.



**FIGURE 3.54** In this position, a person's centre of gravity is at approximately 55–57 per cent of their height.

In some sports, such as pole vaulting and high jump, the most efficient position of the centre of gravity is actually outside the body – often, below the height of the bar.



**FIGURE 3.55** Locate the centre of gravity in each of the images above.



## ABOVE AND BEYOND THE STUDY DESIGN

Locating the centre of gravity in an object or a body, page 165

### Line of gravity

Gravity acts on a body through the centre of gravity. The direction in which gravity acts is called the **line of gravity**. When the line of gravity acts through the centre of the base of support, stability is increased. When it moves towards the outer edge of the base of support, or outside the base of support, stability is disrupted.

Stability is increased when the line of gravity is within the base of support.

Athletes can use this to their advantage. Swimmers position themselves on the starting blocks so that their centre of gravity is close to the front of the base of support (see Figure 3.51 c). This means the swimmer is unstable and can easily accelerate forward into the dive when the starting gun sounds. Sprinters use the same principle to increase their acceleration out of the blocks.

Moving the line of gravity to the edge of the base of support can aid in maintaining equilibrium. Rugby players will lean forward as they move towards an opposition. This moves the line of gravity closer to the oncoming force, meaning it has further to be moved before it moves outside the base of support and stability is disrupted.

#### line of gravity

A theoretical line that passes through the centre of gravity in the direction that gravity acts



Andrew Aylett/Getty Images Sport/Getty Images

**FIGURE 3.56** Rugby players will crouch forwards as they move towards oncoming players, lowering their centre of gravity and moving the line of gravity closer to the front of the base of support.

## COLLABORATIVE TASK

### Prac activity



#### Investigating stability

1 Participate in a yoga class or perform the following exercises:

- Mountain pose
- Chair pose
- Tree pose
- Downward-facing dog pose
- Warrior II pose
- Warrior III pose.



Mountain pose



Chair pose



Tree pose



Downward-facing dog pose



Warrior II pose



Warrior III pose

**FIGURE 3.57** Six yoga poses





- 2 For each pose, record the following:
  - a a diagram (a stick figure is fine!) to represent the base of support, line of gravity and height of centre of gravity
  - b an observation of the stability of the position.
- 3 From your observations, what factors would affect the stability of the human body?
- 4 Provide some practical examples of sports in which athletes change the area of their base of support or the position of their centre of gravity to improve their performance.

## Body mass

The greater the mass of an object or body, the greater the force required to move it, and therefore to disrupt its equilibrium (see pages 132–3 for more about Newton's second law,  $F = ma$ ). If all other factors are equal, the body with the greatest mass will be most stable.

In some sports, such as wrestling, a greater mass and the increased stability that comes with it can be an advantage, but in sports where changes in stability are required to execute the skill, such as gymnastics, lower body mass is more beneficial.

## Friction

Increasing the friction between the body and the surface with which it is in contact increases the person's stability. For example, a surfer waxes their board to increase the friction between their feet and the board, which in turn increases their stability. A golf glove increases the friction between a golfer's hand and the club, reducing the likelihood of the club slipping in their hand. See pages 105–7 for more about friction.

## Enhancing equilibrium, maximising stability and achieving balance

In summary, stability can be maximised by:

- increasing the size of the base of support
- ensuring the line of gravity falls within the base of support
- lowering the centre of gravity
- increasing the mass
- increasing the friction between the body and the surface or surfaces contacted
- extending the base of support in the direction of the oncoming force
- shifting the line of gravity towards the oncoming force.

## Levers

The human body is a system of levers that allow movement to occur.

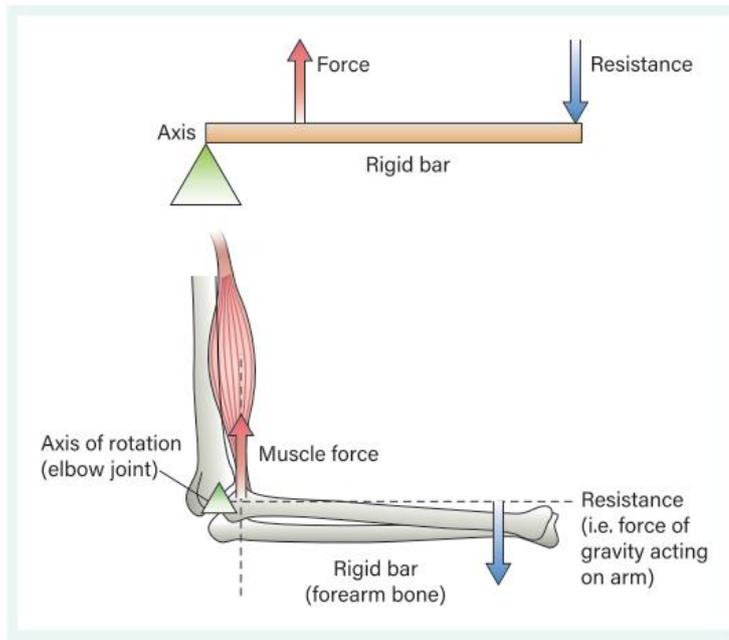
A **lever** is a simple machine consisting of a rigid bar that can be made to rotate around an axis in order to exert a force on another object.

Levers have three parts:

- an axis (or a fulcrum or pivot point)
- a resistance (or a weight or load to be moved)
- a force (or an effort).

### lever

A simple machine consisting of a rigid bar that can be made to rotate around an axis



**FIGURE 3.58** Levers in the human body are called anatomical levers.

## Anatomical levers

In the human body, we refer to levers as anatomical levers, in which the bones represent the rigid bars, the joints are the axis and the muscles contract to apply the force (see Figure 3.58).

Anatomical levers have:

- an axis (a joint)
- a resistance (the body part or weight to be moved)
- a force (applied by a muscle).

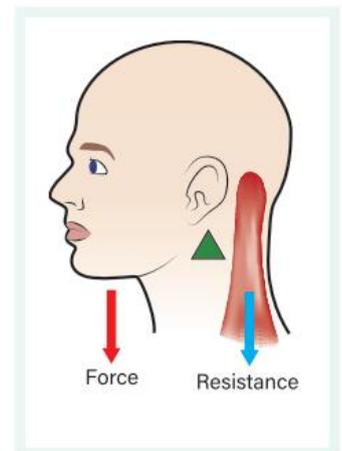
Levers are designed to make jobs easier: to move a resistance or increase the range of motion and speed of the lever itself. The applied force (muscle) acts on the bone to move a resistance. The resistance may be the weight of the body segment itself (e.g. the arm) or an additional load such as a bat or racquet.

## Lever classification

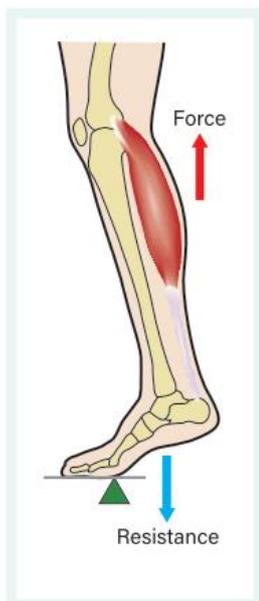
The position of the three components determines the class of lever – first, second or third:

- first-class lever – the resistance and the force are on either side of the axis
- second-class lever – the resistance is between the force and the axis
- third-class lever – the force is between the resistance and the axis.

First-class levers in the human body are not very common. One example is seen in the action of heading a ball in soccer (see page 116). In this example, the muscles in the neck provide the force to lift the weight of the head (resistance) and the joint between the vertebrae and the cranium is the axis.



**FIGURE 3.59** First-class lever



**FIGURE 3.60**  
Second-class lever

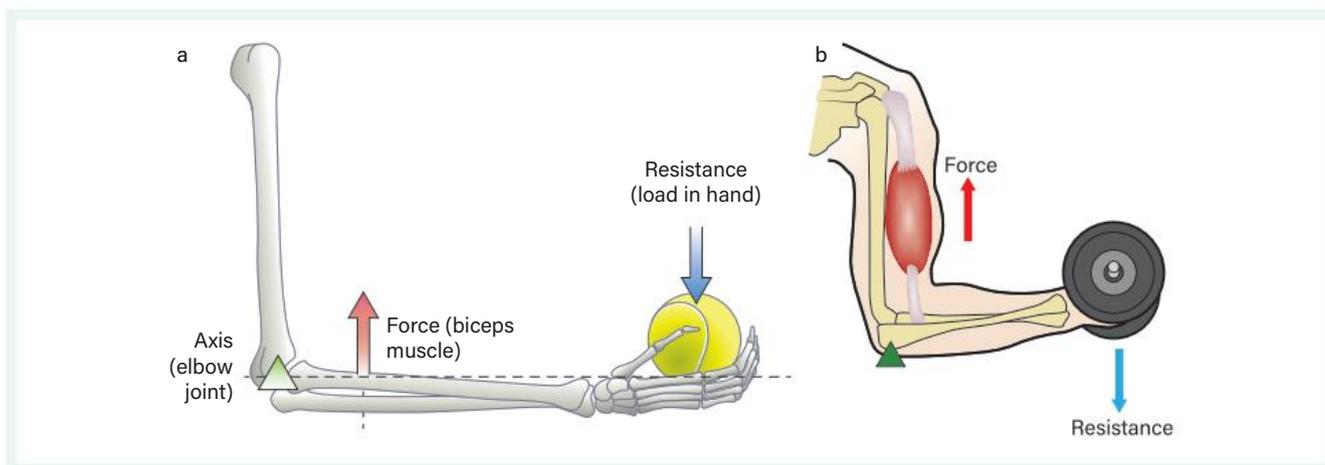
Second-class levers are also not common in the human body because second-class levers are designed to lift heavy loads with relatively less force. For example, when performing a calf raise exercise, the resistance to be moved is the body weight, the force is generated in the gastrocnemius (calf) muscle and the axis is the ankle joint.

The human body is mostly made up of a series of third-class levers, and third-class levers are used to maximise performance in most sporting situations, so we will focus our attention on third-class lever systems.

## Third-class levers

Third-class levers are the most common type of lever, both in the human body and in sporting applications of human movement. In physical activity, sport and exercise situations, the resistance is generally at the end of the lever – for example, the weight to be moved is often a bat, club or ball held in the hand. A simple example is flexion of the elbow. When the elbow is flexed, the axis is the elbow joint, the force is applied by the contracting biceps muscle and the resistance is something being held in the hand, such as a dumbbell or a ball.

The axis of rotation is the joint and the force is applied by the contracting muscle. Notice in the examples in Figure 3.61 that the force is applied where the muscle attaches and pulls on the bone (insertion site), not in the muscle belly. This is important to remember when you need to identify where the force is acting.



**FIGURE 3.61** A third-class lever in the human body

Third-class levers require greater force to move a given resistance, but greater range of motion and speed are gained.

## LOOKING FORWARD

### Generating force

#### Chapter 8

In Chapter 8 you will look at factors that affect muscular strength. The ability of a muscle to generate the force required to move a resistance is affected by the muscle's length, its cross-sectional area, angle of attachment and the velocity of the contraction. A young cricket player may think that a bigger, heavier bat will help them hit the ball for six but, if they're unable to generate the force required to lift the bat, they will be unable to even take a swing at the ball.

# The mechanical advantage of anatomical levers

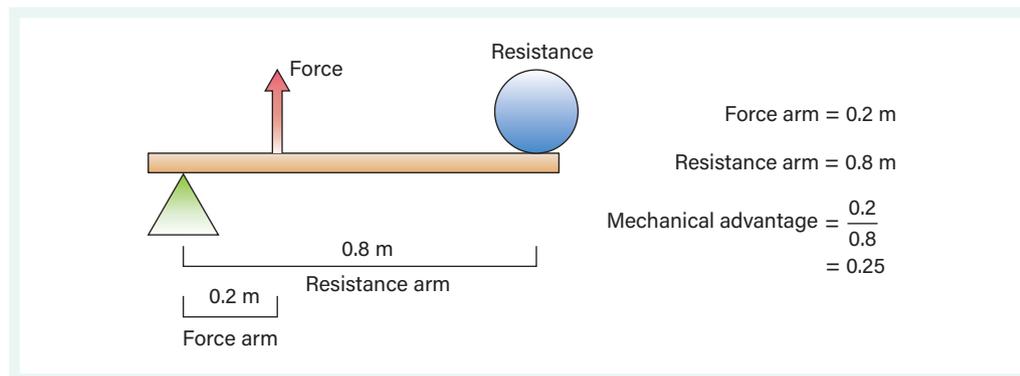
Understanding the role of levers in sport and human movement requires an understanding of the **mechanical advantage** a lever system can have. The mechanical advantage can be calculated by dividing the **force arm** by the **resistance arm**.

$$\text{mechanical advantage} = \frac{\text{force arm}}{\text{resistance arm}}$$

The force arm is the distance from the axis to the force and the resistance arm is the distance from the axis to the resistance.

In the example shown in Figure 3.62, the mechanical advantage ratio is less than 1, which means that a force that is larger than the resistance is required to cause the lever to move. Even though more force is required to move the lever, a small movement near the point of application of the force results in a larger range of motion of the resistance.

Consider the example of the biceps curl shown in Figure 3.61. In the biceps curl, the insertion of the biceps muscle (force) into the radius is very close to the elbow joint (axis). The distance between the two is the force arm. The ball being held in the hand is at a greater distance from the elbow joint. This distance is the resistance arm. In this example, the force arm is shorter than the resistance arm, the mechanical advantage is less than 1 and the lever system is not very efficient – that is, a large force is required to move the relatively small resistance.



**FIGURE 3.62** Force arm and resistance arm of a third-class lever

As the ratio of the force arm to the resistance arm increases, the lever system becomes more efficient and it is easier to move the resistance. In anatomical levers, if the distance between where the muscle inserts to the bone and the joint is greater than the distance between the resistance (the load to be moved) and the joint, then your muscle has the advantage. We see this in the example of the calf raise (see Figure 3.60), and this is why your gastrocnemius can lift the weight of the body relatively easily.

- First-class levers can have a mechanical advantage of 1, greater than 1 or less than 1, depending on the position of the axis.
- Second-class levers always have a mechanical advantage of greater than 1.
- All third-class levers have a mechanical advantage of less than 1.

---

### mechanical advantage

The ratio of the force arm to the resistance arm

---

### force arm

The distance from the axis to the force

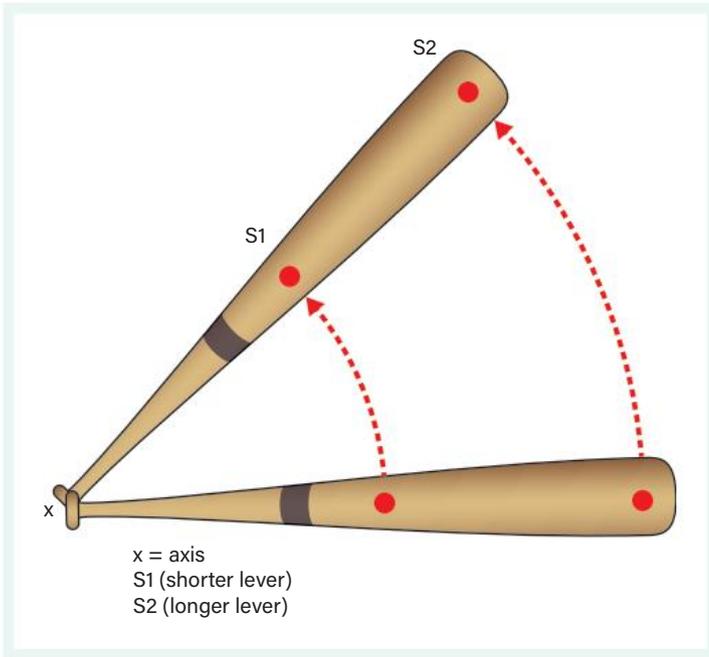
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### resistance arm

The distance from the axis to the resistance

As a series of third-class levers, the lever system in the human body is designed for speed and range of motion, not force production. In the human body is not possible to change the insertion point of muscles, so the force arm length is fixed. What we can do is to lengthen the resistance arm by fully extending the limb when throwing, kicking or striking, and by using equipment such as baseball or cricket bats, golf clubs and hockey or lacrosse sticks, which in turn increases the range of motion and speed of the lever.

Mechanical advantage > 1	Less effort to move a resistance
Mechanical advantage < 1	Increased range of motion Increased angular speed



**FIGURE 3.63** The end of the bat (S2) travels a greater distance than the handle of the bat (S1) in the same time, so it moves at a greater velocity. This principle applies to all sports in which it is possible to increase the lever length with a racquet or bat.

The mechanical advantage provided by levers allows us to move one point of an object a small distance, causing another point of the same object to move a relatively large distance (see Figure 3.63) in the same time, meaning the end of the lever will move with increased speed.

### Lever length

Anatomical levers in the human body are often extended in sporting situations through the use of a racquet, bat or club. This increases the distance from the axis to the resistance, so the resistance arm is longer than the force arm. A greater force is required to swing the club or bat, but the advantage is an increase in the range of motion, resulting in an increase in velocity. The increased velocity translates to the ball being hit or kicked further.

Skilled athletes are able to increase the length of the levers they are using to maximise the velocity of the club or racquet, the hand releasing the ball or the foot kicking the ball, so that the velocity of the hit, kicked or thrown ball is greater.

Figure 3.64 shows an Australian Rules football player kicking a football. Notice that her leg is fully extended to maximise the length of the lever. This in turn imparts a greater velocity to the ball. The same thing can be observed when a tennis player serves the ball; they are at full extension when they connect with the ball.



**FIGURE 3.64** By extending the leg, the lever length is increased.

Russell Freeman/AFL Photos/Getty Images Sport/Getty Images

## COLLABORATIVE TASK

## Prac activity

## Lever length and distance

## AIM

To investigate the effect of lever length on the distance a ball will travel when hit

## EQUIPMENT

- tennis balls
- bat-tennis bats
- tennis racquets
- markers
- measuring tape
- a large outdoor space

## METHOD

- 1 Mark out a starting position from which to complete each trial.
- 2 Hit the tennis ball with your hand, using an underarm forehand action. Measure the distance the ball travels before it reaches the ground. Record your result. Repeat four times.
- 3 Repeat step 2 using the bat-tennis bat and then the tennis racquet.
- 4 Record all your data in a table.
- 5 From your results, calculate the average distance travelled by the ball in each trial: hand, bat tennis bat and tennis racquet.

## DISCUSSION

- 1 Which trial produced the greatest distance?
- 2 **Explain** why longer levers can hit the ball greater distances.
- 3 Golf clubs vary in length. From your findings, **suggest** reasons for the different club lengths used in golf.



## Command term

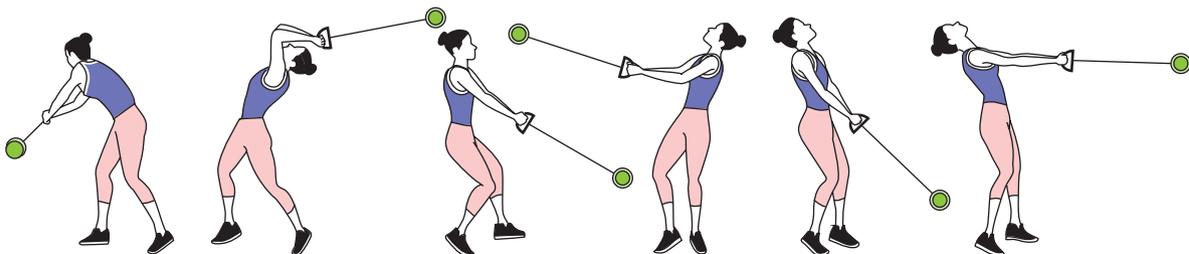
**suggest**

Put forward for consideration a solution, hypothesis, idea or other possible answer

## WORKED EXAMPLE

## LEVERS

©VCAA Exam 2020, Section B, Q2



Based on your understanding of levers, explain why it is important for a hammer thrower to release the hammer with straight arms.





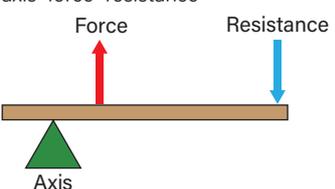
To answer this question fully, three things are needed:

- to identify the class of lever that is shown in the example
- to identify the advantage/benefit of the lever system
- the application to context of the question – in this case, to hammer throwing.

General responses such as ‘Longer levers result in an object travelling further’ would not be awarded full marks. To receive full marks would require a detailed response such as:

*Throwing the hammer uses a third-class lever system. Third-class levers increase the range of motion and speed of the object. By fully extending their arms, the hammer thrower lengthens the resistance arm of the third-class lever. This provides an advantage for speed as there will be a greater velocity at the end of the lever, resulting in the hammer travelling a greater distance than if it was released with bent arms.*

**TABLE 3.09** Summary of third-class levers

Class	Arrangement	Direction of force vs resistance	Functional design	Mechanical advantage	Sporting example	Human body example
Third	axis–force–resistance 	Resistance and force applied in opposite directions	Speed and range of motion (requires large force to move a relatively small resistance)	Always < 1	Hitting a ball	Flexing the elbow

## REAL WORLD APPLICATIONS

### Levers in tennis

Australian tennis player Sam Groth still holds the record for the fastest recorded serve in men’s tennis with a top speed of 263.4 km/h, recorded in 2012. Groth used his height to his advantage when serving. He is tall – 193 centimetres – and his height is reflected in the length of his anatomical levers. His big serve demonstrates the advantage of longer levers in generating velocity.

Elite players can extend the length of the lever, not only with the racquet and by connecting with the ball with their arm fully extended, but also by making their spine the axis of rotation by rotating their body. This extends the length of the anatomical lever that is imparting the force.



**FIGURE 3.65** Long levers assist with increasing the speed of the tennis player's serve.

PA Images/Alamy Stock Photo

### 3.5 CHECK-IN QUESTIONS

- 1 **Define** 'equilibrium', 'balance' and 'stability'.
- 2 **a** Give two examples from different sporting situations of an athlete in a state of static equilibrium.
  - b** Provide two sporting examples where dynamic equilibrium can be observed.
- 3 **List** four sporting examples where contact surfaces are manipulated to either increase or decrease an athlete's stability.
- 4 **List** the four factors that can affect stability. **Explain** the effect each has on the stability of an object.
- 5 Draw and label a third-class lever system.
- 6 **a** **Analyse** the image below and provide feedback to the athlete on the body position needed to maintain their balance on the beam.



Kiyoshi Ota/Getty Images Sport/Getty Images

- b** **Explain** how a gymnast can be balanced but also have low stability.
- 7 Throwing an overhand pass in netball is an example of a third-class lever in the human body. Young players often throw with a bent elbow. Based on your understanding of the mechanical advantage of a third-class lever, provide feedback a coach could use to increase the distance the young player can throw the ball.
- 8 A lacrosse coach provides the following feedback to a player: 'Slide your top hand down the stick when you prepare to shoot.' Based on your understanding of levers, **explain** why the coach provided this advice.



**Assessment**  
3.5 Check-in questions

#### Command term

##### define

Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity

**LEARNING HACK**

When answering questions related to biomechanics, it is okay to use scientific symbols. Table 3.10 is a summary of the terms you have learnt throughout this chapter, their symbols and their units of measurement.

**TABLE 3.10** Units of measurement used in biomechanics

Term	Symbol	Unit	Unit abbreviation
Acceleration	$a$	metres per second per second	$m/s^2$
Angle ( of release)	$\theta$	degrees	$^\circ$
Force	$F$	newtons	N
Impulse	$I$	newton seconds	Ns
Mass	$m$	kilograms	kg
Momentum	$p$	kilogram metres per second	kg·m/s
Speed/Velocity	$v$	metres per second	m/s
Time	$t$	seconds	s
Torque	$T$	newton metres	Nm
Weight	$W$	newtons	N



**ABOVE  
AND  
BEYOND  
THE STUDY  
DESIGN**

MODULE 3.3, PAGE 132

## The physics of ski jumping

Ski jumping involves the athlete starting their motion at the top of a very steep ramp. At this point, the skier has gravitational potential energy (mass  $\times$  gravity  $\times$  height) and as they travel down the ramp this energy is converted to kinetic energy ( $\frac{1}{2} \times$  mass  $\times$  velocity squared) or the energy of motion. At take-off, ski jumpers streamline their body position to minimise the effect of the drag force (air resistance) while trying to maximise lift force. The 'V formation' shown in Figure 3.66 increases the lift force, counteracting the force of gravity and increasing the time the skier is in the air and, therefore, the horizontal distance they travel. However, there is not much the skier can do to counteract the force of gravity and air resistance, and it is these forces that will slow them down and bring them back to Earth.



Alamy Stock Photo/Split Seconds

**FIGURE 3.66** The 'V' formation of the skis increases the skier's flight time, resulting in greater horizontal distance travelled.

## Locating the centre of gravity in an object or a body

The centre of gravity of a perfectly symmetrical object (e.g. a solid rubber ball) that has constant density and mass and uniform weight distribution will be in the exact centre. However, very few objects are like this. When the mass distribution in the object is not constant, the centre of gravity will shift in the direction of greater mass. For example, a baseball bat has greater distribution of mass towards the end away from the handle, so the centre of gravity is closer to that end. The centre of gravity of a golf club is close to the club head and slightly outside the shaft because of the weight distribution in the head of the club. You can locate the centre of gravity of a golf club or baseball bat by balancing the club or bat on your finger and finding the point where it will balance.

Biomechanists are interested in finding a body's centre of gravity because the human body behaves as though all its mass is concentrated at that point. Finding the centre of gravity of the human body is much more difficult than finding the centre of gravity of an object. This is because the body has many moving parts and also because of the different densities of muscle, bone, fat and other body tissues, which are not equally distributed throughout the body. There are different methods that can be used to determine a person's centre of gravity. For example, a reaction board can be used and the sum of the torques acting on the body can be calculated to find the centre of gravity. The segmentation method involves looking at each segment of the body through film images, determining the centre of gravity of each segment using  $x$ - and  $y$ -coordinates, and then adding all the centres of gravity and dividing the result by the total body mass to find the coordinates of the total body's centre of gravity. This calculation is done using a digitised image and a computer program.

# CHAPTER SUMMARY



## Resource

Self-assessment checklist

## Video

Masterclass: Chapter 3

### 3.1 Biomechanical analysis of human movement

In Module 3.1 we looked at biomechanical principles for analysis of human movement, which include:

- linear and angular concepts of human movement including force/torque, momentum, impulse, speed/velocity
- Newton's three laws of linear motion: inertia, acceleration and action-reaction
- projectile motion (height, angle and speed of release)
- equilibrium and human movement: anatomical third-class levers (axis, force, resistance and mechanical advantage) and stability (centre of gravity, base of support and line of gravity).

### 3.2 Linear and angular concepts of human movement

In Module 3.2 we looked at linear and angular concepts of human movement, including force/torque, momentum, impulse, speed and velocity. These biomechanical principles help us to analyse and understand human movement to improve performance in physical activity, sport and exercise.

In summary:

- A force is a push or pull that produces motion or changes the motion of an object.
- Forces in the body are generated by muscles. External forces that affect motion of the body are gravity, air and water resistance, friction and reaction forces.
- Friction is a force that occurs between two surfaces that are in contact with each other. Friction always opposes the motion of an object and can be increased or decreased depending on the desired outcome.
- Torque is the turning effect of the force that has been applied. It is the product of force and the lever arm.
- Angular velocity measures how fast an object or body is spinning, rotating or twisting. Angular velocity increases when the radius of rotation decreases – for example, in a tuck position compared to a layout position.
- The relationship between linear and angular velocity is important in physical activity, sport and exercise as the speed with which a ball travels or the distance it travels is often important to the outcome of the activity.
- Increasing the radius of rotation will increase linear velocity. The most practical way to do this is to increase the length of the implement.
- Mass is the amount of matter an object is made up of.
- Weight is a force exerted on the body by gravity.  $\text{Weight} = \text{mass} \times \text{gravity}$ .
- Momentum is equal to  $\text{mass} \times \text{velocity}$ . The greater the mass or velocity, the more momentum a body has and the harder it is to stop.
- Momentum is conserved when objects collide.
- Angular momentum of an object remains constant unless it is acted on by an external torque. An increase in moment of inertia results in a decrease in angular velocity and a decrease in moment of inertia results in an increase in angular velocity.
- Summation of momentum is the transfer of momentum from the larger, slower-moving body parts to the smaller, faster-moving body parts to maximise the release velocity of the object.

- Impulse is equal to a change in the momentum of an object. Impulse equals the force applied  $\times$  the time over which it is applied.
- Distance and displacement are measures of how far an object or a body has travelled. Both measurements are recorded in metres.
- Speed and velocity measure how fast an object is travelling. Velocity identifies the direction as well as the speed of motion.

### 3.3 Newton's laws of linear motion

In Module 3.3 we looked at Newton's three laws of linear motion: inertia, acceleration and action–reaction. Newton's laws help us to analyse and understand human movement to improve performance in physical activity, sport and exercise.

In summary:

- Newton's first law of motion states that a body will remain at rest or continue in a state of constant motion unless acted upon by an external force.
- Newton's second law of motion states that a force applied to an object will produce a change in motion (acceleration) in the direction of the applied force that is directly proportional to the size of the force.
- Newton's third law of motion states that for every action there is an equal and opposite reaction.
- Acceleration is a measure of how quickly an object or body changes its velocity. Acceleration can be positive (when velocity is increasing), negative (when velocity is decreasing) or zero (this occurs when velocity is constant).
- Inertia is the tendency of a body to resist change in its state of motion. An object requires a force to start it moving and another force to stop it once it is moving. Inertia is related to mass. The greater the mass, the greater the inertia of the object.

### 3.4 Projectile motion

In Module 3.4 we looked at the principles of projectile motion to analyse and understand human movement to improve performance in physical activity, sport and exercise.

In summary:

- Any object or body that is propelled into the air can be considered a projectile.
- Projectiles have both a vertical and a horizontal component to their motion.
- Air resistance and gravity are the only forces affecting projectiles, and often the effect of air resistance is negligible.
- The flight path of a projectile depends on:
  - speed of release
  - height of release
  - angle of release.
- The optimal angle of release for the greatest horizontal distance a projectile can travel is 45 degrees, when the height of release is zero.
- When the height of release is greater than zero (above the landing height) the optimal angle of projection is less than 45 degrees.
- When the height of release is less than zero (below the landing height), the optimal angle of projection is more than 45 degrees.

### 3.5 Equilibrium and human movement

In Module 3.5 we looked at the principles of equilibrium to analyse and understand human movement to improve performance in physical activity, sport and exercise.

In summary:

- Equilibrium is a state of motion where there are no unbalanced forces or torques acting on the body. Equilibrium can be static or dynamic.
- Balance is the ability to maintain and control the equilibrium of the body in different situations.
- Stability is the body's ability to resist any changes or disruptions to its state of equilibrium. Stability is affected by mass, friction, base of support and centre of gravity.
- Levers consist of an axis, a force and a resistance. The positioning of each of these factors determines the mechanical advantage the lever will have.
- The human body is made up mainly of third-class levers. They are designed to increase the range of motion and speed of an object.
- Third-class levers have the force between the resistance and the axis.
- The mechanical advantage determines the role of a lever. Third-class levers have a longer resistance arm and therefore have a mechanical advantage less than 1, resulting in an increase in the range of motion and speed of the lever.
- Longer levers have greater inertia and therefore are more difficult to swing. Junior sporting equipment is often modified to overcome this difficulty.

## CHAPTER REVIEW



Assessment  
Chapter 3 Review

- 1 After taking a catch, a cricketer throws the ball straight up in the air in celebration. Describe the motion of a ball, from when it leaves the cricketer's hand until it returns to their hands, using the terms:
  - distance
  - displacement
  - velocity
  - acceleration.
- 2 An 18-year-old draftee was told he needed to 'put on some muscle' so that he could compete at the elite AFL level.
  - a What is the difference between mass and weight?
  - b How could the player improve his performance on the field by increasing his mass?
- 3 A soccer coach tells their striker to 'chip' the ball in order to clear the wall and go into the goal. How is the angle of release different for this free kick compared with a penalty shot, where there are no obstacles between the player and the goal (other than the goalkeeper)?
- 4 In sports such as pole vault, high jump and long jump, the landing surface is different from the surface the athlete takes off from. **Explain** why mats and sand are used as landing surfaces in these sports.

- 5 The coach of a junior tennis player provides the following feedback: 'As you release the ball, bend your knees.' Based on your understanding of base of stability and conservation of momentum, **explain** the importance of this feedback for increasing the linear velocity of the ball when served.
- 6 **Analyse** the data in the table below to answer the following questions.

Ball	Fastest speed (m/s)
Golf ball	91
Tennis ball	70
Hockey puck (ice)	50
Hockey ball (field)	35
Water polo ball	27

Is there a relationship between the speed a ball travels and the size of the space in which the game is played? **Justify** your response.

- 7 Two riders, Justin and Mike, are riding up Mount Buller. Justin decides to take the road, which is a series of twists and turns, Mike rides a mountain bike up a steep, but direct, straight-line path to the top of the mountain. The riders leave the base of the mountain at the same time and arrive at the top at the same time.
- Who travelled the greater distance?
  - Who had the greater displacement?
  - Explain** how Justin had a faster average speed but both riders had the same average velocity.
- 8 Ruby is learning to surf. The instructor tells her to 'stay low' once she has popped up to her feet. How will this feedback improve Ruby's chance of successfully riding the wave without falling off the board? What other feedback could the instructor provide to help Ruby with her balance?
- 9 Based on your understanding of the relevant biomechanical principles covered in this chapter, **compare** the game of field hockey with ice hockey.
- 10 A young high jumper is trying to increase the height they clear. They have been working on their run-up and trying to increase their run-up speed. **Assess** the suitability of this approach for increasing the height jumped.

### Command terms

#### analyse

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

#### assess

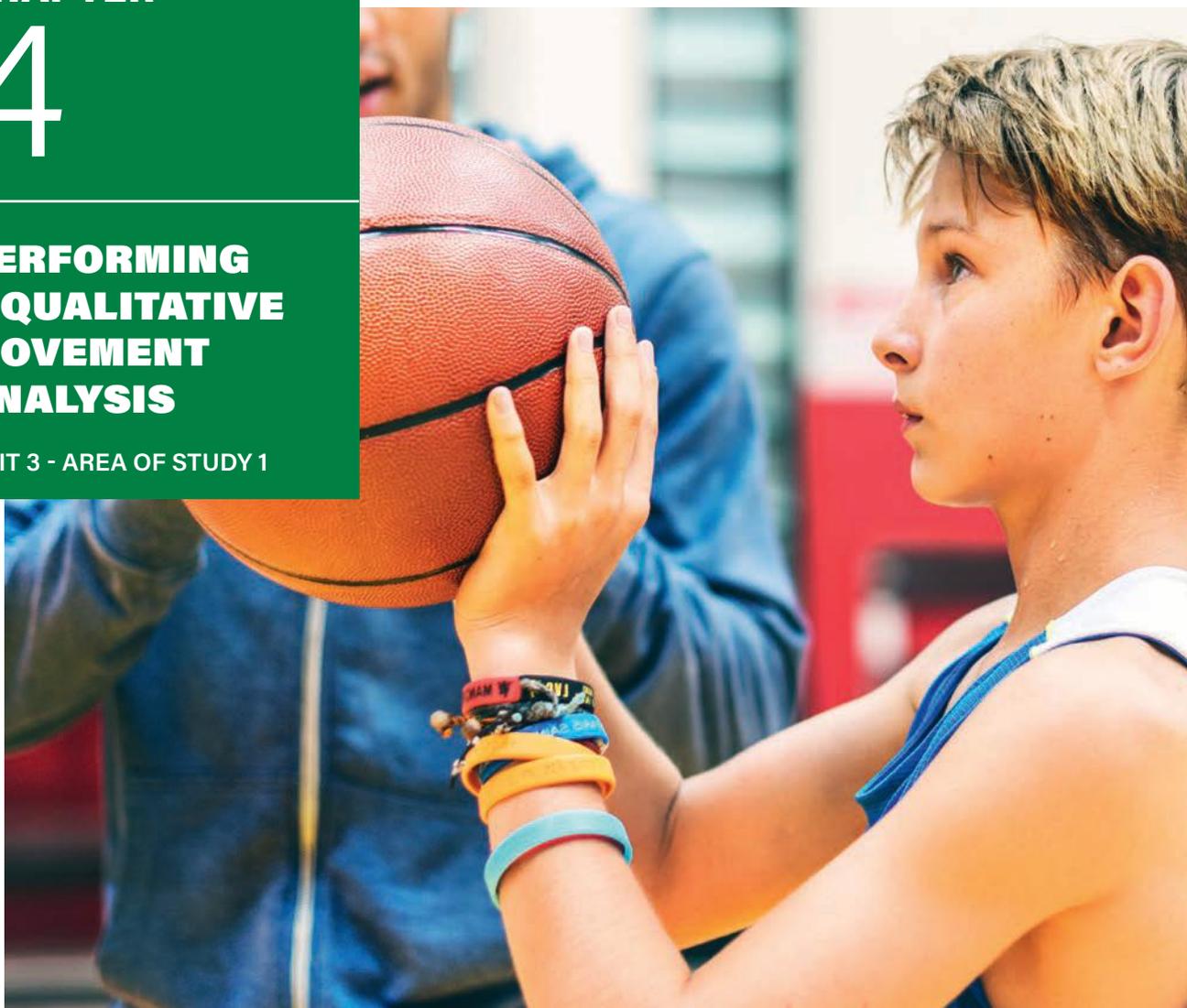
Make a judgment about, or measure, determine or estimate, the value, quality, outcomes, results, size, significant, nature or extent of something

## CHAPTER

# 4

## PERFORMING A QUALITATIVE MOVEMENT ANALYSIS

UNIT 3 - AREA OF STUDY 1



Rawpixel.com/Adobe Stock

**FIGURE 4.01** Once feedback has been implemented, those aspects of performance that need further refinement can be reassessed.

### Quizzes

Chapter 4 Pulse check

- 4.1 Check-in questions
- 4.2 Check-in questions
- 4.3 Check-in questions
- 4.4 Check-in questions
- 4.5 Check-in questions

Chapter 4 Review

### Videos

Masterclass: Chapter 4

- 4.2 In focus: Breaking a baseball pitch down into its sub-routines
- 4.4 In focus: Performing a QMA

### Resources

- 4.5 Template: Skill observation and feedback for improvement

Chapter 4 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



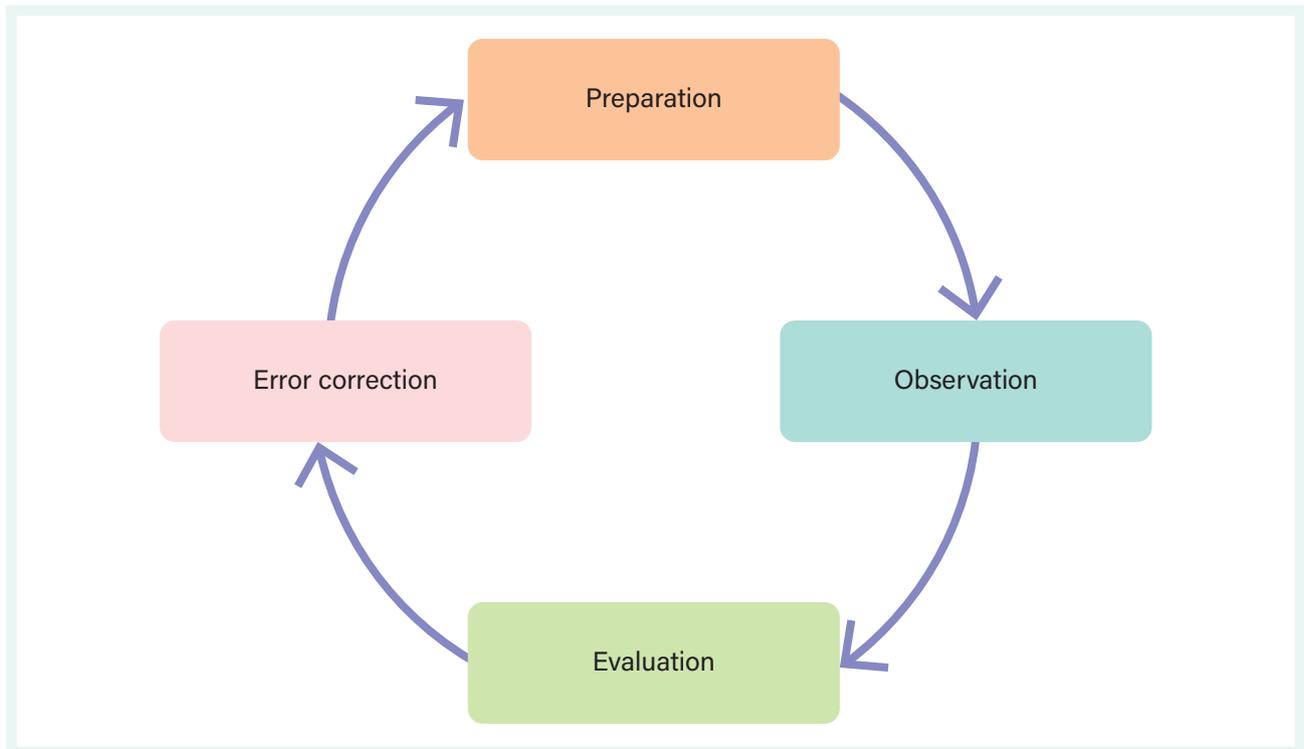
- » The qualitative movement analysis stages (preparation, observation, evaluation and error correction)

## KEY KNOWLEDGE

- » An ability to perform a qualitative movement analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

## KEY SKILLS

Source: *Victorian Certificate of Education Physical Education Study Design (2025–2029)*





Video

Masterclass: Chapter 4

Assessment  
Pulse check

A qualitative analysis involves a purposeful observation of a skill being performed (live or recorded) followed by a judgement on quality of movement, which then allows feedback and revised practice strategies to be provided in an effort to improve performance.

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- 1 Coaches need to observe performances and make split-second decisions on how skills 'rate' in terms of efficiency and execution. What can coaches do to ensure they know what to look out for when skills are performed?
- 2 Why is it important that errors in the way skills are performed are detected, and corrected, at the cognitive stage of learning, rather than after a year of training?
- 3 **List** two advantages of digitally recording a sports skill or movement sequence in an effort to improve the way it is performed.
- 4 **Discuss** how having a knowledge of biomechanical principles can assist coaches to make decisions and suggestions about how movements can be improved.
- 5 Quite often, task constraints are used in practice sessions to improve the way skills are executed. Provide examples of how a basketball or soccer coach might modify a training drill in order to improve how shots for goal are taken.
- 6 **Outline** two options a coach might use to evaluate the effectiveness of the skill-improvement feedback they have provided their players.

## 4.1 CONDUCTING A PERFORMANCE ANALYSIS

In this module you will learn about:

- people who use a qualitative movement analysis and types of data they consider
- the four stages that make up a QMA  
and learn to:
  - decide on whether primary or secondary data (or both) should be used
  - differentiate between qualitative and quantitative data.

The goal of any analysis involving human performance is to identify strengths and weaknesses at the physiological, technical, tactical and psychological levels – all combining to bring about the end performance outcome. Before we can perform the analysis, however, we need to know what data is important and what data collection methods are available.

### Data types

There are only two types of data that can be referred to when conducting an activity/performance analysis. These are often used in conjunction with each other, but there are instances when only one data type proves to be most useful. The data types can be classified as:

- **primary data** – any data that is collected 'first hand' by the person (or group) who is then going to use it. Examples include:
  - » a student's recording of their own service action in volleyball or tennis

#### primary data

Information and data that is collected firsthand – either individually or as a team

- » a student’s self-reflection on how they executed a skill or its outcome
- » observations made by a coach as they view throwing or hitting actions during a softball/ baseball training session
- **secondary data** – any data that has been collected by someone else, on an action or outcome you are involved in, at an earlier stage or time. Examples include:
  - » a video of an elite player performing a skill that is watched by a coach who is hoping to analyse the same skill
  - » a ‘training video’ watched by a student trying to match their movements to those shown in the video
  - » ‘how to’ suggestions and images prepared by a leading sports performer for others to use.

**secondary data**

Information or data that has been collected by others and that is used to increase understanding and application of existing knowledge

## Performance analysis options

There are two options to choose from when considering a movement/performance analysis. Once again, these can be used together, if appropriate, or on their own. They are:

- **quantitative analysis:** This involves the collection, measurement and evaluation of data from the performance of skills and movement sequences. This involves an objective evaluation of performances via the collection of numerical data such as heart rates, GPS movements and forces produced, to name a few variables. It also requires that permanent records be kept so they can be viewed, reviewed and used as benchmarks.
- **qualitative analysis:** This involves non-numerical collection, evaluation and analysis of a skill and mainly involves direct observation of performances. As such, it is also referred to as subjective and the analysis focuses on the quality of the movement and how it is performed, rather than the use of any number or metric. In most cases this option is used to focus on the technique used to perform skills and movement sequences.

**quantitative analysis**

Referring to numerical and statistical data to understand performances

**qualitative analysis**

Collecting and analysing non-numerical data to understand and improve movement concepts

### LOOKING FORWARD

#### Quantitative analysis

#### Chapter 9

While a qualitative analysis is critical in bringing about improvements to the way skills are performed, a quantitative analysis provides measurements and metrics that can also be used to improve skill execution but tends to be much more useful when making changes at the physiological level.

In this chapter, we will focus on how a qualitative movement analysis, combined with knowledge of skill acquisition, practice, feedback and biomechanical principles, can be used to improve the quality of sports performances. A detailed qualitative analysis might describe the precise sequencing and timing of body segments in order to ensure maximum summation of momentum occurs when throwing, kicking or striking a ball.

**TABLE 4.01** People most likely to use a qualitative movement analysis and possible outcomes

Who uses a qualitative movement analysis	Purposes of a qualitative movement analysis
<ul style="list-style-type: none"> <li>▪ Coaches</li> <li>▪ Sports trainers</li> <li>▪ Biomechanists</li> <li>▪ Sports medical staff</li> <li>▪ Physical therapists</li> <li>▪ Physical education teachers</li> <li>▪ Instructors</li> </ul>	<ul style="list-style-type: none"> <li>▪ Analysing movements and skills</li> <li>▪ Modifying movement</li> <li>▪ Error detection and improvement</li> <li>▪ Talent identification</li> <li>▪ Player profiling/ranking</li> <li>▪ Identifying strengths</li> <li>▪ Injury prevention</li> </ul>

## LOOKING BACK

### Sequencing

#### Chapter 3

Recall that movements are quite often made up of 'parts' that need to be coordinated or sequenced correctly to ensure maximum power is produced and summation of momentum occurs. If the sequencing is 'out', a coach needs to be able to suggest how improvements can be made and then incorporated into new practice strategies.

A qualitative movement analysis essentially consists of these four stages:

- preparation
- observation
- evaluation
- error correction.

### DID YOU KNOW?

The evaluation stage is where a detailed analysis occurs, and that's why it is sometimes referred to as the diagnosis stage. The error correction stage is sometimes referred to as the intervention stage where feedback is provided and modifications made to technique, type of practice, equipment, etc.



#### Assessment

4.1 Check-in questions

#### Command term

##### propose

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action



#### Video

In focus: Breaking a baseball pitch down into its sub-routines

#### preparation stage

The first stage in a qualitative movement analysis, where prerequisite knowledge of the skill/ movement is researched and consideration is given to how, where and when to conduct the next stage, which is observation

## 4.1 CHECK-IN QUESTIONS

- 1 **Discuss** why it would be inappropriate for an elite performer to undertake a qualitative movement analysis on themselves despite having high knowledge of what optimal performance looks like and how it feels.
- 2 **List** two examples of professionals who might engage in a qualitative movement analysis.
- 3 Provide two different reasons why a qualitative movement analysis might be undertaken.
- 4 A qualitative movement analysis focuses on the quality of how a technique is performed. **Propose** how 'quality of movement' can be evaluated.

## 4.2 THE PREPARATION STAGE

In this module you will learn about:

- considerations that need to be taken before any performance is viewed and learn to:
- identify critical features of movements and skills
- consider stages of learning when making judgements
- think about best observation strategies
- consider best options for communicating information to learners.

During the **preparation stage**, the person conducting the analysis comes up with a plan that outlines what they need to do in order to offer the best advice to a performer when it comes to making improvements in their technique. This stage is vital to the overall effectiveness of the analysis, and all the planning, research and considerations undertaken here will definitely contribute to how successful the overall improvement strategies are.

During the preparation phase, coaching staff and other people conducting the observation/analysis need to consider the following:

- What are the critical features of the specialised movement sequence or skill?
- What stage of learning and what skill level is the performer currently at?
- Where will the skill be performed and viewed?
- What observation method(s) and considerations should be undertaken?
- How will the information be considered, evaluated and communicated?

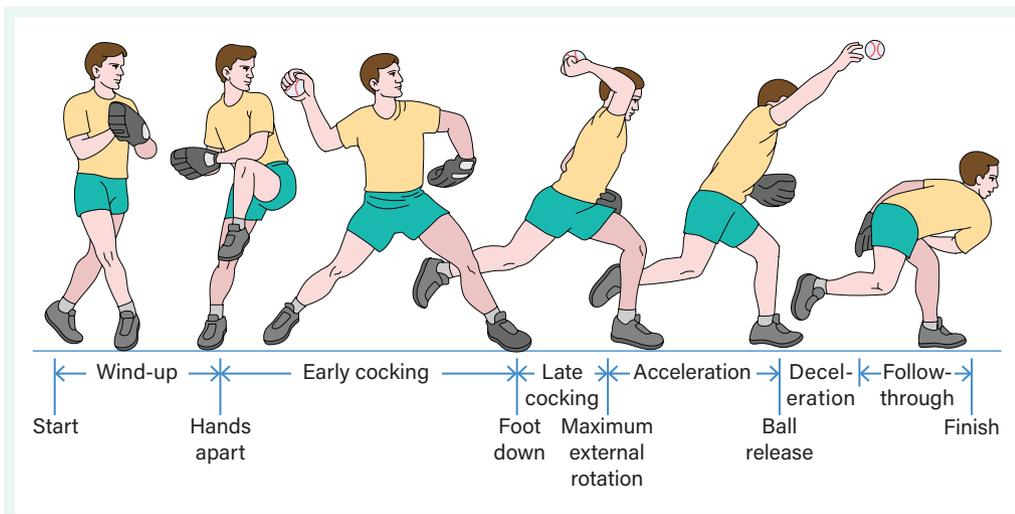
We will explore each of these points in the following pages.

### LEARNING HACK

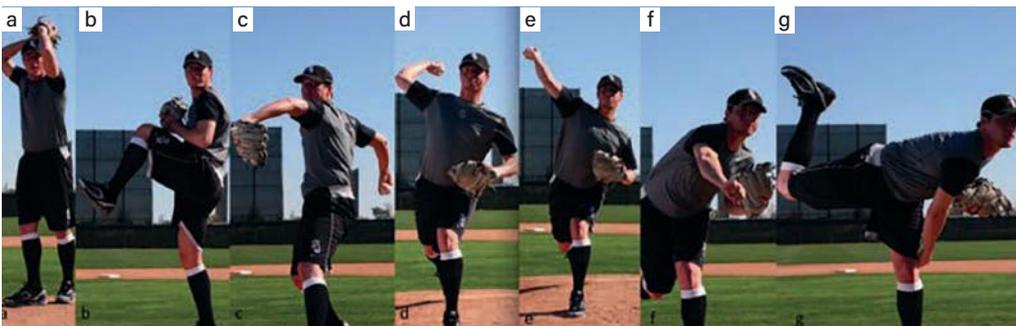
QMA is a commonly used abbreviation for qualitative movement analysis.

## What are the critical features of the specialised movement sequence or skill?

Identifying the critical features of the specialised movement sequence or skill requires research into how the skill is performed most effectively from a biomechanical and physiological perspective. Usually this involves viewing the movements (live or recorded) of elite performers since they tend to model skills at the highest level. The way elite performers execute skills becomes a 'template' to which the performance of others is compared. Additionally, coaches might refer to the findings of other coaches (secondary data) working with the same sportspeople. It is common for coaches to either design, or make reference to, a high-performance rubric that outlines key features of the skill, and quite often breaks a skill or movement sequence down into its various parts.



**FIGURE 4.02** Components of the throwing motion in baseball



**FIGURE 4.03** Components of the baseball throwing motion as viewed from front-on: **a, b** wind-up, **c** early cocking/stride, **d** late cocking, **e** acceleration, **f, g** deceleration/follow-through

Source: Seroyer, S.T. et al. (2010), 'The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention', in *Sports Health* 2010 Mar;2(2):135–46. Reproduced with permission from Sage Publication.



**FIGURE 4.04** Components of the baseball throwing motion viewed from side-on: **a-c** wind-up, **d, e** early cocking/stride, **f, g** late cocking, **h-j** acceleration, **k** deceleration, **l-n** deceleration/follow-through

Source: Seroyer, S.T. et al. (2010), 'The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention', in *Sports Health* 2010 Mar;2(2):135-46. Reproduced with permission from Sage Publication.

### DID YOU KNOW?

Some sportspeople are very successful even though they might use techniques that are not considered to be biomechanically most effective and that may even be quite unorthodox.

## REAL WORLD APPLICATIONS

### THE FISH KICK IS THE FASTEST WAY TO SWIM THAT (ALMOST) NO ONE USES

MATT MILLER, 9 AUGUST 2016

IAN WALDIE/Reuters



**FIGURE 4.05** Misty Hyman of the USA holds up her gold medal after winning the 200 metres butterfly final at the Sydney 2000 Olympic Games.

The fish kick, if done properly, is the fastest way for a human to swim. The technique requires a swimmer to lie sideways and wiggle her body in a fluid motion that mimics that of a minnow or an eel. At the 2000 Olympics, American swimmer Misty Hyman fish-kicked her way to gold in the 200 metres butterfly, beating out two heavily favoured Australian swimmers.

In the video, 'How the fish kick helped Misty Hyman win Gold' on the Slade website, you can watch Hyman employ the fish kick at each turn. Susie O'Neill – an Aussie whose dominance earned her the nickname 'Madame Butterfly' – stays with Hyman through the first 100. But when they reach the final turn, Hyman fish kicks back into a clear lead. O'Neill can't recover.

The fish kick emerged in Sunday night's 4 × 100 men's freestyle relay, when the United States'





Ryan Held used the kick on his turn in the third leg of the race. But Held's fish kick was an unusual sight in Rio. If it's the fastest kick in the world, why don't more swimmers do it?

For one thing, if a swimmer screws up the fish kick, he's risking disqualification. Per the rules outlined by Fédération Internationale de Natation, the sport's international governing body, swimmers attempting the fish kick after turns in downward events – the breaststroke, the butterfly, and the freestyle portion of the individual medley – must not rotate onto their backs, even by a few degrees. In the backstroke, the opposite mandate applies: Athletes who rotate toward their stomachs will be disqualified.

A second problem: The fish kick is supremely difficult to master. In addition to keeping their bodies rotated just so, swimmers must worry about veering away from the center of their lanes, since it's pretty much impossible to keep your eye on the lane markings when you're on your side ... Compared with her competitors, [Hyman is] underwater for much longer, but still maintains her central lane position:

Why did Misty Hyman use the fish kick?  
Because she knew she had to take risks to

win. After reading an article in Scientific American on the swimming techniques of literal fish, Hyman and her coach Bob Gillett developed her signature kick. In an interview with the Chicago Tribune a few years before her Olympics upset, Hyman said, 'I'm not 6 feet tall. ... For swimmers like me, it's either use steroids or use your brains.'

The fish kick isn't the only technique that gives swimmers an edge. In the 1988 Seoul Games, American swimmer David Berkoff helped the U.S. win gold in the men's 4 × 100 medley relay by swimming almost the first 50 metres of his backstroke leg underwater, propelling himself with a dolphin kick. To execute that move, a swimmer stretches flat out – facing either up or down – and kicks his legs together in a fluid motion that resembles that of a dolphin's rear fin.

The underwater dolphin kick was too much of a performance enhancer for swimming's powers that be. In 1988, FINA declared that backstrokers had to surface within 15 metres of starting or turning. In 1998, two years before Hyman's Olympic victory, the governing body passed the same rule for butterfly. Later, it banned the underwater dolphin kick for freestylers as well.

## What stage of learning and what skill level is the performer currently at?

It is very relevant to consider what previous experience the subject has had at performing the skill or motor sequence, and where they are on the stage of learning continuum. This does not change the need for the coach/observer to communicate what the best technique involves, but it does change the type of demonstration/information provided. It also has implications for the type of feedback used and how the skill is practised in an attempt to make improvements.

For example, a swimming coach working with someone learning swimming would definitely consider being in the pool with the learner, rather than on the side of the pool. They would keep instructions simple, demonstrate how body parts move wherever possible (sometimes breaking a stroke down into its parts) and in some cases even assist learners by physically guiding their actions. When working with a more experienced swimmer who is at the associative stage, the coach understands that they can perform the fundamental swimming strokes, kicks and skills to a moderate or high standard/quality. The coach's feedback is more precise and they would be communicating aspects about whole movements, rather than parts, as well as showing swimmers what they are doing compared to what they need to do to improve via a screen (most likely, a tablet).



### Weblink

How the fish kick helped Misty Hyman win gold

## LOOKING BACK

### Stages of learning

#### Chapter 2

Where on the stages of learning continuum a performer finds themselves is a vital consideration when trying to determine how best to bring about improvements.

## Where will the skill be performed and viewed?

The coach/observer needs to select the best setting in which to view the performer performing their skill or movement sequence. It is preferable to have skills performed in a closed environment where the performer is able to control the timing of the skill and not be distracted or influenced by others, and where the same skill/sequence can be performed repeatedly and consistently. This allows the coach/observer and any recording equipment to be positioned optimally to view the execution of the skill from multiple and close-up angles. It also allows the performer to provide immediate feedback about how they are performing the skill along with any 'problems' they might be experiencing. Often, recording this in a reflective journal/diary proves valuable when the coach and subject both consider the level and quality of skill acquisition along with possible progression points moving forward.

## What observation method(s) and considerations should be undertaken?

This will be discussed in further detail in the next section, but essentially can range from direct observation (with or without note-taking) or any form of digital recording, which can be as simple as using a mobile phone or tablet, to using more advanced digital recording paired with drones, high-powered cameras or motion-capture technology.

## How will the information be considered, evaluated and communicated?

A good coach will, ahead of time, consider the following as part of their performance improvement planning:

- The internet has made it very easy to search for information on optimal performance characteristics associated with skills and movement sequences, but only reputable sources, such as professional journals, national coaches and sporting associations and peer-reviewed research articles, should be considered. Information gathered at this stage cannot simply rely on someone's opinion; it must be authenticated, evidence-based and nationally validated by coaching/sporting associations.
- After viewing, or recording, the performance, can I make suggested improvements or will I need to involve others, such as biomechanists, movement analysts or exercise physiologists?
- Should I use computer software to assist my decision-making, isolate major muscles used in the actions, or superimpose angles, flight paths etc?
- How am I going to best provide feedback to the learner/performer in a user-friendly and appropriate manner to ensure they understand what they are required to do?
- How is the progress of the subject going to be tracked (pre- and post-intervention comparisons) and continued refinements be made?

## 4.2 CHECK-IN QUESTIONS

- 1 **List** a reason why it is important during the preparation stage to obtain information relating to the highest level of performance available.
- 2 An internet search on how best to perform a skill or movement sequence will yield hundreds of thousands of 'hits'. What criteria should be used to ensure that they are reliable, and hence can likely be used with high levels of confidence when trying to improve performance?
- 3 **Discuss** why it is important also to include observation considerations during the preparation stage.
- 4 **List** two different types of secondary data a gymnastics coach might refer to while gathering information about the skills performed as part of a floor routine.



**Assessment**  
4.2 Check-in questions

## 4.3 THE OBSERVATION STAGE

In this module you will learn about:

- direct observation vs digital recording of performances and learn to:
- think about multiple variables that should be considered to make observations as effective and useful as possible
- take steps to increase observation and recording reliability.

The **observation stage** primarily involves implementing the observation strategies considered in the previous stage. This might include one or more of the following methods:

- direct observation and note-taking
- digital video recordings
- continuous high-speed photography
- motion capture (mocap)
- viewing position
- viewing plane
- viewing reliability.

We will explore each of these methods in the following pages.

### Direct observation and note-taking

As the name suggests, direct observation and note-taking involves a coach or observer purposefully viewing a skill or movement sequence being performed. This occurs after they have previously considered what key movements and sequences elite performers use when executing the performance, and it typically makes reference to a 'checklist' or benchmark, outlining how optimal movements are executed. The use of a checklist makes the observation more objective, while creating notes has the further advantage that they can be shared and discussed with the performers themselves.

#### observation stage

The second step in a qualitative movement analysis; involves either live or recorded vision of a subject performing a skill or movement pattern



**FIGURE 4.06** A coach taking notes after observing individual performances at training

PeopleImages.com - Yuri A/Shutterstock.com

**TABLE 4.02** A checklist for a volleyball 'dig' that a coach could use when comparing the performance of a learner with that of an elite performer

Ready position	Pre-contact	Contact	Follow-through
			
<ul style="list-style-type: none"> <li>• Eyes are on ball.</li> <li>• Shoulders are square to the ball.</li> <li>• Base is wide, with feet wider than shoulders.</li> <li>• Trunk is leaning slightly forwards, with arms and shoulders forwards of body.</li> </ul>	<ul style="list-style-type: none"> <li>• Arms straighten and hands come together to form flat contact from wrists to elbows.</li> <li>• Knees are bent at 90–120°.</li> <li>• One foot is slightly in front of the other.</li> </ul>	<ul style="list-style-type: none"> <li>• Arms are straight and parallel to thighs.</li> <li>• Ball contact with forearms.</li> <li>• Shoulders perform upwards 'bump action'.</li> <li>• Legs are flexed at contact.</li> </ul>	<ul style="list-style-type: none"> <li>• Arms and body move forwards in the direction of ball.</li> <li>• Arms go back to ready position.</li> <li>• Up on toes in readiness for next action.</li> </ul>

## Digital video recordings

Digital video recording includes the use of highly accessible mobile phones, tablets and other devices such as a GoPro. More expensive digital recording systems involve multiple cameras that can film every player and every movement that occurs within a soccer or hockey field. Some more advanced recording systems, such as Trace, pair with artificial intelligence (AI) to track and record individual players and produce player summaries. They achieve this by inputting the colour of the player's outfit and their number.



**Weblink**  
Trace PlayerFocus

### 🚩 SIGNPOST

Watch examples of how digital recording and AI combine to observe player movements and performance of skills on the Trace website.

## Continuous high-speed photography

Continuous high-speed photography is also known as burst, continuous or sports shooting mode on smartphones and digital cameras.

This technology makes it possible to capture several photos in quick succession, allowing a time-lapse record of performances to be taken. This is advantageous where actions occur so quickly that observation alone is likely to miss key aspects of the skill. Time-lapse images provide information about how the different parts of a skill are sequenced together, and can be very useful in identifying the contribution of different muscle groups and body segments to the overall execution of a skill or movement sequence.



John Bingham/Alamy Stock Photo

**FIGURE 4.07** Continuous high-speed photography is sometimes referred to as time-lapse photography.

## LOOKING FORWARD

### Direct observation vs digital recording

#### Chapter 9

An activity analysis needs to consider the advantages and disadvantages associated with direct observation (with or without note-taking) vs digital recording.

## Motion capture (mocap)

As the name suggests, this technology is used to record body movements and create 3D modelling of how muscles, joints and body parts move together. Physical mocap suits, specialty cameras, body markers and advanced software are used to create photorealistic images and animations. This technology can be used to optimise a tennis serve, bowling action, golf swing or any other sporting action. Of equal importance is the ability to diagnose, and then prevent, injuries resulting from incorrect technique. More advanced applications involve creating simulated movements of the most effective way to run, throw, strike, kick, jump and move in multiple sporting contexts. These can then act as templates of 'ideal' skill execution to be mimicked during training or coaching sessions.



Jacob Lund/Shutterstock.com

**FIGURE 4.08** Motion capture being used during the performance of a triple jump in a closed environment

**reliable**

Able to be relied on; in the case of observations (performances), this depends on how often they can be replicated

As well as how to observe, and ideally record, the skills being performed, consideration needs to be given to the most suitable viewing position and plane (viewing angle) as well as the number of viewings required to obtain a representative or **reliable** indication of 'typical' skill execution.

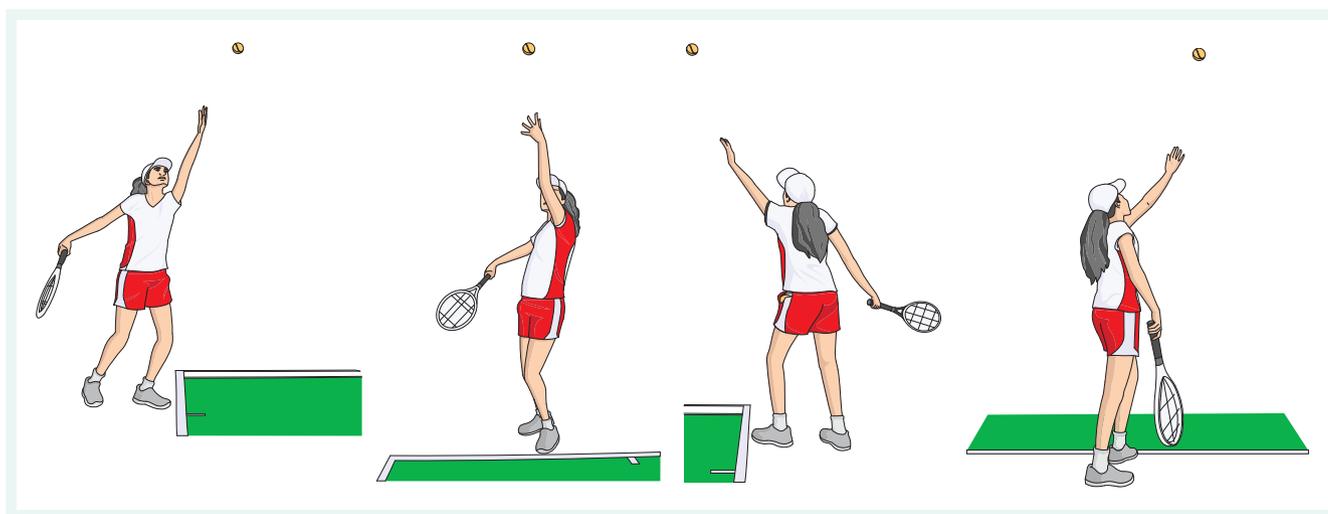
## Viewing position

The observer or recording implement needs to have clear and uninterrupted view of the performance at all times. It is worth trialling or practising a few observations with recording equipment (in most cases) to ensure there is a clear sightline and the equipment can be used effectively and without any problems.

There is a fine balance to be struck between getting close enough to view the performance clearly and distracting the subject by being too close. Optimal viewing positions will become more apparent with repeated practice.

## Viewing plane

Most coaches and observers position themselves side-on to the performer – for example, when players run up and down a playing field such as a netball court or hockey field while the coach stands on the sidelines. However, in some instances it might be better to include other viewing planes (such as front-on, reverse-view and from above), as shown in Figure 4.09.



**FIGURE 4.09** Tennis serving actions viewed from multiple angles/planes

## Viewing reliability

The number of times a performance is viewed in competition is limited by how frequently the skills are performed. A swimmer might only perform a single dive entry and tumble turn if their only event at a swimming competition is the 100 metres freestyle, whereas an athlete competing in the javelin might perform anywhere between three and six throws, depending on their ranking.

Generally, and within reason, the more times a skill can be observed, the better. Hence, it is quite valid to observe performers executing their skills and movement sequences during training sessions. Because of movement variability, there are likely to be small differences in the way skills are performed, even at the elite level and in closed environments. The more times a skill is observed or recorded, the more likely it is that results can be considered to be reliable. A rule of thumb proposes between five and 10 performance observations as a minimum requirement, with 10 being considered highly satisfactory.

### 4.3 CHECK-IN QUESTIONS

- 1 Motion capture technology provides the opportunity to capture and break down movement sequences into all their contributing parts or sections. **Outline** how a coach might use each 'part' to make judgements about the quality of movements.
- 2 **List** two advantages associated with creating an 'optimal movement checklist' in the preparation stage and then using this during the observation stage.
- 3 **Discuss** two advantages associated with practising observation of performances in an effort to collect information about how the skill and movement sequence is executed.
- 4 The observation stage is increasingly being paired with computer software and AI. **Discuss** how this enables the creation of more user-friendly data that can also potentially be shared with the subject themselves.



**Assessment**  
4.3 Check-in questions

#### Command term

##### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

## 4.4 THE EVALUATION STAGE

In this module you will learn about:

- how coaches and others performing a QMA use data and information they have collected to analyse current skill execution
- possible suggestions to improve performances and learn to:
- consider the advantages and disadvantages of making objective and subjective improvement recommendations
- use performance rubrics highlighting quality movement sequences
- prioritise which parts of a skill should be targeted next.



**Video**  
In focus: Performing a QMA

The **evaluation stage** involves looking at similarities and differences between the performer's execution of a movement or skill and that of an elite performer undertaking the same movement sequence/skill. The evaluation can be either:

- **objective** – using performance rubrics, checklists, rating scales etc.
- **subjective** – consisting of personal opinion or interpretation of what has been observed.

Objective evaluations have greater consistency and can more easily be justified to others looking to use the data. Critical features of the skill that make up its **quality** should be ranked. The ranking scale can be 'high, medium, low' or 'excellent, good, poor'. Table 4.03 is an example of one of these evaluations (or 'compare and contrast' tables) that is linked to the volleyball dig checklist in Table 4.02.

The coach or analyst then needs to decide:

- What is the performer doing really well (strengths)?
- Where do problems exist (weaknesses)?
- What might be causing the problems?
- How can the problems be addressed/improved?
- Which problem areas are more important to improve than others?

#### evaluation stage

The third step in a qualitative movement analysis; involves judgements about the quality of movements. Typically, it also involves identifying strengths and weaknesses in the technique and considering how improvements can be made.

#### quality

The extent to which skills and movements can be performed in a controlled and optimal way, ensuring consistent and high levels of performance and reducing likelihood of injury

**TABLE 4.03** Comparing and contrasting how a volleyball dig has been performed with how it is performed by an elite athlete.

Ready position	Pre-contact	Contact	Follow through
<ul style="list-style-type: none"> <li>Eyes are on ball.</li> </ul>	<ul style="list-style-type: none"> <li>Arms straighten and hands come together to form flat contact from wrists to elbows.</li> </ul>	<ul style="list-style-type: none"> <li>Arms are straight and parallel to thighs.</li> </ul>	<ul style="list-style-type: none"> <li>Arms and body move forwards in the direction of ball.</li> </ul>
<b>(H) Great tracking from serve until over own side of net</b>	<b>(M) Arms come together but hands clasped and interlocked</b>	<b>(M) Arms straight but too low</b>	<b>(M) Arms move forwards but body basically unchanged</b>
<ul style="list-style-type: none"> <li>Shoulders are square to the ball.</li> </ul>	<ul style="list-style-type: none"> <li>Knees are bent at 90–120°.</li> </ul>	<ul style="list-style-type: none"> <li>Ball contact with forearms.</li> </ul>	<ul style="list-style-type: none"> <li>Arms go back to ready position.</li> </ul>
<b>(M) Shoulders slightly angled to oncoming ball</b>	<b>(L) Subject is upright</b>	<b>(L) Most contact occurs with wrist/upwards facing hands that are interlocked</b>	<b>(M) Arms and shoulders in front of body, but arms need to be raised</b>
<ul style="list-style-type: none"> <li>Base is wide, with feet wider than shoulders.</li> </ul>	<ul style="list-style-type: none"> <li>One foot is slightly in front of the other.</li> </ul>	<ul style="list-style-type: none"> <li>Shoulders perform upwards 'bump action'.</li> </ul>	<ul style="list-style-type: none"> <li>Up on toes in readiness for next action.</li> </ul>
<b>(M) Feet are shoulder width apart</b>	<b>(L) Both feet aligned</b>	<b>(L) Not apparent, with arms contributing 100% to uplift</b>	<b>(M) Apparent during action, but needs to be sustained</b>
<ul style="list-style-type: none"> <li>Trunk is leaning slightly forwards, with arms and shoulders forwards of body.</li> </ul>		<ul style="list-style-type: none"> <li>Legs are flexed at contact.</li> </ul>	
<b>(L) Trunk forwards with arms beside body</b>		<b>(L) Contact made with straight legs</b>	

L = low, M = medium, H = high

**checklist**

A list of items required, things to be done or points to be considered that can be used by the person who makes the list, or by others, for future reference

While the above **checklist** or template or benchmark approach increases objectivity, it is important to be able to prioritise the critical features. This involves a coach prioritising which areas to focus on. In Table 4.03 six areas have been rated as 'low quality' and trying to improve all of them at the same time might overwhelm the subject and be too difficult to try to address simultaneously. Generally, only one intervention at any time is best, so one correction or improvement strategy at a time is recommended.

In the real world of sport, movement analysts are usually most effective when they work as part of a multidisciplinary team of experts. As such, the coach or observer should not just rely on what has been viewed or recorded and may also refer to the performer's reflection on their own performance, previous research findings from reputable sources and peer presentations on improving the way skills are performed (which was considered at the preparation stage).

**DID YOU KNOW?**

Identifying the source of problems is seldom clear-cut. Problems might result from:

- poor body position or movement timing (biomechanical)
- low physical conditioning (physiological)
- slow evaluation of environmental cues (perceptual motor)
- low motivation levels (psychological).

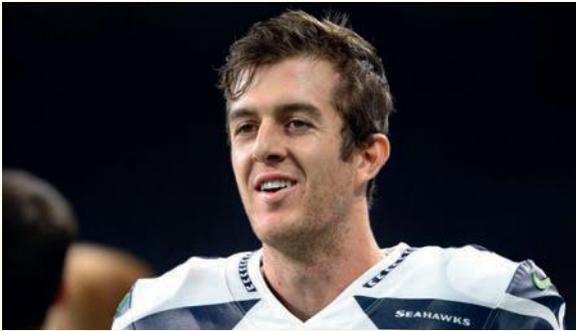
## REAL WORLD APPLICATIONS

## Observation and evaluation reveal similarities between different sports

Some fundamental movement skills, such as kicking, throwing and striking, are transferable from one sport to another.

### DICKSON OUT TO BECOME NFL'S BEST PUNTER AFTER STUNNING DEBUT SEASON

NurPhoto SRL/Alamy Stock Photo



When Australian punter Michael Dickson beat out other NFL greats to be selected for the Pro Bowl – the league’s annual all-star game – he was lauded as a rising star.

But Dickson admits he didn’t even know what the Pro Bowl was at the start of last year.

‘Someone told me, “You’re in the NFL now, so you’ve done it all,”’ he said at the Kayo Sports Super Bowl launch on Sunday, where a game of gridiron was played on the harbour.

But Dickson disagreed – he was looking for the next goal to set himself. ‘Then I looked it up and there was the Pro Bowl,’ he said. ‘As soon as I found that out, I wrote the goal on my mirror.’

Dickson placed a check mark against the goal in advance, to put himself in the mindset for success, and looked at it each day.

By week one of his first NFL season, he had been selected to play. ‘Once I looked in the mirror and it had actually come true, it was a pretty crazy moment,’ he said.

‘You get butterflies. It was just me in my apartment when I found out. I called my family and facetedimed them, it was a crazy good feeling.’

The 22-year-old from Kirrawee, in Sydney’s South, began his sporting career in Australian Rules. After he missed out on being drafted to the Sydney Swans he moved to the University of Texas to test his skills in the NFL.

Since then, Dickson’s success has been fast-paced: he was named the country’s most outstanding college punter in 2017, drafted to the Seattle Seahawks in 2018, and made the Pro Bowl in the same year.

‘It still feels really surreal,’ he said. ‘Me and mum were laughing about my year when I got back. She was like, “You made the Pro Bowl in your first year, that hasn’t been done for thirty-something years”.

‘When you’re doing it, you don’t even realise it,’ he said. ‘Looking back at the stadium, even in college, and seeing that you’re playing in front of 100,000 people every other week is insane.

‘But it still doesn’t really feel like I’m the person who’s doing it. I’ve got so many more goals that I want to reach, I don’t feel like I really can absorb everything yet.’

His list of goals includes making the Pro Bowl again next year, and for as many years as he can after that.

‘I want to set a new standard for myself each year,’ he said.

He also hopes to one day be considered the best punter in the league. But until then, his sights are set on helping his team make the illustrious Super Bowl next year.

‘If we can get to a Super Bowl, that’s priority number one,’ he said.

Source: Natassia Chrysanthos, ‘Dickson out to become NFL’s best punter after stunning debut season’, *The Age*, 3 February 2019



### Assessment

#### 4.4 Check-in questions

## 4.4 CHECK-IN QUESTIONS

- 1 **a List** another professional whom a coach might call upon to assist them during the evaluation stage of a qualitative movement analysis.
  - b** What information might this other professional provide to assist in making improvements to movement sequences and skills?
- 2 The evaluation stage often involves the use of a movement checklist. Clearly **discuss** how a coach makes use of this recording tool to make decisions about improving the quality of movements and skill execution.
- 3 Consider why the communication of improvement strategies resulting from the evaluation stage needs to be individualised when working with cognitive vs associative performers.

## 4.5 THE ERROR CORRECTION STAGE

In this module you will learn about:

- the importance of feedback in bringing about performance improvements and modifications
- task constraints to be considered when designing practice sessions and learn to:
  - select the most appropriate practice conditions based on stages of learning, type of skill and performance environment
  - conduct a post-intervention evaluation to evaluate effectiveness of error correction strategies.

### error correction stage

The fourth and final stage in a qualitative movement analysis; involves implementing improvement strategies to address weaknesses and errors in technique

### closed environment

A setting where the learner has full control over the timing and execution of skills being performed; characterised by being in a familiar and stable place where skills can be repeated with high levels of consistency

### distributed practice

A learning strategy in which practice is broken up into a number of short sessions over a longer period of time

The final stage in a qualitative movement analysis is the **error correction stage**.

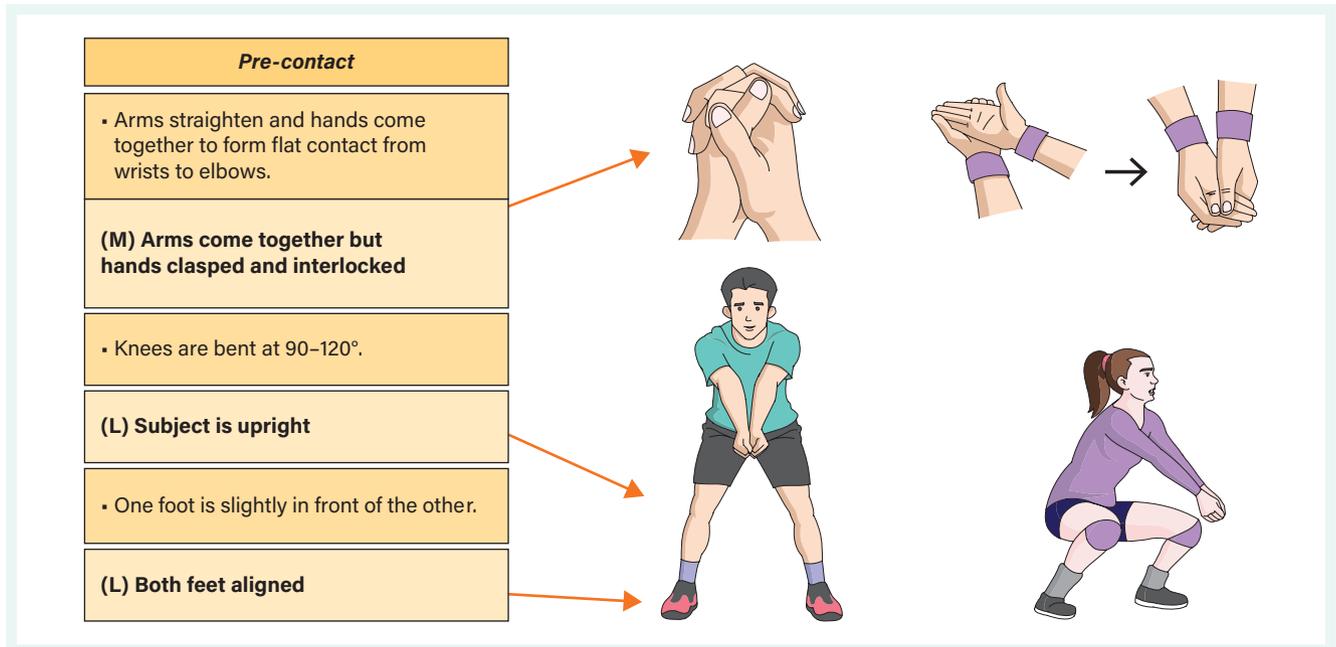
When making improvements to the way skills are performed, it is imperative to recall the ways skills are best learnt and practised, and that relevant feedback is provided to ensure continued development with increased confidence. Wherever possible, the suggested modifications should be practised in a **closed environment** that has high levels of predictability and low levels of variability. This ensures that the modified movements have a chance of being stored as a new motor program that will easily be recalled and repeated with future trials.

**Distributed practice** is often used with cognitive learners because they have short concentration spans and benefit from receiving smaller amounts of feedback more often. Associative and autonomous learners, in most instances, have higher levels of fitness, allowing them to perform for longer periods of time without fatiguing and losing concentration. They are more likely to partake in massed practice to trial modified movements, and don't need to receive feedback so frequently. Although learners in these stages are better able to self-correct than cognitive learners, effective error correction can only occur via augmented feedback provided by coaches or other performance specialists.

Coaches can correct errors and improve movement sequences by:

- discussing possible improvement strategies with players and letting them know what the focus is going to be
- breaking down a skill into its sub-routines and focusing on improving parts of the skill. This is more manageable than trying to improve all aspects that need quality improvements

- demonstrating what the correct movement application looks like. This is made easier when digital recordings are taken so that players can see themselves performing a skill and contrast that with the same skill being undertaken by an elite performer
- physically moving a player's body parts so they experience what better-quality movement feels like (most likely at cognitive stage).



**FIGURE 4.10** Breaking a skill down into its sub-routines and focusing on improving parts of the skill is more manageable than trying to improve all aspects that need quality improvements. Note: L = low, M = medium.

To implement an **intervention** takes time. Regular feedback needs to occur throughout, and after, each practice session. If available, coaches use digital recordings of the original movement sequence to show performers how the changes they have made contribute to improved movements. Some movements are ingrained (habitual) and are difficult to modify. This may require physical manipulation of movements, or the use of training aids or taping, which encourage prescribed movement patterns. Additionally, practice can involve task constraints that encourage performers to change the way they usually execute skills and movement sequences.

#### intervention

Implementing an action or program in an attempt to bring about improvements

## COLLABORATIVE TASK

### Activity

#### Observing a skill and providing improvement feedback

For this activity you will pair up with a classmate. Each of you will perform the same skill, while the other observes the quality of movements associated with its execution and records this on a checklist focusing on the four stages found in every movement skill:

- preparation/preliminary movement
- force production
- critical instant
- recovery/follow-through.





**Template**

Skill observation and feedback for improvement

**PROCEDURE**

- 1 Decide on a skill you would like to perform and receive improvement feedback on from your partner. This skill is to be performed in a closed environment five times (known as trials). Typically, this should be a skill that requires minimal teacher supervision and uses easily accessible sporting equipment. Examples are a tennis serve, a hockey push, a volleyball serve, a shot at goal in basketball or netball and a kick for accuracy in Australian Rules football.
- 2 A partner positions themselves in an optimal viewing position and records how the skill is executed by considering multiple key elements.

Skill:	Preliminary preparation			Force production			Critical instant (point of contact, release or flight)			Follow-through		
	E	G	P	E	G	P	E	G	P	E	G	P
<b>Key elements:</b>	<ul style="list-style-type: none"> <li>Evidence of speed build-up</li> <li>Correct planes and pathways of movement</li> <li>Full movements and range of motion</li> </ul>			<ul style="list-style-type: none"> <li>Correct sequencing of body parts</li> <li>Involvement of multiple body parts</li> <li>Correct timing demonstrated</li> </ul>			<ul style="list-style-type: none"> <li>Strong base of support/stability</li> <li>Correct body positioning in relation to equipment</li> <li>Effective use of equipment and body parts</li> </ul>			<ul style="list-style-type: none"> <li>Movement continues with flow/balance</li> <li>Effective transfer of body weight</li> <li>Quality of movement</li> </ul>		
<b>Trial 1</b>												
<b>Trial 2</b>												
<b>Trial 3</b>												
<b>Trial 4</b>												
<b>Trial 5</b>												

E = excellent; G = good; P = poor

**ANALYSIS AND DISCUSSION**

- 3 Which parts of the skill or movement sequence do you believe were performed with:
  - highest quality (strengths)
  - lowest quality (weaknesses)?

Briefly **discuss** why you made this evaluation.

- 4 Select areas that you identified as 'poor quality' or 'weaknesses' and **suggest** possible ways that improvements could be made. You should **identify** the relevant biomechanical principles that underpin your suggestion as well as possible task constraints that can be used during practice/training to encourage technique modifications.
- 5 Consider the best way to provide your classmates with feedback about how to make improvements to their performance. Create a flash-card made up of key focus areas, cue words and tips you need to communicate to your classmate. Include diagrams if this helps you deliver your feedback.

**Command term**

**suggest**

Put forward for consideration a solution, hypothesis, idea or other possible answer

**🚩 SIGNPOST**

Watch the video *The Biomechanics of a Soccer Kick* on YouTube to see how Laura (expert) and Lara (rookie) complete the same soccer drills/skills. They achieve different outcomes based on how they complete the four main components – preliminary movement, force production, critical instant and recovery/follow-through – required in all movement skills.



**Weblink**

The Biomechanics of a Soccer Kick

## Post-error-correction/intervention evaluation

After feedback has been provided and the improvement strategy practised over a reasonable period of time (two or more weeks), it is imperative that primary data be collected again to evaluate the effectiveness of the 'new' technique or movement sequence. This process is known as **intervention evaluation**.

- Primary data must be collected under the same conditions as the original primary data collection, or as close as possible to them. This time the data is considered to be post-intervention.
- You should see some improvement, but don't worry if this is not the case as there are many variables to consider.
- To what extent (fully, partially, with improved success etc.) has the intervention/improvement strategy achieved your desired outcome and improved the quality of movement?
- What parts of the strategy have 'worked' and thus will be continued as is or (possibly) with slight modifications?
- Do any aspects of the of the suggested strategies need to be removed totally and reconsidered?

Once these reflections and evaluations have taken place, a new set of strategies are decided on and practised before another round of observation, evaluation and error correction takes place. This time, the preparation stage might not occur, or might be much shorter, given all of the previous time invested in researching and preparing for the observation stage. The qualitative movement analysis can be considered to be a continuous 'loop' in an effort to ensure that movements are performed with greater efficiency and fluency, and much more closely replicate the movement sequences of elite performers.

**intervention evaluation**  
Understanding what impact an intervention has had and to what extent improvements have been made relative to goals



KAMPUS/Shutterstock.com

**FIGURE 4.11** Post-intervention evaluation is important to gauge the effectiveness of skill refinement.

**Assessment**

4.5 Check-in questions

**Command terms****describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

**explain**

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

## 4.5 CHECK-IN QUESTIONS

### 1 ©VCAA Exam 2021, Section B, Q6 c

Michelle has asked her coach how she can improve her goal-shooting technique. **Describe** how the coach may use a qualitative analysis to improve Michelle's goal-shooting technique.

2 Once motor programs are established, they can be difficult to change. With this in mind, **explain** why coaches work really hard to teach and establish correct movement sequences when skills are performed during the early stages of practice. This might occur for a 5-year-old learning to swim or a 55-year-old learning how to play golf.

3 **Discuss** how the feedback provided to a young swimmer about dive entries to the pool would vary from that provided to a national-level swimmer seeking to improve the same skill.

4 **Outline** two circumstances in which error correction should occur in an open or game-like setting.

## CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 4

### 4.1 Conducting a performance analysis

A qualitative movement analysis involves making judgements on the quality of movement, followed by feedback and revised practice strategies, in an effort to improve performance.

- Four stages make up any qualitative movement analysis: preparation, observation, evaluation and error correction.
- Primary and secondary data can be referred to when conducting an activity/performance analysis.

### 4.2 The preparation stage

- The preparation stage involves planning and research, including the following:
  - What are the critical features of the specialised movement sequence or skill?
  - How is the skill performed at the elite/highest level?
  - What stage of learning and what skill level is the performer currently at?
  - Where will the skill be performed and viewed?
  - What observation method(s) and considerations should be undertaken?
  - How will the information be considered, evaluated and communicated?

### 4.3 The observation stage

- The observation stage requires people to consider the following:
  - Do I use direct observation alone or take notes as well?
  - Should I consider some form of digital recording, which allows permanent records to be kept for future reference?
  - What is the optimal viewing distance from the subject and from which angles should the movement be considered?

### 4.4 The evaluation stage

- The evaluation stage involves looking at similarities and differences between the performer and an elite performer undertaking the same movement sequence or skill.
  - It can be either objective (using performance rubrics, checklists or rating scales) or subjective (personal opinion or interpretation).
  - Quality should be ranked, usually by using checklists or performance templates.
  - What are the strengths and weaknesses and what might be causing poor-quality movements?
  - How can problems be addressed/improved?
  - Which problem areas are more important to improve than others?

### 4.5 The error correction stage

- The error correction stage involves making improvements to the way skills are performed. Considerations include the following:
  - How can biomechanical principles be referred to when making improvements?
  - How are skills best learnt/practised?
  - What types of feedback need to be used?
  - Distributed practice is often used with cognitive learners, while massed practice is used with higher stages of learning.
  - Different techniques and changes to motor programs take time to be implemented.
  - Regular feedback needs to occur throughout, and after, each practice session.
- After feedback has been provided and the improvement strategy practised over a reasonable period of time (two or more weeks), it is imperative that primary data be collected again to evaluate the effectiveness of the 'new' technique or movement sequence.

# CHAPTER REVIEW



Assessment  
Chapter 4 Review

- 1 **Outline** why simply knowing the serving accuracy of a volleyball player does not provide useful information to a coach hoping to make improvements to a player's serving technique.
- 2 Some coaches want to simply observe how a skill is being performed and then make suggestions as to how it can be improved without undertaking the preparation stage. **Outline** two reasons why taking this 'short cut' may compromise the effectiveness of analysis.
- 3 **©VCAA** Exam 2019, Section B, Q7 b  
How may a coach benefit from using qualitative movement analysis data instead of quantitative serve accuracy data?
- 4 Follow-through is a vital part of most movement skills ranging from a tennis serve or forehand to a golf swing or softball hit, yet this is often overlooked by many novice coaches. Clearly **discuss** how an effective follow through in any of these examples leads to more effective performance of the skill.
- 5 **©VCAA** Exam 2020, Section B, Q4  
Peta is a soccer coach who is applying biomechanical and skill acquisition principles to help players refine their goal-shooting skills. Performing a qualitative movement analysis, Peta observes that while the players are generally accurate with their goal kicking, there is very little power generated when they strike the ball.  
With reference to the relevant biomechanical principles, **discuss** the type of feedback that Peta can provide to the players to correct this error and refine their skill. Your response should include reference to:
  - feedback
  - summation of momentum
  - angular velocity
  - levers.
- 6 A tennis player is experiencing problems when trying to execute a smash, and more times than not ends up hitting the ball out of court. The following table summarises the different phases that make up the smash and what the player is observed doing. In the last column, **suggest** a way in which this part of the smash might be 'corrected' or improved.

Phase	Movement observed	Suggested improvement
<b>Take-off</b>	Pushing off the ground with both feet in a front-on position	
<b>Backswing</b>	Racquet brought back to side of body level with head (minimal elbow flexion)	
<b>Contact</b>	Impact made above the head with ball travelling upwards with limited straightening of arm	
<b>Downswing</b>	Rapid until racquet level with torso and then slows from waist to being level with feet	
<b>Follow-through</b>	Minimal follow-through with racquet not passing body	

**7** ©VCAA Exam 2020, Section B, Q9 b

A young golfer is having their swing technique assessed by their coach. The coach has prepared a checklist and has observed the golfer's swing technique. **Explain** why using digital recording as part of a qualitative analysis is the optimal method of observation to analyse and improve the golfer's swing technique.

- 8** A group of Year 7 students are introduced to American football but are not given suitable instructions or demonstrations about how to throw the gridiron ball to enable effective passes or throws for distance to occur.
- a** Research the different phases of a gridiron throw/pass and **summarise** the stages in a table similar to the one used in Question 6.
  - b** **Extrapolate** how the analysis applied to one skill might be transferable to another skill that has similar movement sequences. For example, can the skill of serving in tennis be transferred to serving in volleyball? In your response **identify** the two different sport skills you have chosen to highlight the concept of 'transferability.'

**Command term****extrapolate**

Infer and/or extend information that may not be clearly stated from a narrative, opinion, graph or image by assuming existing trends will continue

## CHAPTER

# 5

## ACUTE PHYSIOLOGICAL RESPONSES TO EXERCISE

UNIT 3 - AREA OF STUDY 2



Quino AI/Unsplash.com

**FIGURE 5.01** Acute responses only last for the duration of any activity.

### Quizzes

Chapter 5 Pulse check

- 5.1 Check-in questions
- 5.2 Check-in questions
- 5.3 Check-in questions
- 5.4 Check-in questions

Chapter 5 Review

### Videos

Masterclass: Chapter 5

- 5.1 In focus: Gaseous exchange
- 5.2 In focus: Stroke Volume has a finite capacity

5.2 In focus: Arteriovenous Oxygen Difference

5.3 In focus: Motor Unit Recruitment

5.4 In focus: Active vs passive recoveries and effects on EPOC

### Resources

5.1 Template: Recording respiratory rate

5.2 Template: Heart rate (bpm) for submaximal and maximal exercise

Chapter 5 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



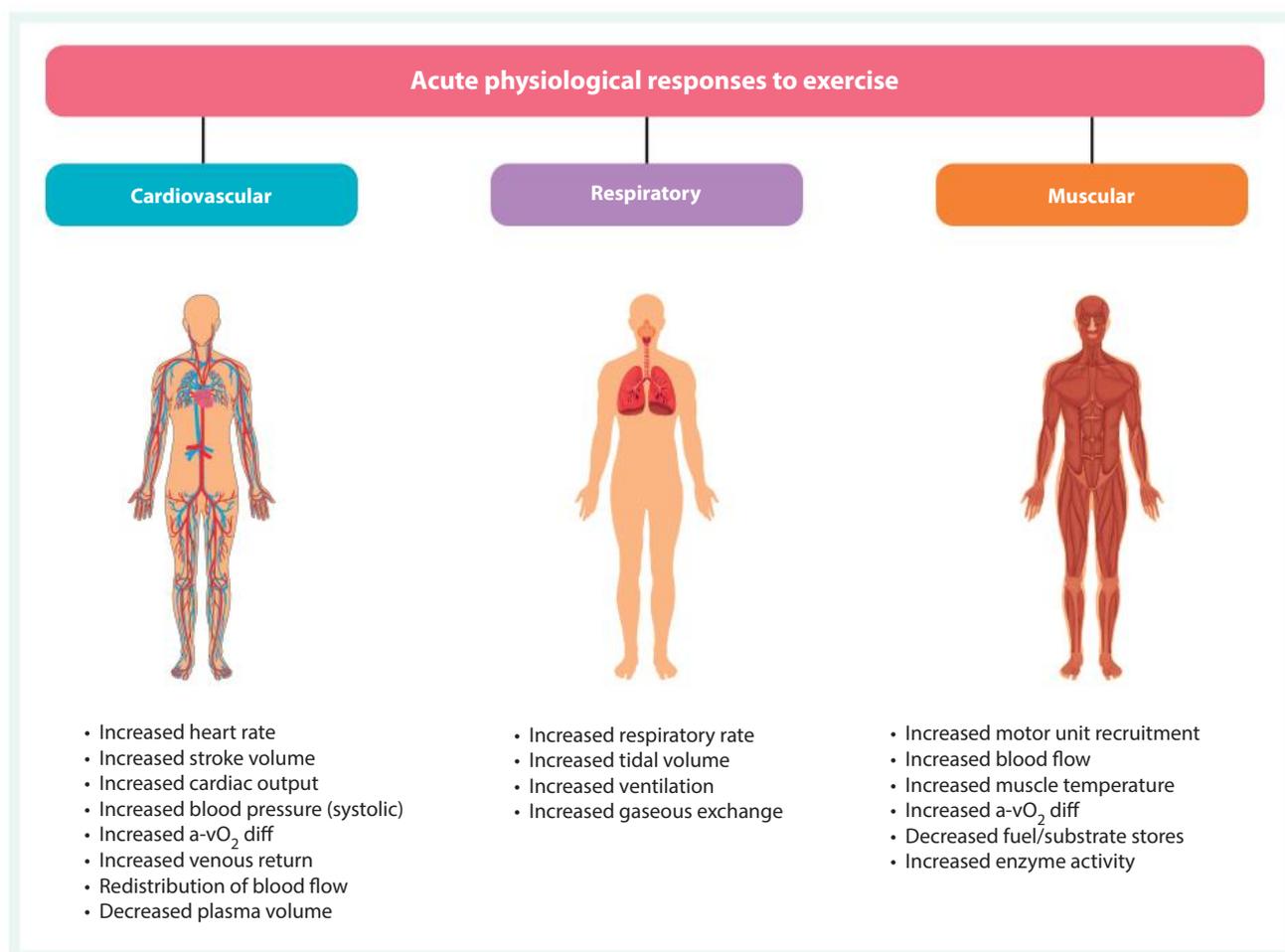
- » acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems
- » oxygen uptake at rest, during physical activity and recovery, including oxygen deficit, steady state and excess post-exercise oxygen consumption (EPOC)

## KEY KNOWLEDGE

- » an ability to:
  - participate in a range of laboratory activities to collect and analyse data on the range of acute effects that exercise has on the cardiovascular, respiratory and muscular systems of the body
  - explain the changes in oxygen demand and supply at rest, during submaximal and maximal exercise

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 5

**acute responses**

The body's immediate changes to exercise; these are short-term – that is, they last for the duration of exercise or training and while returning to pre-exercise levels (recovery)

**Assessment**

Pulse check

When we exercise, changes occur in the body to meet the increased energy and physiological demands of the activity. The respiratory, cardiovascular and muscular systems work together to meet these increased demands. The respiratory system takes up oxygen, the cardiovascular system transports it, and the muscles use it to allow multiple different movements to occur. Together they provide a volume (V) of oxygen (O<sub>2</sub>) to different body parts – this is referred to as VO<sub>2</sub>. The initial responses of these three systems are called **acute responses** and are only short-term because they only last for the duration of exercise.

This chapter investigates how each of these body systems responds to supply more oxygen and fuels to working muscles, and how they also remove wastes. The level of response depends on the intensity and type of exercise being undertaken.

**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- List** two changes that occur at the respiratory system level when you warm up.
- Discuss** any changes that occur to the heart to allow more blood to be pumped to working muscles as exercise intensity increases from resting levels.
- Apart from increasing muscle temperature, what occurs at the muscular level during a warm-up?
- Why do we sweat towards the end of a warm-up?
- Suggest** three different sporting activities that would require participants to have a very high VO<sub>2</sub> max.

**DID YOU KNOW?**

Despite VO<sub>2</sub> being thought of as a respiratory response, it involves the cardiovascular and muscular systems as well and cannot be singled out as only being 'respiratory' in nature.

**REAL WORLD APPLICATIONS****Warm-ups before exercise/training**

Soccer has gained increasing popularity among men and women and there are currently about 300 million registered players, referees and technical staff worldwide, approximately 40 million of whom are female players. Soccer is the world's most popular sport, and the FIFA World Cup is the biggest sporting event on the planet, not only filling stadiums but also pulling in 30 billion TV spectators across the tournament. FIFA is aware not only of this development but also of its responsibility to care for the health of players.

The '11+' program is an injury-prevention program that was developed for FIFA by an international group of experts based on their practical experience with different injury-prevention programs for amateur players aged 14 or older. It is a complete warm-up package and should replace the usual warm-up prior to training. The warm-up has three parts, with a total of 15 exercises, which should be performed in the specified sequence at the start of each training session:





## Part 1 examples



## Part 2 example



## Part 3 example



**FIGURE 5.02** The 11+ warm-up/injury prevention program

- 1 running exercises at a slow speed combined with active stretching and controlled partner contacts
- 2 six sets of exercises focusing on core and leg strength, balance and plyometrics/agility, each with three levels of increasing difficulty
- 3 running exercises at moderate–high speed combined with planting/cutting movements.

This is an example of how a warm-up prepares the body for the activity that is about to be performed and, ideally, focuses on all three body systems. Most warm-ups will consist of 5–10 minutes of aerobic-based activities, followed by **dynamic stretching** and strengthening exercises. Specificity is an important consideration so try to incorporate a lower-intensity version of the movements you are likely to be performing after the warm-up, and gradually increase the intensity to mimic that of the session you are about to engage in.

#### **dynamic stretching**

Actively moving joints and muscles through a range of movement, usually with sport-specific motions

## **🚩 SIGNPOST**

To find out more about the 11+ program, which has significantly reduced injuries during training and games in soccer as well as preparing major body systems for the challenges ahead, visit the Football Victoria website.



**Weblink**  
The '11+' Manual

## 5.1 ACUTE RESPIRATORY RESPONSES TO EXERCISE

In this module you will learn about:

- acute respiratory responses and learn to:
- link acute respiratory responses to changes in oxygen supply, carbon dioxide removal and gaseous exchange at both lungs and muscles.

### ventilation

The amount of air inspired and expired, measured in litres per minute (L/min)

The respiratory system is responsible for the uptake of oxygen and the removal of carbon dioxide (CO<sub>2</sub>) at the lungs. At the beginning of exercise, muscle receptors stimulate increased **ventilation** (V) by sending messages to the respiratory centre in the brain telling it to increase the volume and rate of breathing. Exercise results in deeper and more frequent breaths being taken and an increase in the amount of oxygen exchanged for carbon dioxide at the lungs. The acute respiratory responses to exercise can be summarised as:

- increased respiratory rate
- increased tidal volume
- increased ventilation
- increased gaseous exchange.



Maksym Tymchyk/Unsplash

**FIGURE 5.03** All acute respiratory responses seek to increase oxygen availability to muscles.

### Increased respiratory rate

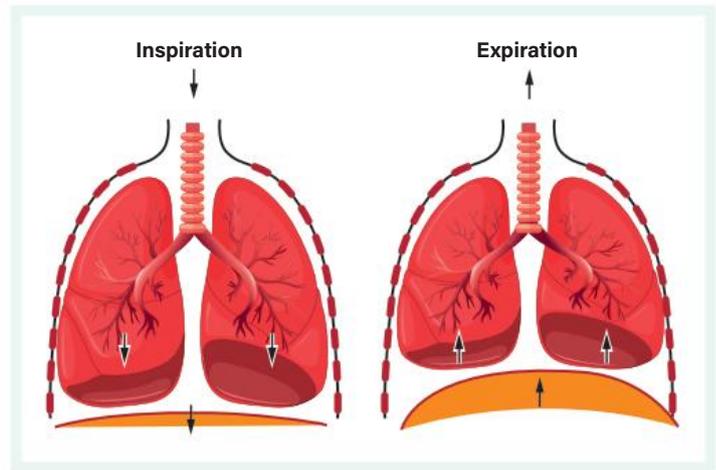
Respiratory rate refers to the number of breaths taken per minute. On average, this tends to be around 15 breaths per minute while resting, but it can vary depending on age, sex, training status and many other factors. As exercise commences, the rate will increase in direct response to the demand for oxygen. Performing a warm-up will see a gradual increase, whereas working at higher intensities will see a more rapid rise in respiratory rate, which can reach 50–60 breaths per minute.

## Increased tidal volume

Tidal volume (TV) reflects the depth, or amount, of each breath taken. The amount of air taken in per breath at rest tends to be around 0.5 litres, and this also increases as exercise intensity increases, up to 4–5 litres.

It is worth noting that:

- tidal volume measures the amount of air per breath containing only 20 per cent oxygen
- males have a higher tidal volume than females due to having larger lungs
- tidal volume has a **finite capacity**, which is reached at submaximal intensities.



**FIGURE 5.04** Role of the diaphragm during inspiration (increasing TV) and expiration (decreasing TV)

## Increased ventilation

Ventilation (V) is a measure of how much air the lungs breathe in and out per minute and is calculated by multiplying respiratory rate by tidal volume:

$$\text{ventilation (L/min)} = \text{respiratory rate (breaths/min)} \times \text{tidal volume (L/breath)}$$

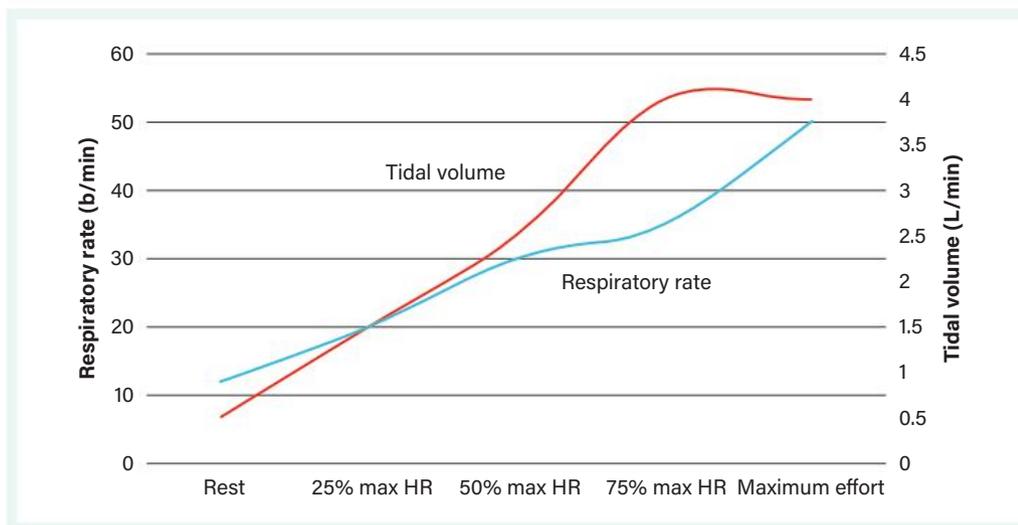
Table 5.01 reveals the changes in ventilation that occur when changing from rest to submaximal efforts. Note that the tidal volume has not increased above submaximal levels.

**TABLE 5.01** Comparison of respiratory rate, tidal volume and ventilation at rest and during exercise

Condition	Respiratory rate (breaths/min)	Tidal volume (L)	Ventilation (L/min)
Rest	12	0.5	6
25% max HR	20	1.5	30
50% max HR	30	2.5	75
75% max HR	35	4.0	140
Maximum effort	50	4.0	200

### finite capacity

The limiting value of a variable, beyond which it is not capable of any further increase



**FIGURE 5.05** Respiratory rate and tidal volume at rest and varied intensities

**gaseous exchange**

The process of swapping oxygen and carbon dioxide. These gases move passively by diffusion across different surfaces – for example, between the blood and either the lungs or muscles.

**alveoli**

The very small air sacs, found in the lungs, where exchange of oxygen and carbon dioxide (gaseous exchange) takes place



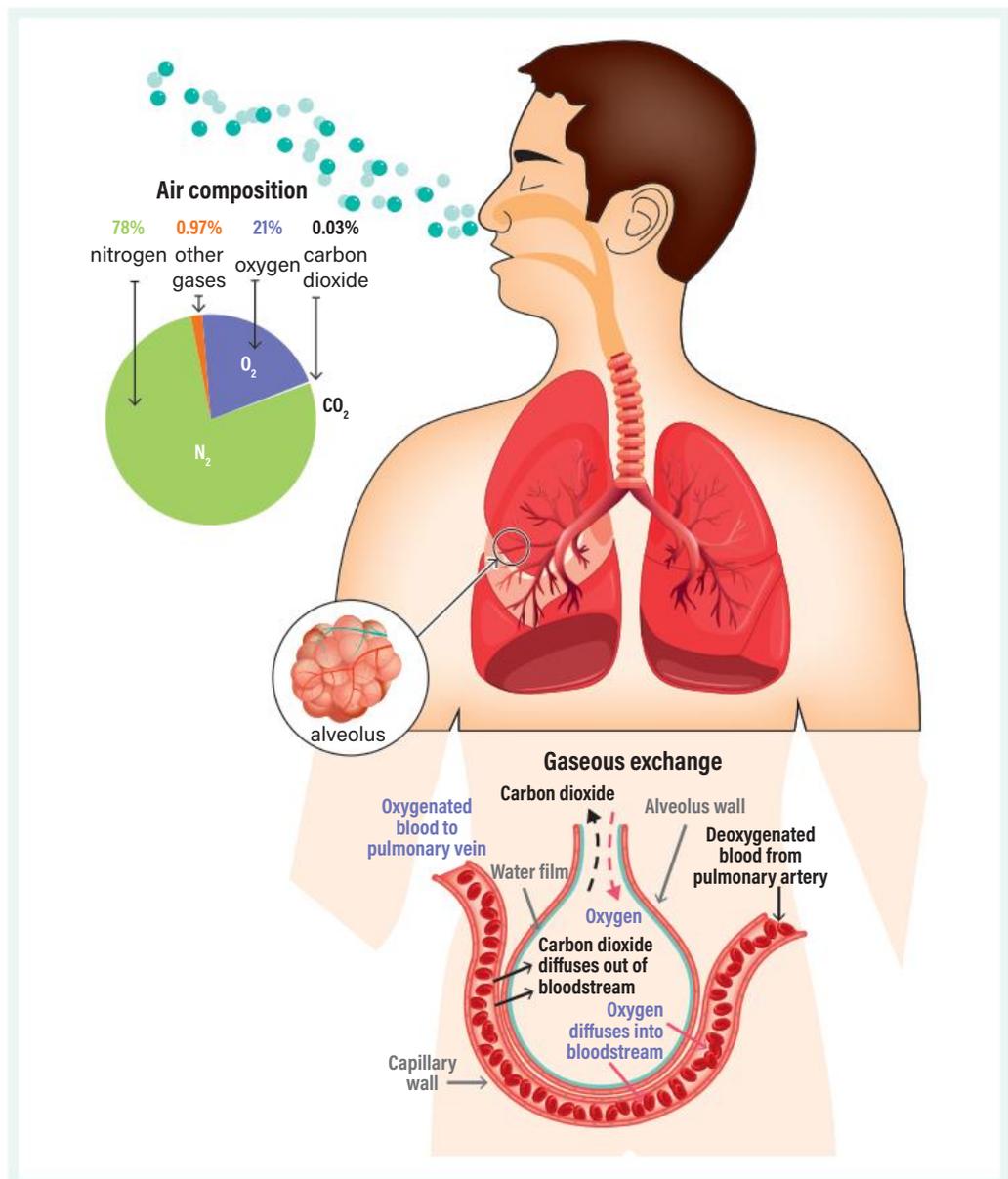
Video

In focus: Gaseous exchange

## Increased gaseous exchange

**Gaseous exchange** takes place at the lungs and also at the muscles, where gases move from high concentration to lower concentration. As we breathe in, more oxygen enters the lungs and the **alveoli** (singular: alveolus) than is present in the surrounding capillaries. The carbon dioxide concentration in the capillaries is higher than that in the alveoli, so oxygen moves into the capillaries and carbon dioxide moves out – the gases are exchanged! The opposite occurs at the muscles to allow oxygen to move out of the capillaries into the muscles and carbon dioxide to move from muscles into capillaries. Carbon dioxide is then returned to the lungs and exhaled.

Gaseous exchange is sometimes referred to as diffusion, and more specifically, when it happens at the lungs, as pulmonary diffusion. During exercise, the diffusion rate is increased so that greater amounts of oxygen and carbon dioxide can be exchanged at the alveoli and the muscles. This means more oxygen is available at the muscles and more carbon dioxide (which has been produced as a by-product of aerobic energy production) can be removed.



**FIGURE 5.06** Respiratory system characteristics and mechanisms during gaseous exchange

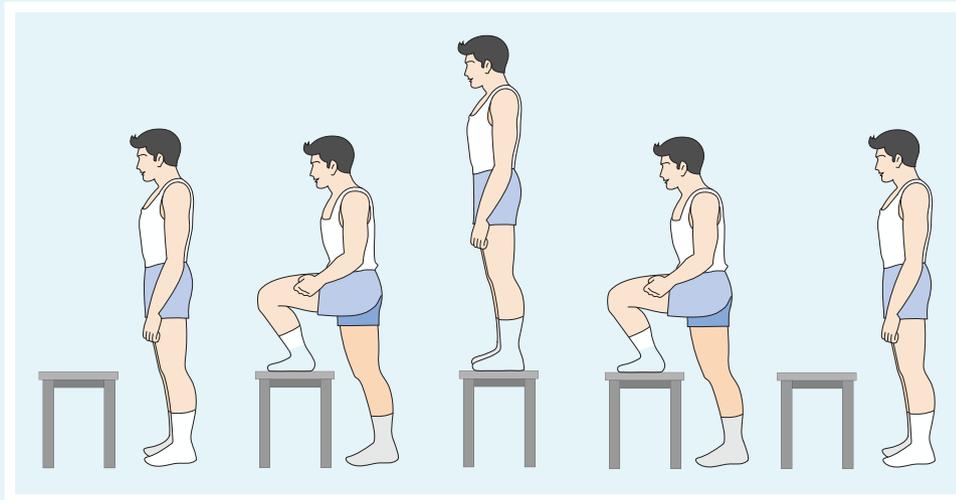
Source: Adapted from Carolina Biological Supply Company

- Pulmonary diffusion at maximal exercise increases by between two and three times due to:
- increased alveolar volume
  - greater capillary blood volume
  - increased alveolar–capillary surface area contact.

## COLLABORATIVE TASK

### Lab activity

#### Respiratory rate at rest and varied exercise intensity



**FIGURE 5.07** The step test

#### AIM

To determine the change in respiratory rate in response to different workloads

#### EQUIPMENT

- step or platform (40–50 centimetres high)
- online metronome

#### METHOD

##### Submaximal exercise

- 1 Subjects sit quietly for 1–2 minutes. Record their resting respiratory rate by counting how many breaths they take per minute (you can count how many breaths they take in 20 seconds and multiply this by 3).
- 2 Subjects complete 1 minute of continuous exercise step-ups to be performed at the same workload/pace. Start with the metronome rate set at 30 beats per minute (1 second up, 1 second down).
- 3 After 1 minute of stepping, record subjects' respiratory rate while they are standing still for 20 seconds. Then ask them to complete another minute at the same pace/workload. After another minute of stepping, record their standing respiratory rate for another 20 seconds while they are standing still.
- 4 Subjects then perform 1 minute of stepping at a higher workload – this time, 35 bpm. After 1 minute of stepping, record subjects' respiratory rate while they are standing still for 20 seconds, then ask them to complete another minute at the same pace/workload (35 bpm). After another minute of stepping, record their standing respiratory rate for another 20 seconds while they are standing still.



**Template**

Recording respiratory rate





- 5 Subjects then perform 1 minute of stepping at a higher workload – this time, 40 bpm. After 1 minute of stepping, record subjects' respiratory rate while they are standing still for 20 seconds, then ask them to complete another minute at the same pace/workload (40 bpm). After another minute of stepping, record their standing respiratory rate for another 20 seconds while they are standing still. Wait for 1 minute and record their recovery heart rate. Record it again after 2 minutes and 3 minutes.

### RESULTS

Metronome pace		30 bpm		35 bpm		40 bpm		Recovery (min)		
Subject	Rest	1	2	3	4	5	6	1	2	3
1										
2										
...										

### DISCUSSION

- 1 Graph the respiratory-rate responses for the step-up exercises. **Describe** any trends evident from the activity performed and associated changes to respiratory rate.
- 2 Comment on the likely changes to tidal volume throughout the step-up test.
- 3 **Discuss** the likely oxygen consumption that occurred throughout the step-up test. **Explain** your answer with reference to the fact that ventilation has a direct relationship with  $VO_2$ .
- 4 **Compare** your data with that of another person in the class. **Explain** any differences.
- 5 **Predict** (by drawing on the graph) the respiratory-rate response of a highly trained cross-country runner to the same continuous activity.

### Command terms

#### describe

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

#### predict

Give an expected result of an upcoming action or event; suggest what may happen based on available information

## LOOKING FORWARD

### Using acute responses to determine fitness levels

#### Chapter 10

The Harvard step test is a submaximal, indirect field test that can be used to estimate a person's aerobic power. It is often used with subjects who cannot undertake a maximal fitness test.



### ABOVE AND BEYOND THE STUDY DESIGN

Blood redistribution during exercise, page 226

Sex differences at the respiratory, cardiovascular and muscular levels, page 227

The 'fast' and 'slow' parts of EPOC, page 228

## 5.1 CHECK-IN QUESTIONS

- 1 **Describe** the relationship between respiratory rate, tidal volume and ventilation.
- 2 **Explain** what is meant by the statement that 'tidal volume has a finite capacity.'
- 3 **Discuss** why the movement of gases increases to coincide with increased exercise intensity. Focus on gaseous exchange at the lungs in your response.
- 4 a **Calculate** the ventilation for a 100-metre swimmer taking 30 breaths per minute with a tidal volume of 4.0 litres.  
b **Suggest** how and why the ventilation of a 1,500-metre swimmer is different from that of a 100-metre swimmer.
- 5 Some endurance athletes, such as marathon runners and road cyclists, participate in training camps that take place at high altitudes. **Propose** why athletes find it more difficult to take up the same amount of oxygen 'at altitude' than when they are training at sea level.



### Assessment

5.1 Check-in questions

### calculate

Determine from given facts, figures or information; obtain a numerical answer showing the relevant stages in the working; determine or find (e.g. a number, answer) by using mathematical processes

### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer

### propose

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action

## 5.2 ACUTE CARDIOVASCULAR RESPONSES TO EXERCISE

In this module you will learn about:

- acute responses to exercise by the heart and blood vessels and learn to:
  - identify 'cardio' vs 'vascular' acute responses
  - link cardiovascular responses to respiratory responses due to close relationships between the two body systems
  - consider the cardiovascular system's role in supplying oxygen and fuels as well as removing wastes.

The cardiovascular system consists of the heart, blood vessels and blood. It is responsible for transporting oxygen and fuels to working muscles, thus providing energy for movements, and removing both waste and accumulated by-products. As exercise intensity increases and there is an increased demand for both oxygen and fuel, there must be an associated increase in cardiovascular supply to meet this demand. The acute cardiovascular responses to exercise can be summarised as:

- increased heart rate
- increased stroke volume
- increased cardiac output
- increased blood pressure
- increased arterio-venous oxygen difference
- redistribution of blood flow
- decreased plasma volume.

### DID YOU KNOW?

Before you exercise, your heart rate will likely increase even while you're resting or not moving. This is called the 'anticipatory rise' and occurs when the brain releases adrenaline and noradrenaline. It helps the body prepare for, and adapt to, forthcoming exercise faster and more efficiently.



**FIGURE 5.08** An athlete monitors his heart rate during a desert run.

#### resting heart rate

The number of heartbeats per minute while the body is in a state of rest

#### maximum heart rate

The highest number of beats your heart can pump per minute

#### LEARNING HACK

Sports physiologists often abbreviate 'maximum heart rate' to either max HR, HRmax or HRM.

## Increased heart rate

Heart rate refers to the number of contractions or beats per minute the heart experiences. **Resting heart rate** varies between individuals and can be affected by age, training and health status, body composition and many other factors. The average resting heart rate for most healthy adults is between 55 and 85 beats per minute.

There is a direct linear relationship between exercise intensity and heart-rate response in an effort to supply more oxygen and fuels to working muscles. Someone rowing at 50 per cent of their **maximum heart rate** (max HR) will not need as rapid an increase in their heart rate as someone who is rowing at 75% max HR at the start of the

activity. Similarly, the heart of the person choosing the lower workload will not be pumping as frequently (beats/min) as that of the person working at higher intensity.

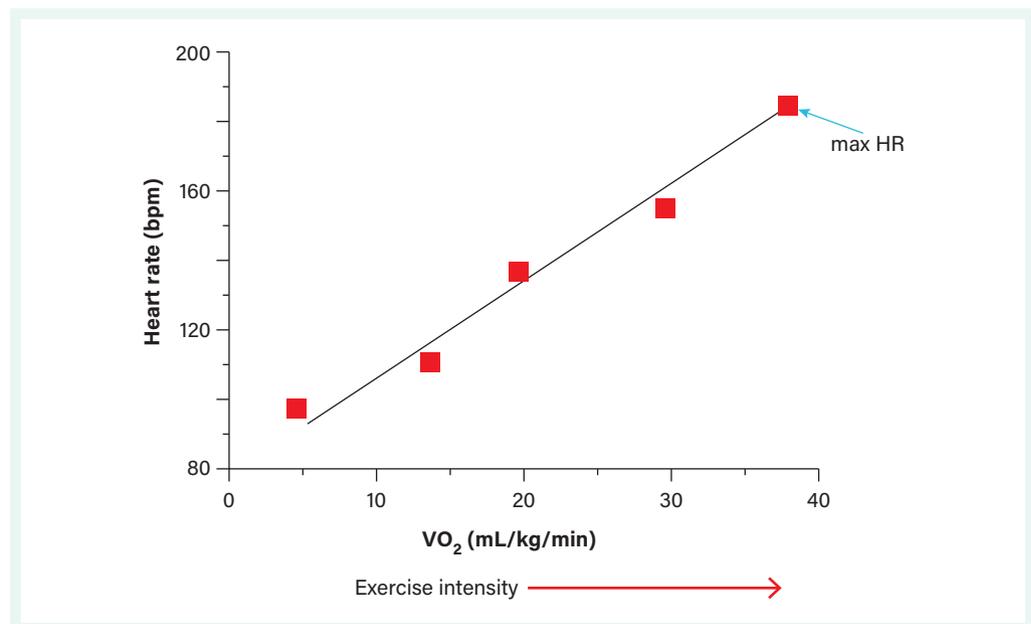
Quite often, exercise intensity is referred back to a person's maximum heart rate and what percentage of this they are required to perform at in order to meet activity/exercise demands.

A rough estimate of a person's maximum heart rate in beats per minute (bpm) is given by:

$$\text{max HR} = 220 - \text{age in years}$$

A 20-year-old might thus have a max HR of  $220 - 20 = 200$  bpm. If they wanted to work at 50% max HR, this would mean trying to keep their heart rate at 100 bpm while exercising/training.

Figure 5.09 reveals the direct linear relationship between heart rate and exercise intensity/oxygen demand.



**FIGURE 5.09** Heart rate and oxygen consumption during exercise at different intensities

## LOOKING FORWARD

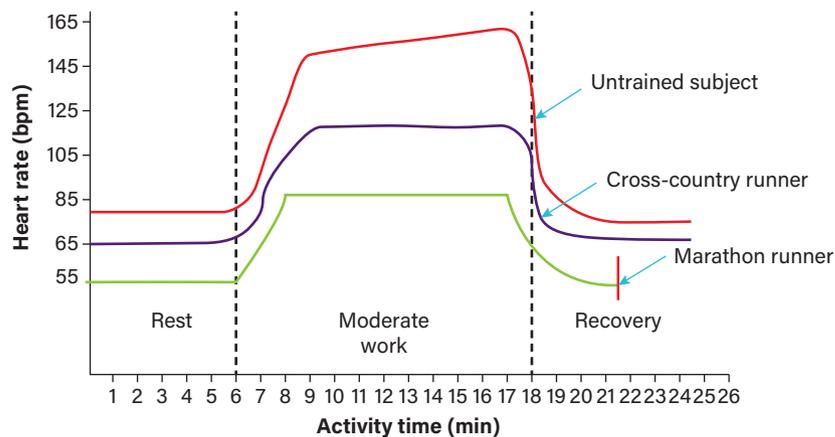
### The heart becomes more efficient with aerobic training

#### Chapter 15

When oxygen demand can be met by the body being able to supply sufficient amounts, the person is said to be in 'steady state'. You will learn that aerobic training results in athletes having lower resting and **submaximal heart rates**. This happens because their hearts become more efficient and can pump out larger volumes of blood, oxygen and fuels with fewer beats per minute.

#### submaximal heart rate

A range of heart-rate responses between resting and maximal values. These can be further classified as low submaximal (< 50% max HR), moderate submaximal (50–75% max HR) or vigorous submaximal (75–99% max HR).



**FIGURE 5.10** Heart-rate responses to moderate-intensity work for untrained and trained subjects

Why does our heart rate increase when we are nervous or preparing for a task?

## LOOKING FORWARD

### Are you ready for fitness testing or to start a training program?

#### Chapter 10

Before undertaking any fitness test, the 'informed consent' process needs to be applied. Whenever someone who has a pre-existing injury or health condition undertakes any form of physical activity or training, they need to complete a health screening questionnaire such as the PARQ.



**Template**

Heart rate (bpm) for submaximal and maximal exercise

## COLLABORATIVE TASK

### Lab activity

#### Heart rate at rest and varied exercise intensity

**AIM**

To determine the change in heart rate in response to submaximal and maximal exercise

**EQUIPMENT**

You will need heart-rate monitors. (If not available, calculate heart rate manually for 15 seconds at either the radial or carotid pulse.)

**METHOD**

**Submaximal exercise**

- 1 Subjects sit quietly for 3–5 minutes. Record their heart rate (or take resting pulse manually).
- 2 Subjects complete 5–8 minutes of continuous exercise (e.g. running, cycling, step-ups) to be performed at the same workload/pace.
- 3 Record subjects' heart rates after each minute of exercise in a results table, as shown below.
- 4 Subjects perform an active recovery (walking) until heart rate drops to below 100 beats per minute. Record heart rate at 1, 3 and 5 minutes post-exercise.

**Maximal exercise**

- 5 Record subjects' resting heart rates.
- 6 Subjects perform six maximal and consecutive sprints from side to side on a basketball or netball court. Record heart rate at completion of last sprint.

**RESULTS**

**Heart rate (bpm) for submaximal exercise**

	Pre-test	Continuous exercise										Recovery		
Subject	Rest	1	2	3	4	5	6	7	8	9	10	1	3	5
1														
2														
...														

**Heart rate (bpm) for maximal exercise**

Subject	Pre-sprint	Post-sprint
1		
2		
...		

**DISCUSSION**

- 1 Graph the heart-rate responses for both submaximal and maximal exercise on the same axis. **Describe** the shape of each graph in terms of heart-rate changes.
- 2 Comment on the likely stroke volume that would be experienced in both these different types of activities.
- 3 Did heart rate increase more with maximal exercise or submaximal exercise? **Explain** your answer with reference to physiological responses to exercise.
- 4 **Explain** why heart rate needs to increase linearly with increased exercise workloads.
- 5 **Compare** your data with that of another person in the class. Explain any differences.
- 6 **Predict** (by drawing on the graph) the heart-rate response of a highly trained triathlete to the same continuous activity and that of a highly trained sprinter to the six court-width sprints.

**Command terms**

**explain**

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

**compare**

Recognise similarities and differences and the significance of these similarities and differences

## Increased stroke volume

Stroke volume is a measure of how much blood is ejected from the left ventricle with each contraction, or systole. The pressure this creates on the arteries leaving the heart is known as systolic blood pressure: the harder the heart pumps, the greater the pressure created on the blood vessels leaving the heart.

The left ventricle can't keep increasing in size to accommodate larger and larger volumes of blood – it, too, has a finite capacity, which, in untrained subjects, occurs around 50% max HR. The ventricle size of males is larger than that of females because male hearts are larger. Endurance athletes have larger ventricles than untrained subjects, and their stroke volume can keep increasing up to much higher intensities of 80–90% max HR.

Figure 5.11 reveals the resting and maximal values of stroke volume for untrained, moderately trained and highly trained endurance athletes.

## Increased cardiac output

**Cardiac output** (Q) can be calculated by multiplying stroke volume (SV), which is the amount of blood pumped out of the left ventricle of the heart per beat, and heart rate (HR). This provides an indication of how much blood is being pumped from the heart each minute.

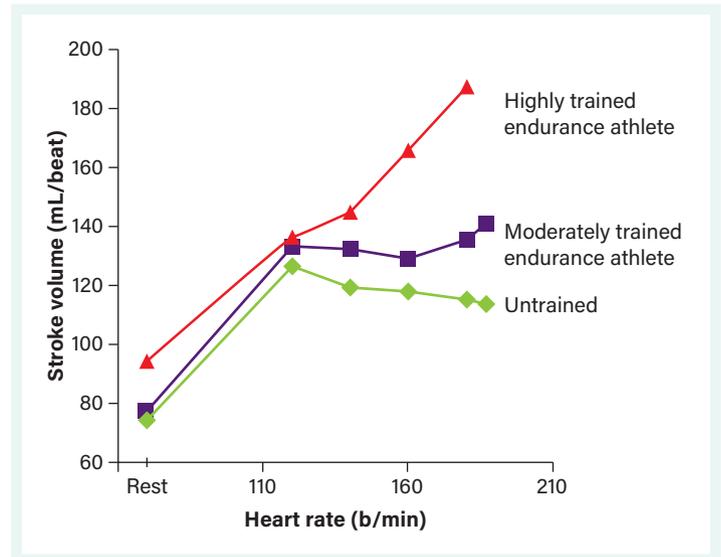
$$\text{cardiac output (L/min)} = \text{HR (beats/min)} \times \text{SV (L/beat)}$$

If we use the untrained and highly trained heart rates and stroke volumes at rest and maximal intensity from the graph in Figure 5.11, Table 5.02 shows how they combine to produce cardiac output.

**TABLE 5.02** Changes in stroke volume, heart rate and cardiac output in untrained and trained individuals at rest and during maximal exercise

Training status		Stroke volume (mL/beat)	Heart rate (beats/min)	Cardiac output (L/min)
Untrained	Rest	70	60	4.2
	Maximal exercise	110	180	19.8
Trained	Rest	90	50	4.5
	Maximal exercise	190	200	38.0

Heart rate is the most important factor in increasing cardiac output during exercise. During submaximal exercise, heart rate will increase until the oxygen demands of the activity have been met. It will then level off, as the body has reached a steady state where oxygen supply equals oxygen demand.



**FIGURE 5.11** Stroke volume and heart-rate responses in untrained and trained subjects

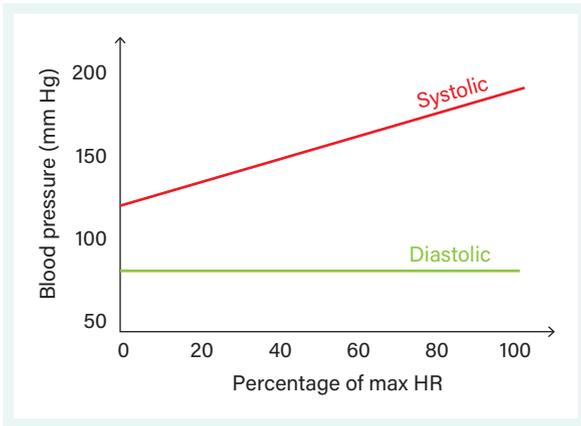
### cardiac output

The amount of blood squeezed/pumped out of the left ventricle per minute



### Video

In focus: Stroke Volume has a finite capacity

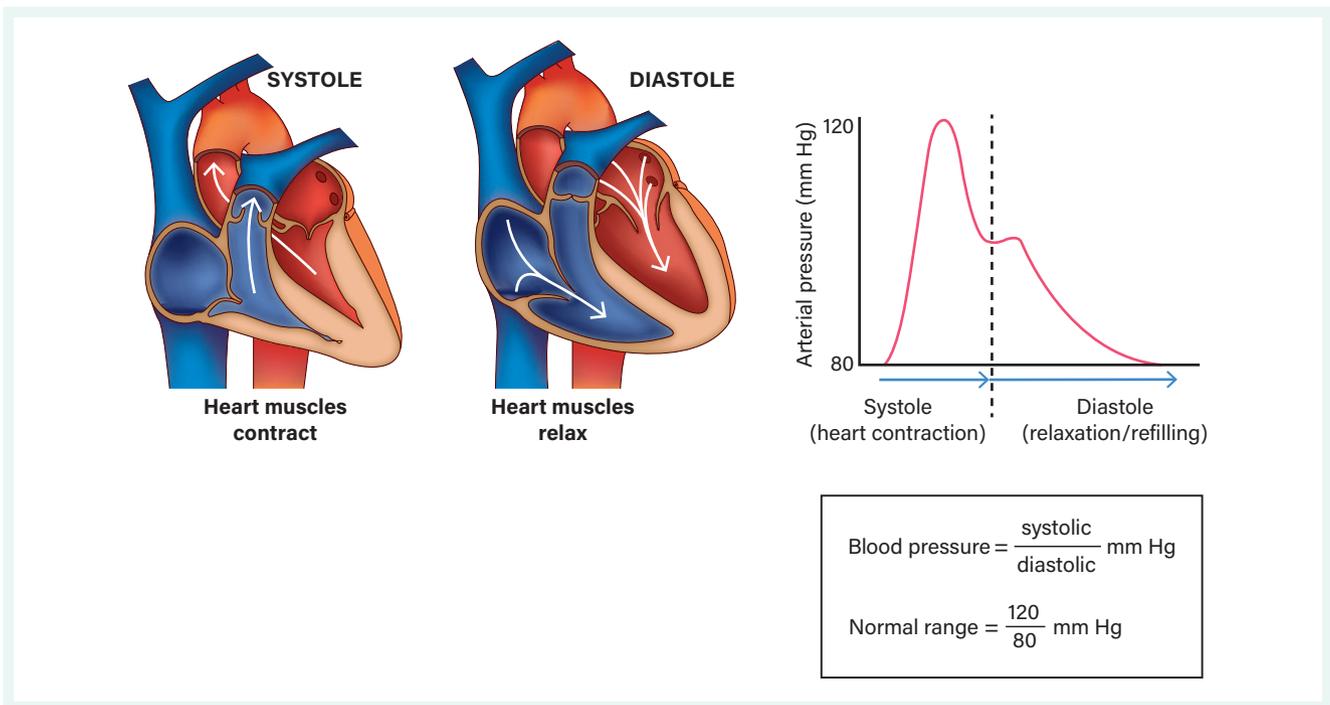


**FIGURE 5.12** Blood-pressure changes during dynamic exercise

## Increased blood pressure

As mentioned, when the heart pumps more blood out per beat and contracts more forcefully, the pressure occurring on the arterial walls increases significantly. Blood pressure is made up of two key parts: systolic blood pressure and diastolic blood pressure. **Systolic blood pressure** measures the pressure created with each contraction, or systole, of the heart. **Diastolic blood pressure** records the pressure created when the heart relaxes and the ventricle fills.

The harder the heart pumps, the greater the systolic blood pressure, but the diastolic blood pressure does not vary greatly during exercise.



**FIGURE 5.13** Arterial pressure created during heart contraction (systole) and relaxation/filling (diastole)

### systolic blood pressure

The higher of the two blood-pressure values, which represents the force of blood against arterial walls while your ventricles contract and pump blood out of the heart

### diastolic blood pressure

The lower of the two blood-pressure values, which represents the force of blood against arterial walls as the heart relaxes and the ventricles refill with blood – in the period of time when your heart relaxes between beats

### DID YOU KNOW?

Compared to dynamic exercise and muscle contractions, isometric contractions such as those used when performing a wall squat or a 'plank' result in significant increases in blood pressure – especially the systolic component.

## Increased arteriovenous oxygen difference

There is a difference between the oxygen concentration in arterial blood and that in venous blood, and this is known as the **arteriovenous oxygen difference** (a-vO<sub>2</sub> diff). Arterial blood oxygen concentrations will always be higher because the blood is yet to be transported to working muscles, where the oxygen will be extracted and used. Hence, the oxygen concentration in venous blood will always be lower.

At rest:

arterial oxygen concentration = 20 mL O<sub>2</sub>/100 mL blood

venous oxygen concentration = 14 mL O<sub>2</sub>/100 mL blood

a-vO<sub>2</sub> diff = 20 - 14 = 6 mL O<sub>2</sub>/100 mL blood

### arteriovenous oxygen difference

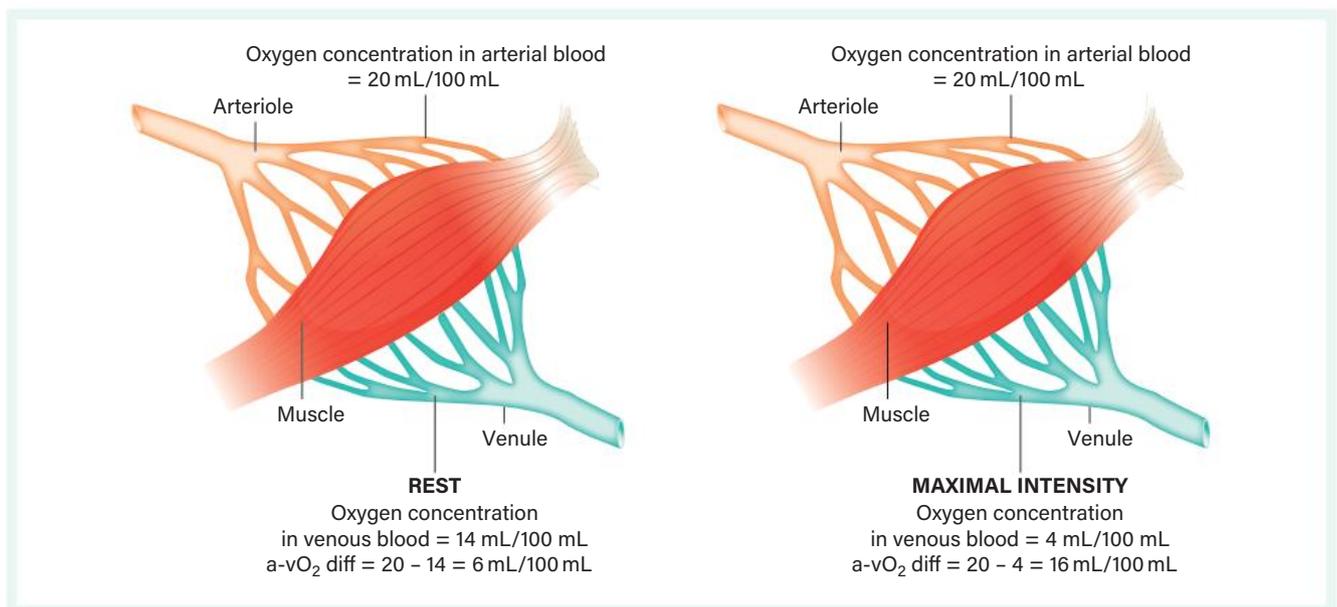
A measure of the amount of oxygen taken up from the blood by the tissues, as indicated by the difference in oxygen concentration between arterial blood and venous blood; measured per 100 mL of blood



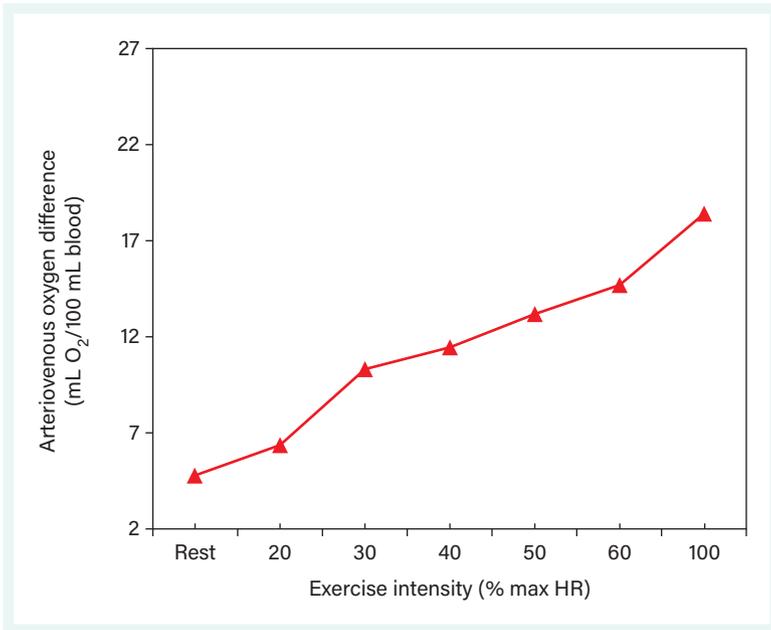
Video

In focus: Arteriovenous Oxygen Difference

Another direct relationship exists with this variable: the greater the exercise intensity and the more oxygen extracted by working muscles, the greater the a-vO<sub>2</sub> diff. Resting a-vO<sub>2</sub> diff figures are much lower than those when working maximally because the demand for, and use of, oxygen is significantly higher – sometimes between three and four times larger. Many sports scientists use a-vO<sub>2</sub> diff as an indirect measure of how much oxygen muscles are using.



**FIGURE 5.14** The arteriovenous oxygen difference at rest and at maximal intensity



**FIGURE 5.15** Arteriovenous oxygen difference at rest and at varied intensities of exercise performed on a cycle ergometer

**vascular shunt**

The process of redistributing blood throughout the body through simultaneous vasoconstriction and vasodilation, depending on physiological needs

**vasoconstriction**

A process whereby blood vessels narrow/constrict their internal diameter, thereby decreasing blood flow

**vasodilation**

A process whereby blood vessels increase/expand their internal diameter, resulting in an increase in blood flow

**plasma**

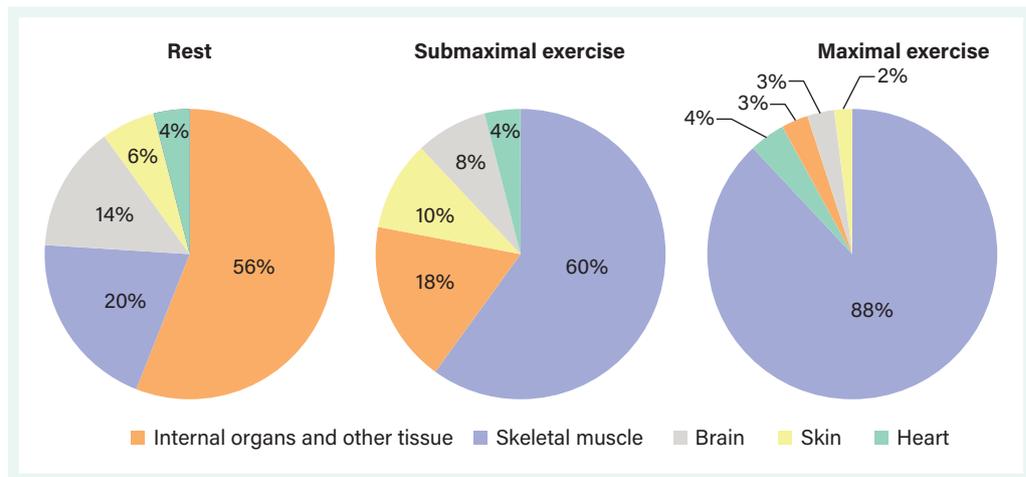
The liquid portion of blood that transports fuels to cells, removes wastes from cells and helps maintain body temperature

## Redistribution of blood flow

Blood flow around the body changes significantly when moving from rest to increased activity and workload levels. At rest, the skin and skeletal muscles receive between about 20 and 25 per cent of the cardiac output. During exercise, the cardiovascular system redistributes blood so that more of it goes to the working muscles and less to other body organs such as the digestive system. Interestingly, as more heat is produced by working muscles and our external temperatures increase, body temperature also increases, and more blood is sent to the skin to aid with thermoregulation.

This redirection of blood flow is caused by a mechanism called the **vascular shunt**, which involves simultaneous **vasodilation** and **vasoconstriction** of blood vessels. This

process allows between 80 and 90 per cent of the cardiac output to go to active skeletal muscles and skin at maximal rates of work. It works a little bit like a roadworks with detours, where cars are redirected to some routes and stopped from travelling on others. The blood vessels allow more blood to travel to the working muscles, and they don't allow much to travel to other organs. When exercise stops, the blood distribution returns to its normal 'pre-detour' route.



**FIGURE 5.16** Blood flow from the heart at rest and at submaximal and maximal exercise

## Decreased plasma volume

During endurance activities, when body temperatures rise and sweating occurs, blood volumes decrease. Studies have shown that **plasma** volume can decrease by 10 per cent during prolonged endurance activities. Plasma is the liquid component of blood and assists in thermoregulation as well as with promoting efficient blood flow throughout the cardiovascular system. The size of the decrease depends on the intensity of the exercise, environmental factors

Adapted from Abernethy et al., 2013

(such as temperature) and the individual's level of hydration. Athletes who are hydrated before exercise, and who hydrate throughout the exercise period, are less likely to experience plasma decreases that might have a negative effect on their performance.

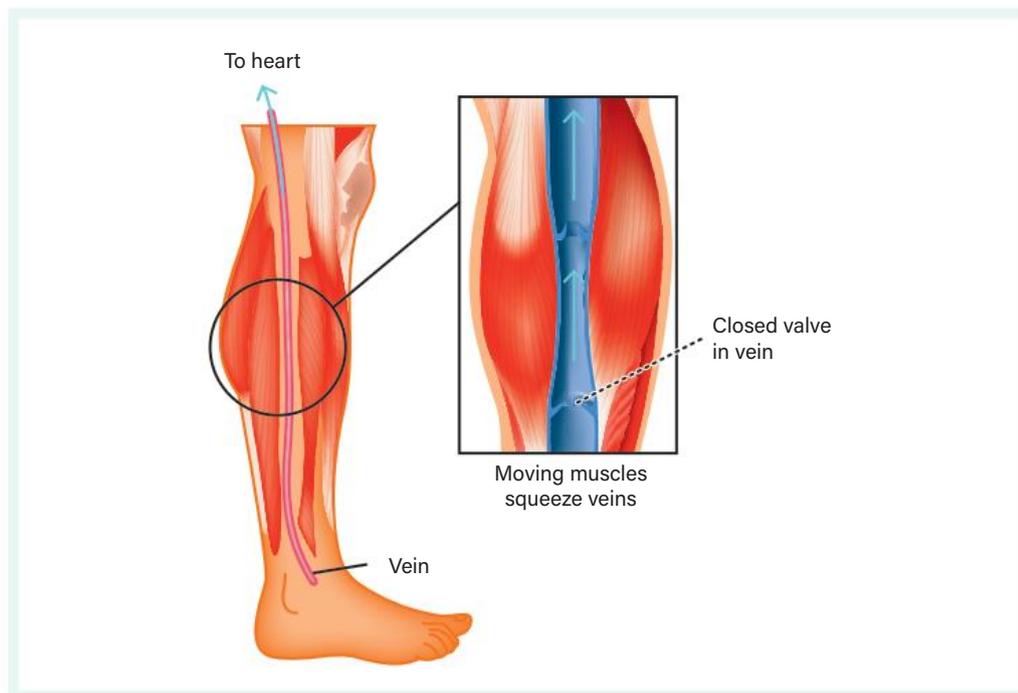
### DID YOU KNOW?

Cramping is the result of an involuntary, sudden muscle contraction that doesn't relax, and it can be quite painful and debilitating. Several factors combine and can contribute to cramping. Two such factors that experts frequently cite are dehydration and lack of oxygen.

The heart can only eject as much blood as it has in its ventricles, so it is important for an increase in cardiac output to be accompanied by an increase in **venous return**. During exercise, the venous return is increased via the muscle pump created when muscles contract and 'squeeze' veins, pushing the blood contained within them back to the heart. In essence, this muscular pump helps the vascular pump (the heart) return blood to the heart and lungs.

#### venous return

The rate of blood flow back to the heart, which can be increased by performing an active recovery



**FIGURE 5.17** Increased venous return/decreased venous pooling that occurs during an active recovery

### LOOKING FORWARD

**An active recovery promotes venous return and prevents venous pooling**

#### Chapter 7

An active recovery promotes venous return by having muscles squeeze the blood vessels they surround. This assists the heart's pumping action by creating a 'muscle pump' to increase the flow of blood back to the heart.



## Assessment

5.2 Check-in questions

## Command terms

**state**

Give a specific name or value or other brief answer without explanation or calculation

**account for**

State reasons for; report on

## 5.2 CHECK-IN QUESTIONS

- 1 **State** the relationship that exists between cardiac output and ventilation.
- 2 It is generally accepted that males have a higher cardiac output than their female peers. **Account for** this difference and provide a performance advantage it creates for endurance athletes.
- 3 The resting heart rate of aerobically trained athletes tends to be lower than that of athletes who are trained to perform more explosively and repeatedly with breaks. For example, the resting heart rate of a soccer midfielder could be 50 bpm, whereas the resting heart rate of a goalie might be 60 bpm. **Suggest** any cardiovascular factor that might explain this difference.
- 4 Use your understanding of the vascular shunt mechanism to **discuss** why athletes should avoid large meals immediately before competing in events that require large amounts of oxygen.
- 5 **Discuss** why it is important for triathletes to be fully hydrated before an 8-hour event and also to hydrate throughout the event. You should focus on potential redistribution of blood that will occur if the triathlete starts to experience dehydration and elevated body temperatures and how this contributes to slower performance times.

## 5.3 ACUTE MUSCULAR RESPONSES TO EXERCISE

In this module you will learn about:

- acute muscular response to exercise
- how the brain works with the muscular system to vary the amount of force produced and learn to:
  - link fuel usage to exercise intensity and duration
  - consider the different effects of exercise on slow- and fast-twitch muscle fibres
  - link increased muscle temperature to increased enzyme activity and need to thermoregulate.

Juice Dash/Shutterstock.com



**FIGURE 5.18** Increased motor unit recruitment produces more forceful contractions.

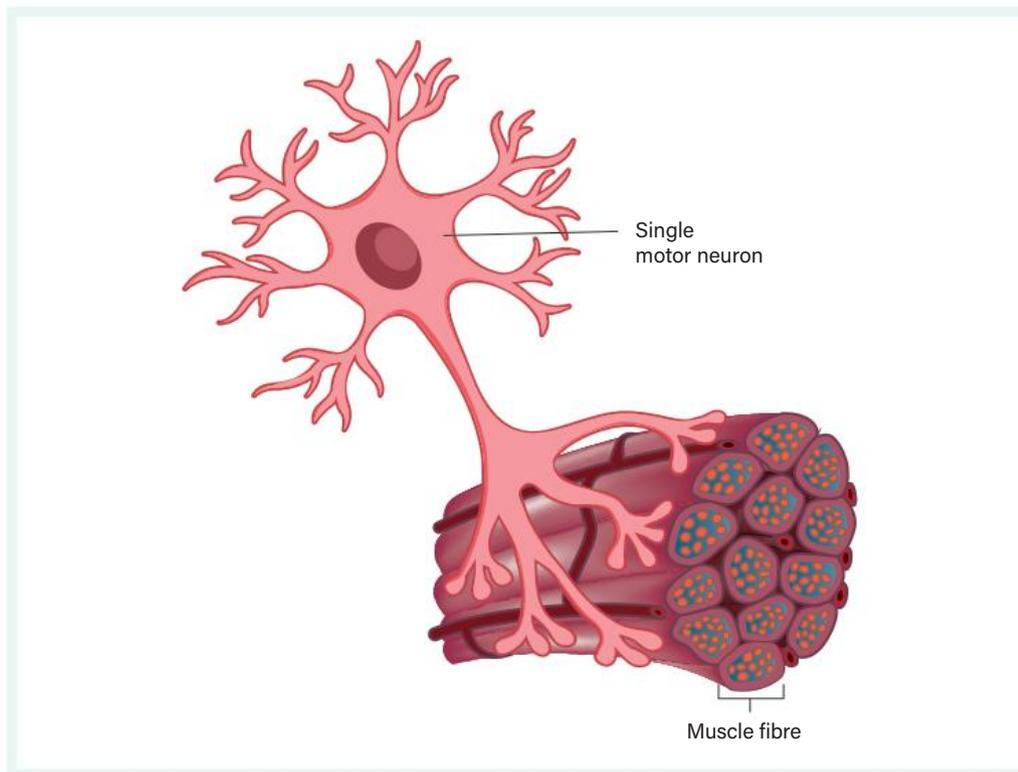
In order for exercise to begin, the muscular contractions responsible for movement need to increase. All physical activity, exercise and sports require movement of the body. Whether the action is walking the dog, going for a run or kicking a football, the muscles involved need to increase their activation and contraction frequency. The acute responses will vary according to the intensity and duration of the activity about to be performed. These responses include:

- increased motor unit recruitment
- increased use of fuels and energy substrates (decreased fuel stores)
- increased muscle temperature
- increased blood flow to working muscles
- increased arteriovenous oxygen difference
- increased enzyme activity.

## Increased motor unit recruitment

When moving from rest, the amount of force developed in a working muscle needs to increase. Muscle fibres within a muscle are activated by a **motor neuron**, which is the connection between the central nervous system and the specific muscle required to perform a particular activity. To do this, the brain can either increase the number of **motor units** recruited, or it can increase the frequency of messages sent to activate the motor unit. Depending on the required strength and speed of the contraction, the number of motor units recruited and the rate at which they are recruited can be adjusted.

Muscle fibre recruitment follows a set pattern called the size principle, which states that motor units will be recruited in order of size, from smallest to largest, depending upon the intensity. Smaller, slow-twitch (ST) fibres that are slower to contract and generate less force are recruited first, followed by fast-twitch fibres.



**FIGURE 5.19** A motor unit consists of a motor neuron and all the fibres it stimulates.

When a motor unit is activated, it will contract maximally or not at all, depending on the strength of the stimulus (this is the 'all or nothing principle'). Increasing the frequency of the messages will also increase the force produced in the muscle. Figure 5.20 shows that when we require low-intensity/low-force contractions, slow motor units and small motor neurons are recruited. However, if we require higher intensity of effort with greater muscular force, faster motor units and larger motor neurons are called on to produce muscle contractions. In the example shown, a low to moderate amount of force would be produced by the smaller motor units recruited.

### motor neuron

A nerve cell responsible for carrying signals away from the central nervous system towards muscles to cause movement

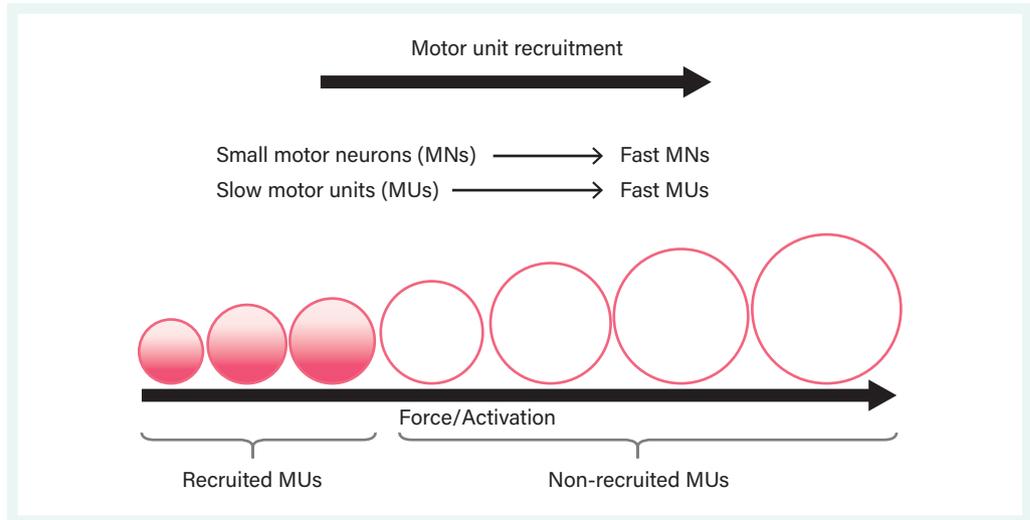
### motor unit

A single motor neuron (nerve cell) and all the muscle fibres that neuron can potentially stimulate



### Video

In focus: Motor Unit Recruitment



**FIGURE 5.20** Motor units are recruited based on the intensity of effort required.

Adapted from Motor Unit Recruitment & Biofeedback in Rehabilitation, mTrigger, LLC

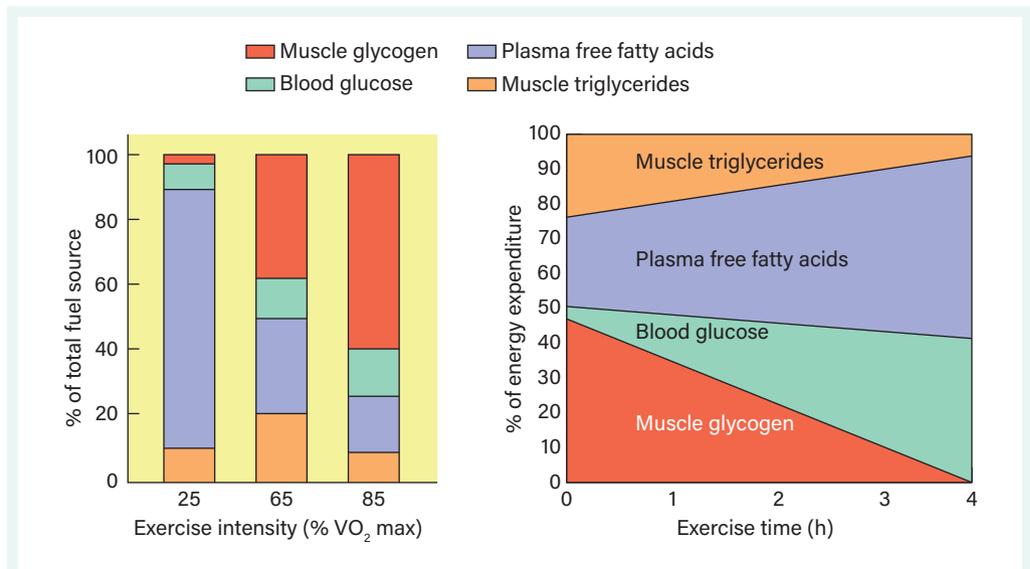
## Increased use of fuels and energy substrates

Muscles use food fuels and chemical fuels to produce energy, so contractions involved in running, jumping, throwing and all physical actions can occur.

Chemical fuels such as creatine phosphate (CP) and adenosine triphosphate (ATP) are broken down much more quickly than food fuels such as carbohydrates, fats and proteins. The contribution made by these fuels, or **substrates**, varies depending on the intensity and duration of the activity being performed and the major energy system being used at any given time. Another consideration is the availability of these fuels and whether they have had the opportunity to be replenished while the performance has continued.

**substrate**

A molecule that is broken down by enzymes



**FIGURE 5.21** The effect of (left) exercise intensity and (right) duration on fuel use during exercise

Adapted from Powers & Howley (2007), *Exercise Physiology*, McGraw Hill

For example, if energy is required very quickly to perform a 20-metre sprint from the midfield in soccer, CP is broken down anaerobically and more quickly than other fuel options. If the player performs another sprint in quick succession, before CP has had a chance to rebuild itself, or a longer sprint is performed after a period of rest, more CP will be depleted. Creatine phosphate is never totally depleted and cannot be significantly resynthesised to pre-sprint levels unless a passive recovery has occurred. Additionally, carbohydrates are broken down at a slightly slower rate, but also without oxygen, and contribute to energy production. If the player is simply jogging from one side of the field to the other, they might be using mainly fats, with less contribution from carbohydrates; both will be broken down aerobically and at a slower rate than that required for the earlier sprint.

Note that carbohydrates are broken down to glucose and stored as muscle and liver glycogen. Fats are broken down to free fatty acids and triglycerides. Proteins are not often used as a fuel source because they produce ATP at extremely slow rates and we need to conserve them for more important functions such as repairing muscles and enzymes, along with production of haemoglobin, which is vital to oxygen transport around the body.

## LOOKING FORWARD

### Blood flow away from working muscles contributes to fatigue

#### Chapter 7

Increased muscular heat will transfer into elevated core temperatures, which require athletes to thermoregulate. This means they need to 'get rid' of the excess heat. If they do not, they will start to overheat and experience reduced ability to keep performing at their required intensity, and in some cases will be forced to stop. This will be covered in greater detail in Chapter 7 when considering heat-related fatigue mechanisms.

Exercise causes a decrease in level of all fuels within the muscle. ATP, CP and muscle **glycogen** levels all decrease, as does intramuscular triglyceride concentration. Glycogen content decreases more rapidly with endurance activities compared to high-intensity sprint activities, as shown in the graphs in Figure 5.22. The preferential recruitment of slow-twitch (ST) fibres for endurance activities and fast-twitch (FT) fibres for sprint activities is determined by the characteristics of each fibre type. This is because high-intensity sprint events use FT fibres that rely more on stored ATP and CP as a fuel for energy production, while endurance events utilise ST fibres that use glycogen and fats. (Fuels required for physical activity are discussed in more detail in Chapter 6 on energy systems.)

## LOOKING FORWARD

### The characteristics of the different fibre types

#### Chapter 15

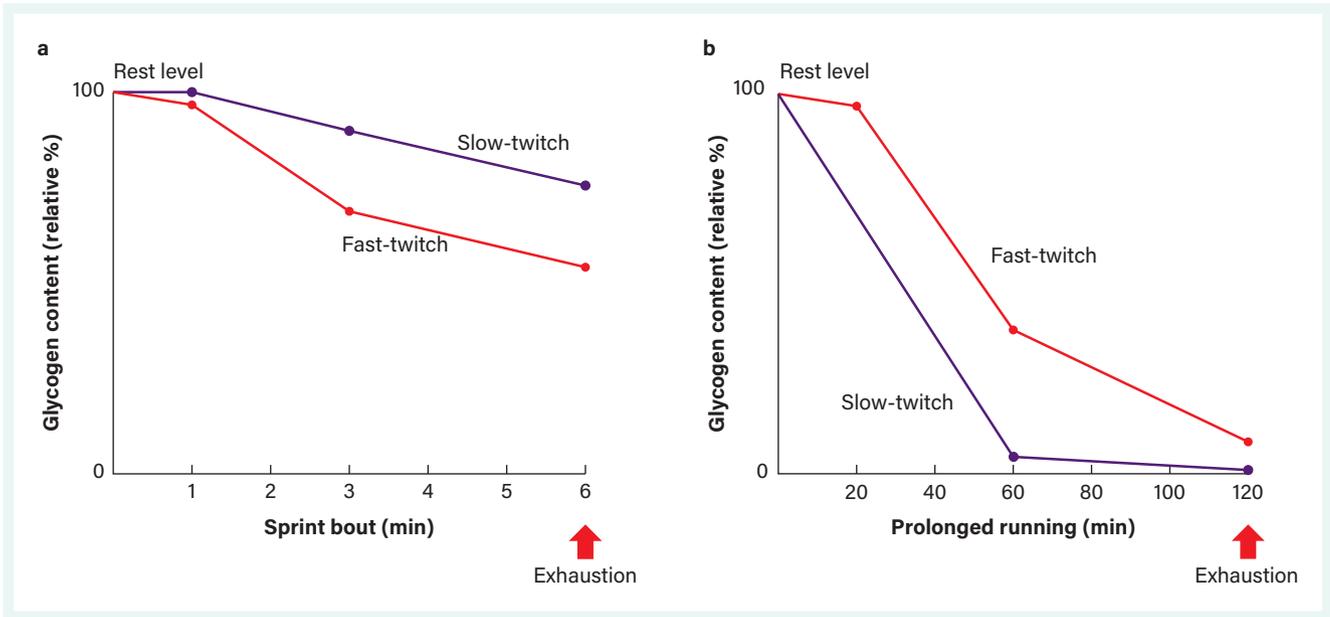
We will look at the characteristics of the different fibre types in more detail, especially the two different types of fast-twitch fibres, in Chapter 15.

#### glycogen

An important energy store in the muscles and liver. When the body requires energy, glycogen is broken down to glucose to be released into the bloodstream.

#### LEARNING HACK

Creatine phosphate (CP) or phosphocreatine (PC) is the same chemical fuel used by the ATP-CP system. The two names are often used interchangeably.



**FIGURE 5.22** Varied glycogen demands in fast- and slow-twitch muscle fibres depending on intensity and duration of effort

## Increased muscle temperature

When exercise commences, there is an increase in the rate of ATP production occurring in the muscles. Heat is the by-product of the process of converting chemical energy (fuel) to mechanical energy (movement). The longer the duration of an activity, the greater the amount of muscle contractions and hence the more associated heat is produced at the muscles.



iStock.com/jacoblund

**FIGURE 5.23** The muscle contractions during physical activity produce heat as a by-product.

## DID YOU KNOW?

Performing a warm-up decreases joint viscosity and promotes joints to move through a larger range of motion. This, in turn, leads to improved performance and may reduce the risk of injury.

## Increased blood flow to working muscles

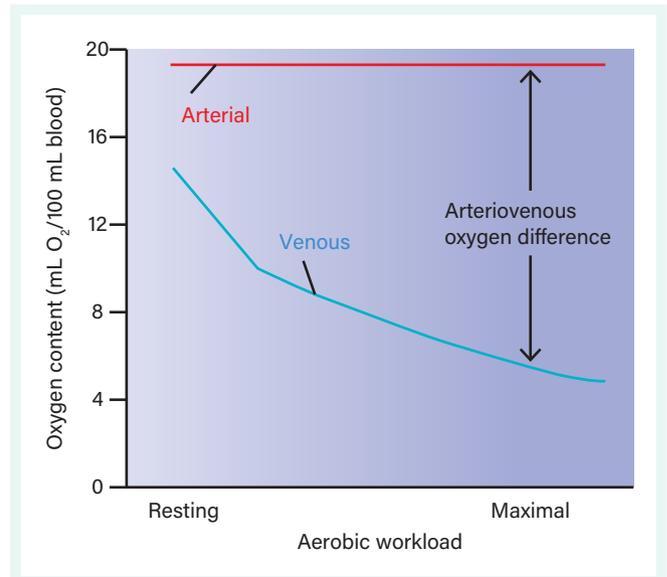
As part of the redistribution of blood flow during exercise, blood is directed away from non-essential organs (vasoconstriction) to the working muscles (vasodilation). During exercise, skeletal capillaries expand to allow:

- increased blood flow to provide more fuels
- greater surface area to increase diffusion rates of oxygen into, and carbon dioxide out of, the muscles
- increased removal of metabolic wastes.

## Increased arteriovenous oxygen difference

Because the body systems work together closely to take up, transport and use oxygen, the arteriovenous oxygen difference is directly linked to exercise intensity and the demand for oxygen by muscles. The arterial concentration of oxygen will always be higher than the venous concentration because the blood is yet to be transported to and through muscle capillary networks, where oxygen will be extracted and used.

Recall that there is a direct linear relationship between exercise intensity and a-vO<sub>2</sub> diff.



**FIGURE 5.24** Arterial and venous oxygen concentration at rest and varied workloads

## LOOKING FORWARD

### Myoglobin, haemoglobin and mitochondria

#### Chapter 15

The arteriovenous oxygen difference is very much linked to supplying and extracting oxygen at the muscles. **Myoglobin** carries and stores oxygen in muscles. It is closely related to **haemoglobin**, which transports oxygen throughout the cardiovascular network. Myoglobin supplies **mitochondria** with oxygen so they can produce aerobic ATP. Endurance athletes have higher levels of haemoglobin, myoglobin and mitochondria. Knowing this helps explain how the a-vO<sub>2</sub> diff is considerably higher in endurance athletes owing to their ability to transport more oxygen into muscles and then use it to produce aerobic energy.

#### myoglobin

An oxygen-binding protein, mainly found in muscles, the main roles of which are storing oxygen and transporting it to the mitochondria, where aerobic ATP is produced

#### haemoglobin

An oxygen-binding structure found in red blood cells, used to carry oxygen from the lungs to the rest of the body

#### mitochondria

(singular: mitochondrion) Small structures found within muscles that produce adenosine triphosphate (ATP) in the presence of oxygen

## DID YOU KNOW?

High concentrations of myoglobin in muscles allow athletes to hold their breath for long periods of time. This would be a big advantage for 'free diving.'

**enzymes**

Protein-based structures that help to speed up chemical reactions in our bodies that build some substances up and break others down

**LEARNING HACK**

Enzymes speed up (catalyse) chemical reactions in cells. More specifically, increased temperatures lower the threshold necessary to start processes and reactions by binding to another substance known as a substrate.

**Assessment**

5.3 Check-in questions

## Increased enzyme activity

In essence, **enzymes** allow the important chemical reactions involved in the production of energy and removal of wastes to occur at a faster rate. They tend to be temperature-sensitive and, as muscles produce more heat with increased frequency of contraction, enzyme activity also increases to produce energy via the three different energy systems.

### 5.3 CHECK-IN QUESTIONS

- 1 Clearly **discuss** how the biceps and triceps muscles produce different forces depending on the type of task they are required to perform – for example, throwing a dart vs throwing a javelin.
- 2 **Outline** why the arteriovenous oxygen difference has a direct linear relationship with exercise intensity.
- 3 **State** what happens to the ‘fuel mix’ of fats and carbohydrates used to produce energy to swim 100 metres freestyle in 1 minute compared with a slower time of 2 minutes.
- 4 **Suggest** how increasing the diameter of capillaries within muscles during exercise leads to improved performances in sporting events.
- 5 Increased muscle temperature can have both positive and negative consequences for athletic performance. Provide an example of a positive and a negative consequence for a sport of your choice.

## 5.4 OXYGEN UPTAKE AT REST, OXYGEN DEFICIT, STEADY STATE AND RECOVERY

In this module you will learn about:

- how the body supplies oxygen at rest and various stages of exercise
  - how oxygen uptake post-exercise contributes to recovery during passive and active formats
- and learn to:
- identify oxygen deficit, steady state and EPOC from data
  - link oxygen availability to energy produced anaerobically and/or aerobically
  - link oxygen uptake at rest, exercise and recovery to acute responses and body system function.

We know that there is a direct link between exercise intensity and the amount of oxygen the body requires. At rest, we don't need a large amount of oxygen, but as we start to exercise this increases linearly. The muscles might have high demands for oxygen if the intensity is high from the start of a performance, but this cannot be met immediately.

### Oxygen uptake at rest

When resting, the body does not need to produce large amounts of energy, and demand for oxygen is relatively low. Resting heart and respiratory rates can easily match the body's low demand for oxygen. Resting oxygen consumption levels are on average around 0.3 litres

per minute for adults. If exercise intensity and associated oxygen demand is low, this can be met quite quickly by increasing both heart rate and respiratory rate, which will both level off once the demand has been met. However, if the exercise intensity is high, the heart rate and respiratory rate both need to increase significantly to meet the demand. This cannot occur very quickly, so there is a lag between the rapid demand and the body's ability to meet it via increased uptake and supply.

## Oxygen deficit

The period during which oxygen supply cannot meet the amount required by working muscles is referred to as **oxygen deficit**. The greater the discrepancy between oxygen demand and the body's ability to supply oxygen, the greater the oxygen deficit. Periods of oxygen deficit in any activity indicate increased contribution from the anaerobic energy systems, which work together to supply the 'shortfall' in aerobic energy/ATP. An oxygen deficit always exists at the start of any exercise and can also occur at any time in an activity when the demand for oxygen is greater than the body's ability to supply it. Generally, the larger the oxygen deficit, the higher the intensity of effort and the greater the anaerobic contribution to ATP production.

### oxygen deficit

A situation where the body cannot fully meet its oxygen demands (oxygen demand is greater than oxygen supply). The shortfall in oxygen supply sees larger amounts of energy being produced by anaerobic pathways.

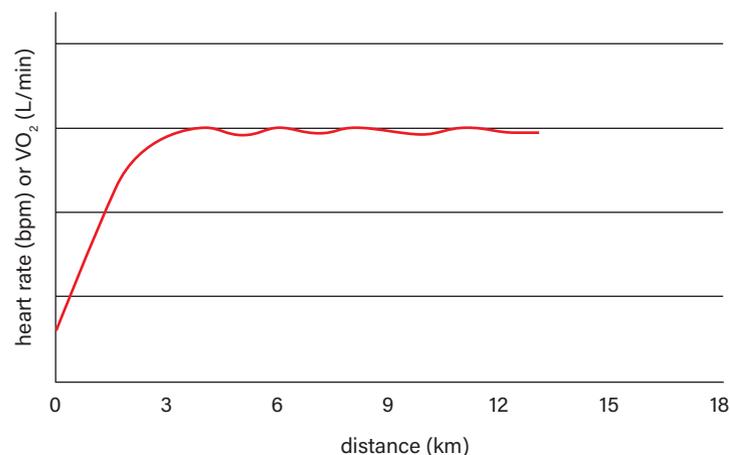
## WORKED EXAMPLE

©VCAA Exam 2018, Section B, Q8 e and f

During the men's 15 km free cross-country event, Taufatofua's average speed was recorded during four different distance sectors of the course. The results are shown in the table below.

Distance sectors (km)	Average speed (km/h)
0–1.5	16.84
1.5–7.5	16.22
7.5–13.5	15.13
13.5–15	17.75

The graph below is a representation of Taufatofua's oxygen consumption during the first 13.5 km of the 15 km free cross-country event. The final 1.5 km of the course is flat.



- e Complete the graph above for the last 1.5 km of the event and the 2 km Taufatofua completed as recovery. Shade and label the graph to demonstrate your understanding of Taufatofua's oxygen consumption, including:
- steady state
  - periods of  $O_2$  deficit
  - period of excess post-exercise oxygen consumption (EPOC).
- f During recovery, Taufatofua's heart rate remained elevated. **Explain** what is occurring physiologically.

### Steps to answering question e

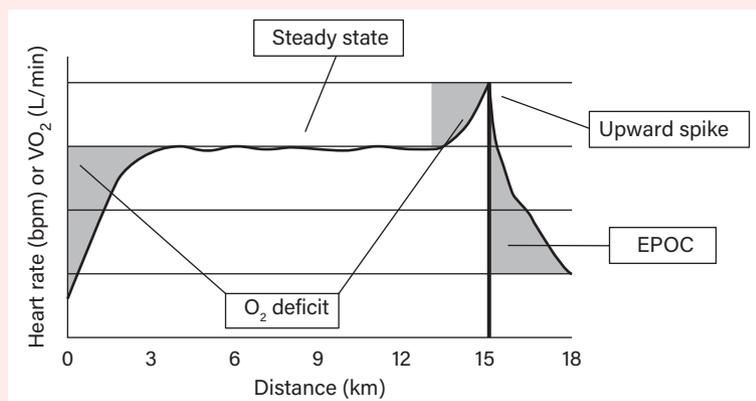
#### 1 Relevant information/data from the question:

- Steady state reached from 3–13.5 km (small fluctuations not significant and does not need to be a straight line).
- The table reveals athlete increases speed over last 1.5 km of course, which would have associated increases in HR and  $VO_2$  – if this cannot be met, oxygen deficit will occur after earlier steady state.
- Asked to shade periods (plural) of oxygen deficit – this indicates there are more than one!

#### 2 Need to shade and label (two different instructions). Shading is often associated with areas rather than a particular point on a graph.

- Note that heart rate and oxygen consumption cannot go below pre-exercise levels in the 3 minutes of recovery (or at all).
- Knowing the race finished at 15 km, it's a good idea to rule a line upwards at this point for clarity and for reference (end of second oxygen deficit and start of recovery/EPOC – decreases in HR and  $VO_2$ ).

### Suggested response



### Steps to answering question f

- 1 The command word in Question 8 f is **explain**. This is asking you to give a detailed account of why and/or how with reference to change, reasons or mechanisms.
- 2 What is occurring physiologically while heart rate remains above resting levels/elevated during recovery? You cannot simply state 'body returning to pre-exercise levels' as this is too vague.

### Suggested response

- Restoring CP stores – passive rest allows for restoration of CP assisted by oxygen consumption.
- An increase in heart rate helps to distribute more oxygen to assist with the removal of metabolic by-products.
- An increase in heart rate assists the body to return to pre-exercise body temperature more quickly.
- Restoration of oxygen to myoglobin.
- Increase in heart rate also creates a venous pump to increase venous return.

## LOOKING BACK

### Oxygen

#### Module 5.1

Recall that more oxygen is taken up by increasing respiratory rate, tidal volume and gaseous exchange. This oxygen is, in turn, increasingly transported to working muscles via increased heart rate, stroke volume and myoglobin/mitochondria activity. During periods of oxygen deficit, all these variables will increase unless they have already reached their finite capacity.

## Steady state

When we can supply sufficient oxygen to meet the body's demand, the variables mentioned in the 'Looking back' box will remain constant and level off, and the person is said to be in a **steady state**. Generally, we are at a steady state when resting and after running, cycling or swimming at moderate intensity for a couple of minutes. The greater the exercise workload, the longer it will take for the body to meet oxygen demands with oxygen supply and the later steady state will occur. This 'levelling off' is sometimes referred to as a 'plateau' in cardiac output, ventilation and volume of oxygen consumed per minute ( $\text{VO}_2$ ). In this state most, but not all, of the ATP is being produced via the aerobic energy system.

#### steady state

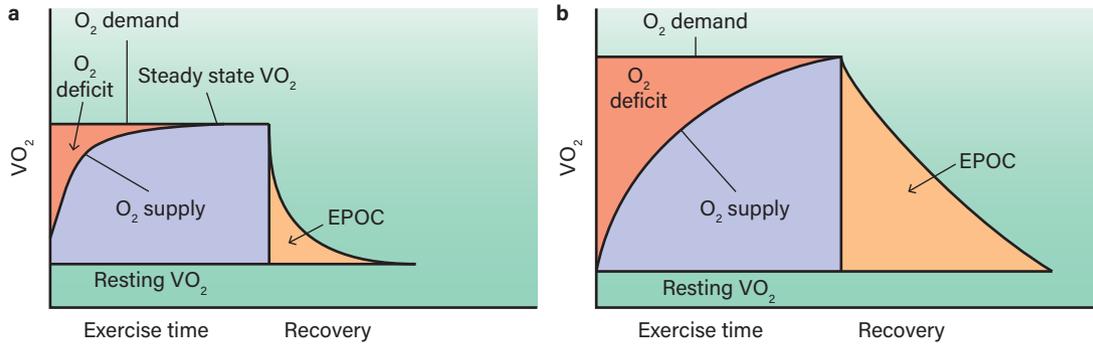
A situation that occurs when exercise intensity remains unchanged or within a small range, and variables such as oxygen uptake and heart rate remain stable, because almost all of the ATP is being produced aerobically



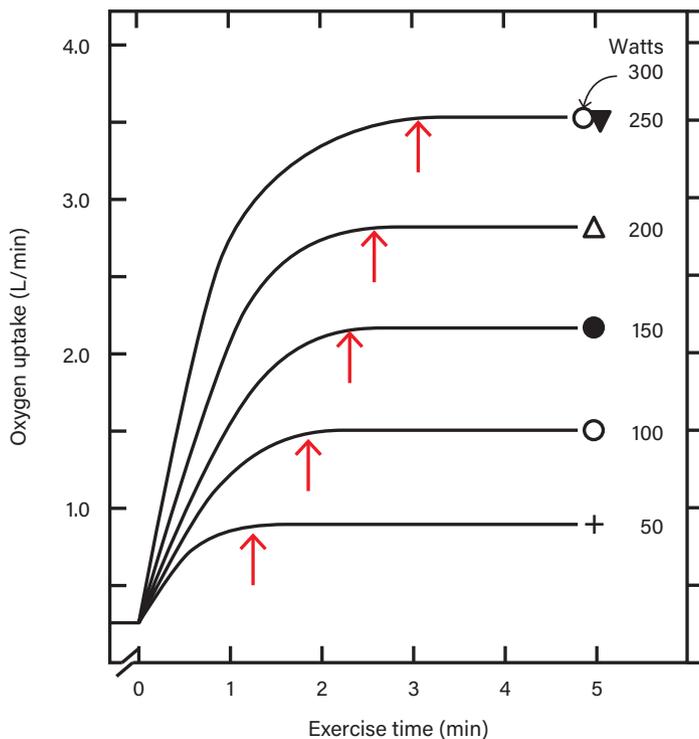
iStock.com/Clerkenwell

**FIGURE 5.25** Steady state occurs during the middle stages of a 2,000-metre rowing event when oxygen supply meets oxygen demand.

Aerobic training of the kind undertaken by endurance athletes will greatly increase a person's ability to take up, transport and utilise oxygen so they will have both a smaller oxygen deficit and a lower steady state. Why? Essentially, this has to do with their improved ability to produce aerobic ATP via more efficient and higher-functioning respiratory, cardiovascular and muscular systems (in particular, slow-twitch fibres and fast-twitch fibres with aerobic characteristics).



**FIGURE 5.26** Oxygen uptake at rest, steady state and recovery following two different exercise intensities: **a** moderate intensity; **b** high intensity



**FIGURE 5.27** Varying oxygen uptake and steady state in response to different cycling workloads

Figure 5.27 reveals how oxygen consumption changes with varied exercise intensities/workloads. It also reveals how steady state is not achieved until oxygen demand is met by oxygen supply.

### Excess post-exercise oxygen consumption (EPOC)

Once exercise ceases, the demand for energy and ATP drops significantly as the subject performs either a passive or an active recovery. The period where oxygen consumption remains above resting levels is known as **excess post-exercise oxygen consumption (EPOC)**. You may have already concluded after analysing the graphs that there is a direct relationship between oxygen deficit and EPOC.

#### excess post-exercise oxygen consumption (EPOC)

The volume of oxygen used during recovery from exercise that is in excess of resting oxygen consumption



Video

In focus: Active vs passive recoveries and effects on EPOC

## LOOKING FORWARD

### Passive recovery

#### Chapter 7

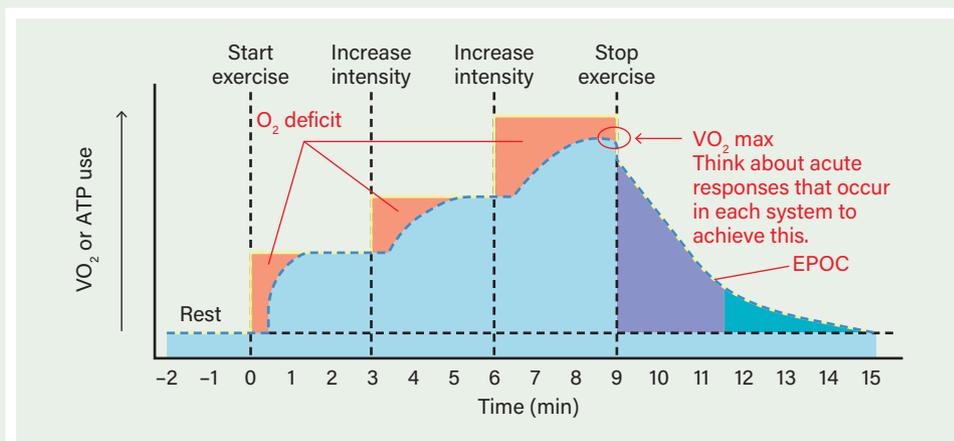
A passive recovery is often performed in order to quickly replenish CP stores that may be required if repeat high-intensity efforts are needed. This would be the case while performing short-interval sprints focusing on training the ATP-CP system and/or speed. With passive recoveries, oxygen consumption drops rapidly and returns to resting levels as quickly as a couple of minutes – but not immediately.

When metabolic by-products have accumulated during the training or exercise period, an active recovery is recommended. This keeps oxygen uptake, delivery and utilisation higher than a passive recovery and extends EPOC with the purpose of oxidising and removing the by-products at a faster rate. An active recovery deliberately increases the amount of oxygen being supplied to working muscles in an attempt to remove metabolic by-products and return to pre-exercise conditions sooner.

Because endurance and aerobically trained athletes have higher  $VO_2$  maximums, they can take up, transport and utilise more oxygen than untrained subjects. Because of this, not only can they perform at higher intensities aerobically, but they can also return to pre-exercise levels at a faster rate. They will have both a smaller oxygen deficit and smaller EPOC as a result of this training adaptation.

## 5.4 CHECK-IN QUESTIONS

- 1 State** why you believe steady state in a school cross-country can be achieved more quickly by students who train regularly than by their non-trained peers.
- 2 Suggest** why oxygen deficit is greater for a 200-metre track sprinter than for a 200-metre freestyle swimmer.
- 3 Refer** to the oxygen consumption graph in Figure 5.28 for a graduated treadmill test.



**FIGURE 5.28** Oxygen consumption during a graduated  $VO_2$  max treadmill test, in which treadmill speed increases every 3 minutes

**Explain** why the subject experiences larger oxygen deficits and shorter periods of steady state every 3 minutes, coinciding with increased treadmill speed.

- 4 Explain** why performing a warm-up immediately before participating in a 5-kilometre Parkrun would be beneficial. Be sure to make reference to both oxygen deficit and steady state in your response.

### LEARNING HACK

The size of the oxygen deficit is matched by EPOC – that is, the greater the oxygen deficit, the greater EPOC tends to be. It is also worth noting that any deficits occurring during continuous activity accumulate and add together to create a larger EPOC. Refer to Question 3 in the Module 5.4 Check-in questions.



**Assessment**  
5.4 Check-in questions



## ABOVE AND BEYOND THE STUDY DESIGN

MODULE 5.1, PAGE 202

# Blood redistribution during exercise

## REAL WORLD APPLICATIONS

### Eating before swimming

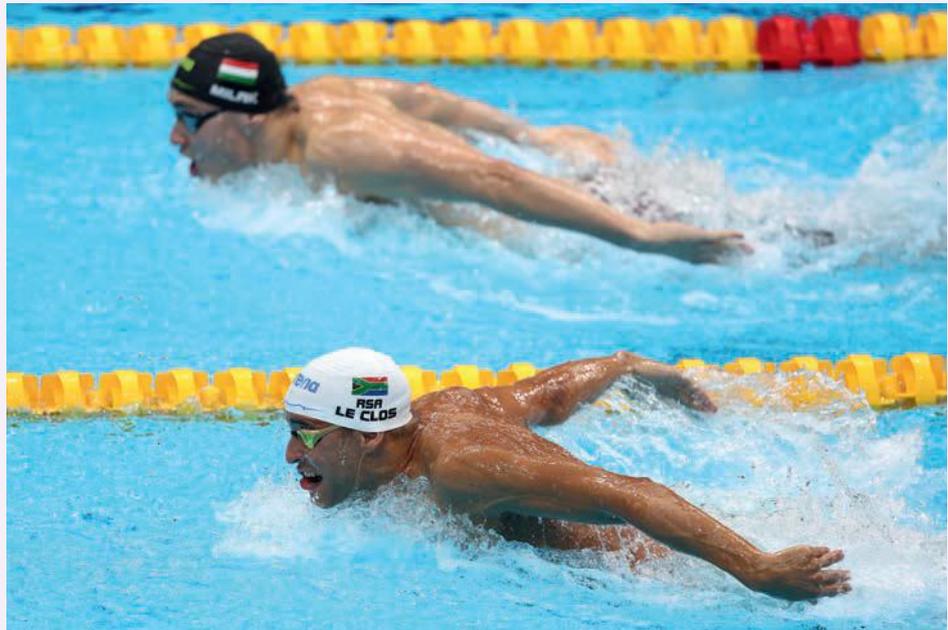
Some people believe that the risk of drowning is increased if you go for a swim immediately after eating a large meal. This is actually a myth.

Eating before swimming may not increase the risk of drowning, but it might lead to minor cramps. Many surf lifesaving organisations recommend waiting for 30 minutes to 1 hour following a big meal before jumping into the pool, sea or lake for a swim.

As we eat and digestion commences, there is a large increase in the amount of blood required by the digestive system to break down foods and transport nutrients to various body parts, including muscles, to be used or stored as energy. If we exercise at the same time, the muscles need increased blood supply to transport oxygen and fuels. The digestive and muscular systems must then compete for blood supply and, in some cases, this conflict might lead to muscles cramping through insufficient oxygen supply.

It's important to note that the body won't compromise blood flow to the extent that it would significantly hinder the functioning of arm and leg muscles. If you find this happening, don't panic. Reduce the intensity of arm and leg actions while in the water and try to make your way back to shore, the deck or the side of the pool.

Fats and proteins take longer than carbohydrates to be digested/broken down and used as fuels, and are not recommended in large quantities before a swim. Smaller meals or snacks containing carbohydrates digest quickly and are the recommended pre-swim meal. A sports drink consumed simultaneously can also speed up digestion if you have a race within an hour or so. Generally, competitive swimmers are advised not to eat within 30 minutes of races.

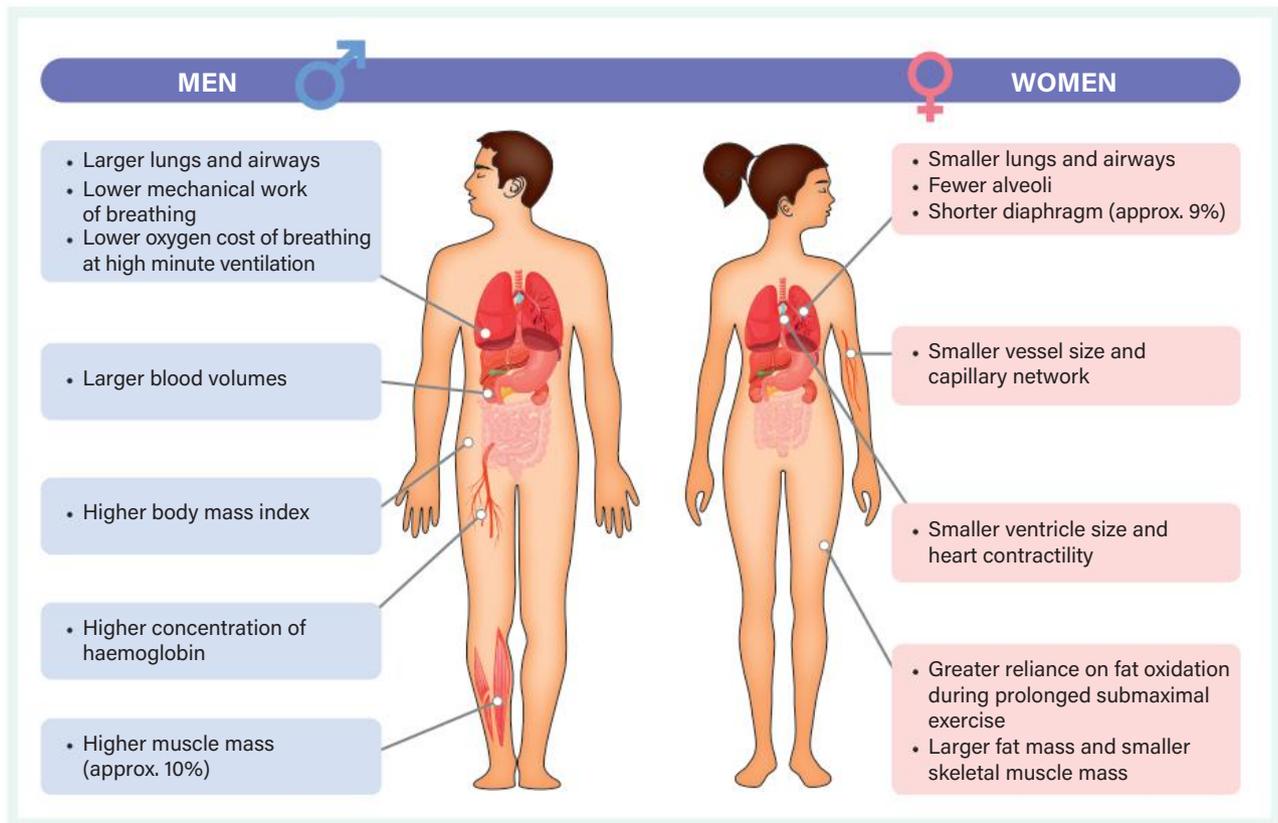


**FIGURE 5.29** Competitive swimmers will not consume solid foods within 30 to 60 minutes of the scheduled start time of their event.

Clive Rose/Getty Images Sport/Getty Images

## Sex differences at the respiratory, cardiovascular and muscular levels

Figure 5.30 summarises some of the sex differences at the respiratory, cardiovascular and muscular levels that explain why males outperform their female counterparts in endurance events. Use any of these to support your understanding of why males have smaller oxygen deficits and are able to return to pre-exercise levels faster than their female peers when competing in events such as the 20-kilometre cross-country skiing race or the triathlon.



**FIGURE 5.30** Sex differences at the respiratory, cardiovascular and muscular levels. Elite male marathon runners have relative  $\text{VO}_2$  max values that are approximately 10 per cent higher than those of their female peers.

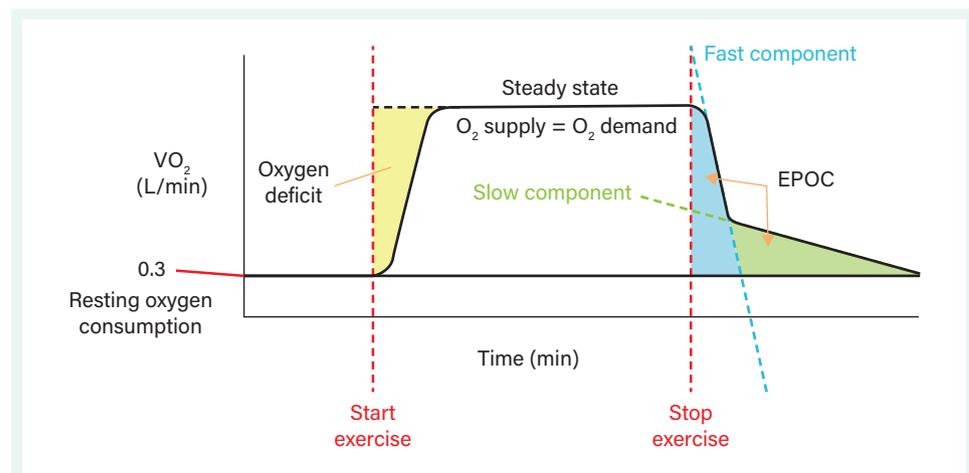
## The 'fast' and 'slow' parts of EPOC

Regardless of the type of recovery performed after exercise, during EPOC the body is trying to restore itself to pre-exercise levels. Some recovery processes occur fairly quickly (within 3 minutes) and within what is known as the 'fast component of EPOC'. These include:

- replacing muscle stores of ATP
- resynthesising creatine phosphate
- restoring oxygen levels in myoglobin and haemoglobin
- reoxygenation of blood.

The following recovery processes commence once exercise stops and EPOC starts, but take longer to complete (up to 24 hours or more) and make up what is referred to as the 'slow component of EPOC'. These include:

- removing metabolic waste products such as carbon dioxide from the muscles
- oxidising accumulated lactic acid/ $H^+$  ions and converting some to muscle glycogen
- thermoregulation by returning core temperature to pre-exercise levels via sweating and increased blood flow to the skin
- beginning muscle repair by shuttling amino acids to the muscles and assembling proteins that contribute to muscle recovery and growth.



**FIGURE 5.31** Oxygen deficit, steady state and EPOC (with a fast and a slow component)

# CHAPTER SUMMARY

## 5.1 Acute respiratory responses to exercise

- Respiratory rate increases linearly as exercise intensity increases, from 10–12 breaths/minute up to maximums of 40–45 breaths/minute.
- Tidal volume has a finite/maximum capacity, which is reached submaximally.
- Ventilation ( $V$  or  $V_e$ ) =  $RR \times TV$ . People with larger lung volumes will have a larger ventilation capacity. (This explains lower resting and submaximal respiratory rates in endurance athletes.)
- Gaseous exchange increases linearly with exercise intensity as the alveolar surface area increases and more oxygen is taken up at the lungs and more carbon dioxide is produced at muscles and cells.
- $VO_2$  is *not* a respiratory variable because it consists of oxygen uptake (respiratory), transport (cardiovascular) and extraction/use (muscular) and is a result of all three body systems working together.



**Resource**  
Self-assessment checklist

**Video**  
Masterclass: Chapter 5

## 5.2 Acute cardiovascular responses to exercise

- Heart rate increases linearly as exercise intensity increases, up to a maximum (220 – person's age).
- Stroke volume has a finite/maximum capacity, which is reached submaximally.
- Cardiac output ( $Q$ ) =  $HR \times SV$ . People with larger ventricles will benefit by having larger cardiac output. (This explains lower resting and submaximal heart rates in endurance athletes.)
- Blood pressure (especially systolic) increases in line with exercise intensity and the heart pumping both harder and faster – with increased contraction force and frequency.
- Blood is shunted towards areas where it is most needed (via vasodilation) and is simultaneously redirected away from other areas (vasoconstriction). During exercise, 75–85 per cent of blood leaving the heart is sent to working muscles.
- Larger cardiac output must be matched by increased venous return because the cardiovascular system is a 'closed circuit'.
- Arteriovenous oxygen difference mirrors exercise intensity in a linear relationship, shifting from 4–5 mL  $O_2$ /100 mL blood at rest to 15–17 mL  $O_2$ /100 mL blood.
- Exercise or sports lasting longer than 1 hour might see a drop in plasma levels. Unless countered by hydration during the activity, this will lead to elevated heart rates, less oxygen being transported to working muscles and increased likelihood of fatigue.

## 5.3 Acute muscular responses to exercise

- Increased motor unit, motor neuron and muscle fibre recruitment allow for increased muscle contraction force to be produced.
- Muscles consist of slow-twitch and fast-twitch muscle fibres, which are preferentially recruited according to the amount of force and the duration of activity about to be performed.
- Increased blood flow to muscles allows for greater amounts of oxygen and fuels to be delivered as well as faster removal of wastes and metabolic by-products.

- Heat is produced at muscles when energy is released when ATP is broken down. The longer muscles contract for, the greater the amount of heat produced, resulting in elevated muscle temperatures. Moderate heat at muscles is ideal because it speeds up enzyme activity, but excessive heat is counterproductive because it leads to fatigue when thermoregulation is challenged.
- Arteriovenous oxygen difference is an indirect measure of how much oxygen the muscles are using. It increases linearly along with exercise intensity as muscles extract and utilise more and more oxygen with increasing intensity.
- Muscles use food fuels (carbohydrate, fat and protein) and chemical fuels (CP and ATP) to produce energy. The greater the demand for energy, the greater the use of these fuels.

### 5.4 Oxygen uptake at rest, oxygen deficit, steady state and recovery

- At rest, oxygen uptake and supply matches a low demand and this is considered to be 'steady state'.
- Oxygen deficit always occurs at the start of exercise, when the demand for oxygen cannot be met by body systems, and most of the ATP is produced anaerobically.
- A large oxygen deficit indicates a large demand for oxygen, created by high-intensity/explosive efforts. ATP needs to be produced quickly and anaerobically until more oxygen can be taken up and transported to working muscles.
- Oxygen deficits can occur during any activity when the intensity increases rapidly and the body cannot meet the associated increased oxygen demand.
- A steady state is experienced at rest when oxygen supply meets oxygen demand. Following initial oxygen deficits at the start of exercise, a steady state is reached when the demand for oxygen is met by the body's systems.
- Steady states are reached when the demand for oxygen can be met – this occurs more quickly with lower-intensity efforts compared with higher-intensity efforts, as well as in endurance-trained athletes.
- During maximal efforts such as a 400-metre sprint or a 100-metre freestyle swim, steady state will not be reached because of the inability to meet the demand for oxygen by body systems.
- Multiple steady states can be reached during continuous activities such as a cross-country run or a graduated treadmill workout/test where the speed is increased at regular intervals.
- Excess post-exercise oxygen consumption (EPOC) occurs at the conclusion of exercise and training and represents the period where oxygen consumption remains above resting levels.
- There is a direct relationship between oxygen deficit and EPOC. Higher intensities, resulting in demand for oxygen that cannot be met, result in larger amounts of EPOC.
- EPOC can be deliberately increased via an active recovery, which might be used to speed up oxidation and removal of metabolic by-products. An active recovery is associated with increased oxygen levels at the muscles and also with greater muscle pumping action, which promotes vascular return to the heart.

# CHAPTER REVIEW

- When compared with rest, participating in a 30-minute treadmill run at 75% max HR would result in:
  - a decrease in blood volume, an increase in oxygen consumption and an increase in intramuscular energy substrates.
  - a decrease in oxygen consumption, a decrease in blood volume and a decrease in intramuscular energy substrates.
  - an increase in the  $a-vO_2$  diff, an increase in oxygen consumption and an increase in blood flow to working muscles.
  - an increase in oxygen consumption, a decrease in intramuscular energy substrates and an increase in blood volume.
- A student jogs 200 metres from their locker to class in an effort not to be late. After 10 minutes, they realise that they have forgotten important group work and ask if they can leave class to get it from their locker. The teacher says, 'Sure, but you've got to be quick' and this time the student sprints to their locker and back to class. Compared with the earlier jog, the sprint would result in a:
  - higher oxygen deficit, lower steady state and larger EPOC.
  - lower oxygen deficit, higher steady state and smaller EPOC.
  - higher oxygen deficit, no steady state and smaller EPOC.
  - higher oxygen deficit, no steady state and larger EPOC.
- Explain** why the arteriovenous oxygen difference has a direct linear relationship with exercise intensity.
- During repeat sprints in a game of netball, **identify** the muscle fibre type that would preferentially be called upon to perform these movements. In addition, **identify** the preferred food fuel these fibres would use to enable repeated high-intensity efforts.
- The following table shows data that was taken at the start and end of a 200-metre and a 1,500-metre freestyle race for two national-level swimmers who are same age and gender.

	200 m freestyle	1,500 m freestyle
<b>Time (min:s)</b>	1:47.00	15:01.08
<b>Resting HR (bpm)</b>	73	56
<b>Average speed (m/s)</b>	1.9	1.7

- Apart from decreased fuel stores, **list** two other acute muscular responses both swimmers would experience after they dive off the blocks and complete their swimming events.
- Explain** why the 200-metre swimmer had an elevated resting heart rate, well above that of the 1,500-metre swimmer.
- On the following axis, **predict** what the oxygen consumption would be like for the 200-metre and 1,500-metre swimmers. Ensure you indicate periods of oxygen deficit, steady state and EPOC for each swimmer.



**Assessment**  
Chapter 5 Review

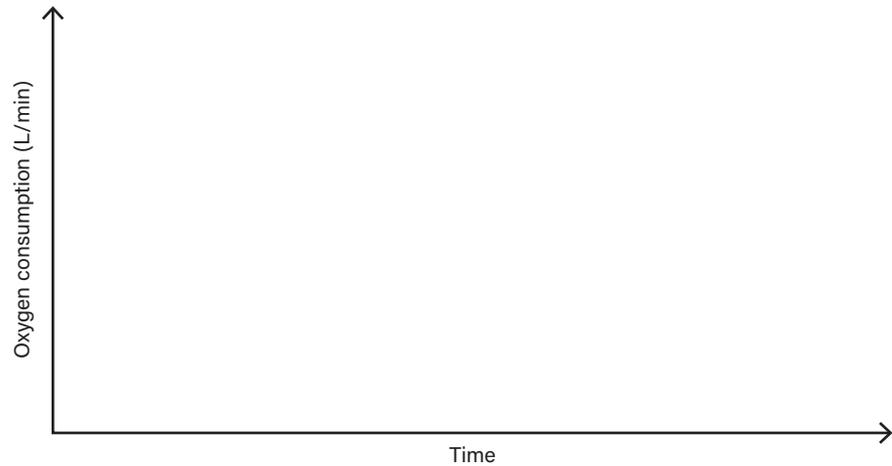
## Command terms

### identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

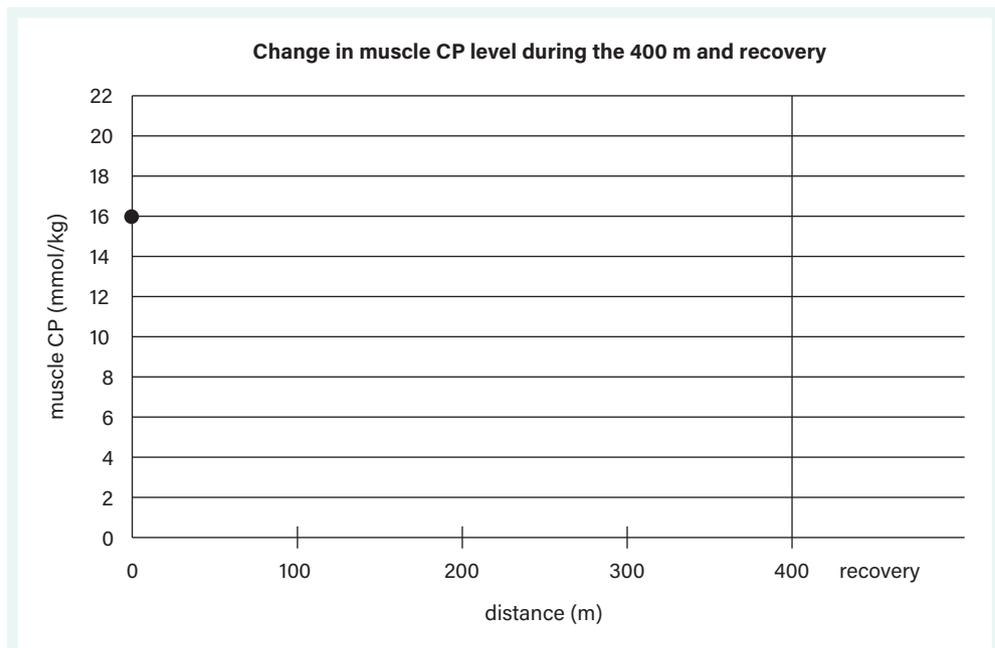
### list

Provide a series of related words, names, numbers or items that are arranged consecutively



6 ©VCAA Exam 2019, Section B, Q3

- a Indicate the physiological changes (increase, decrease, stay the same) that would be expected in the runners at the end of the 400 m for each of the following parameters.
- Diastolic blood pressure
  - Tidal volume
  - Intramuscular ATP
- b Complete the following graph to show the change in muscle creatine phosphate (CP) level during a 400 m sprint and passive recovery. The initial muscle CP level was 16 mmol/kg.



- 7 Refer to Figure 5.28. If the subject performs an active recovery following the graduated treadmill test:
- State** the effect will this have on the overall EPOC, as well as the 'fast component' and 'slow component', compared with a passive recovery.
  - Describe** what occurs at the muscular level during an active recovery to promote venous return to the heart and assist in the removal of metabolic by-products from the muscles.
- 8 **©VCAA** Exam 2022, Section B, Q11

A highly trained amateur trail runner completed two 12 km training sessions, on different training days, on a trail-running track in an area with frequent uphill and downhill sections. The trail runner completed the two training sessions in approximately 64 minutes each. On both training days, the temperature was above 27°C but the trail runner was well hydrated.

**Analyse** the interplay of energy systems and include in your response the role of the acute responses of the cardiovascular and respiratory systems in the provision of energy to the trail runner.

### Extended response

- 9 An Olympic triathlete competing in high temperatures (above 35°C) will have additional heat loads placed on them. Their performance consists of a 1,500-metre swim, a 40-kilometre bike ride and a 10-kilometre run, and takes approximately 2 hours to complete.
- Discuss** how their performance would start to deteriorate during the bike and run parts of the course if they cannot thermoregulate effectively and experience elevated muscle and core temperatures.
- Your response needs to include acute responses at the cardiovascular, respiratory and muscular systems that explain how an inability to thermoregulate will cause the triathlete to slow down.

### Command terms

#### analyse

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

#### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

## CHAPTER

# 6

## THE PRODUCTION OF ENERGY FOR HUMAN MOVEMENT

UNIT 3 – AREA OF STUDY 2



Sport In Pictures/Alamy Stock Photo

**FIGURE 6.01** Energy for movement comes from three energy systems.

### Quizzes

Chapter 6 Pulse check

**6.1** Check-in questions

**6.2** Check-in questions

**6.3** Check-in questions

Chapter 6 Review

### Videos

Masterclass: Chapter 6

**6.3** In focus: Energy system interplay

### Resources

**6.3** Energy system checklist

**6.3** Template: Data collection

**6.3** How to write an energy system interplay response

Chapter 6 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



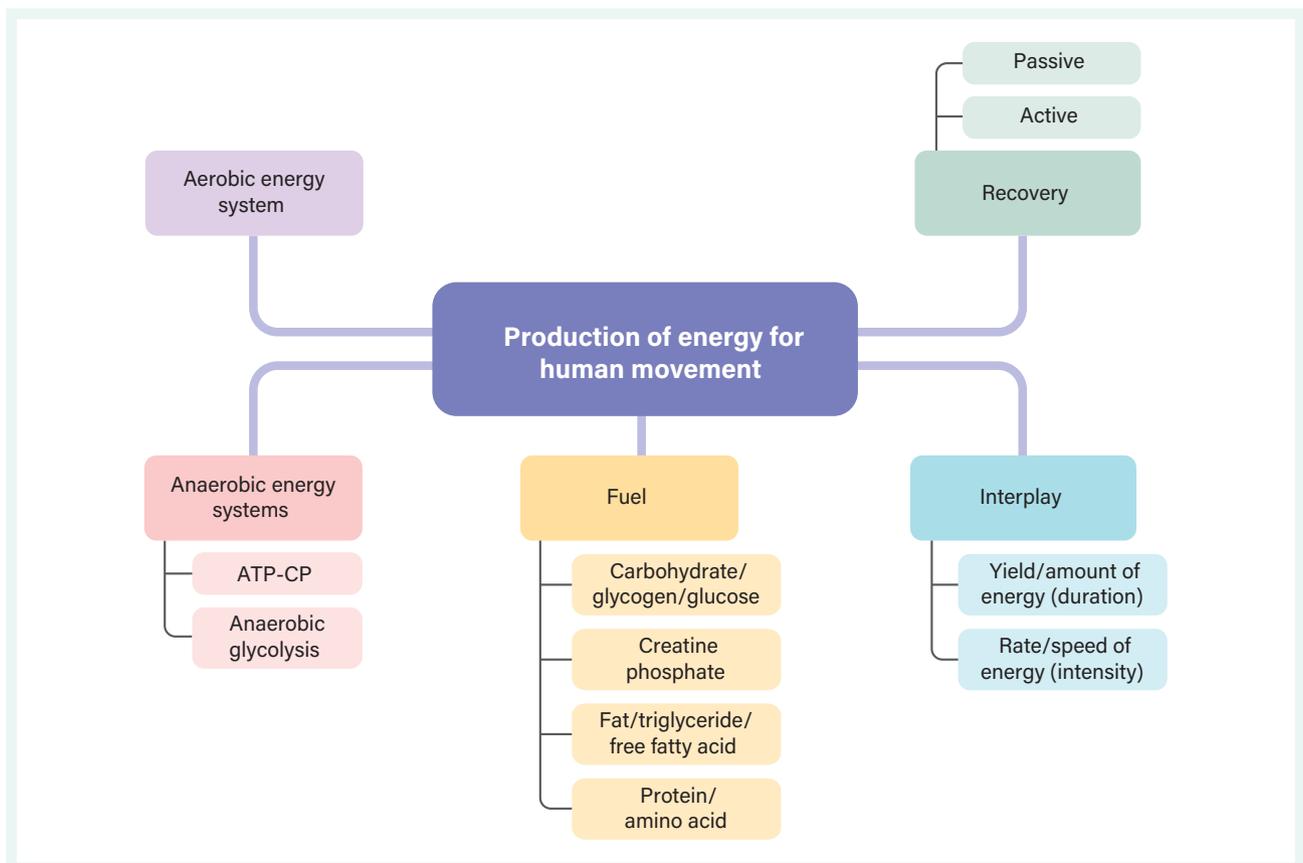
- » the three energy systems (ATP-CP, anaerobic glycolysis and aerobic) including their fuels (chemical and food), rate and yield of each system, their contribution at rest and varying intensities and recovery rates associated with active and passive recovery
- » interplay of energy systems in relation to the intensity and duration of physical activity, sport and exercise

## KEY KNOWLEDGE

- » perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery
- » participate in a variety of physical activity, sport and exercise and describe, using appropriate terminology, the interplay and relative contribution of the energy systems

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 6

**Assessment**

Pulse check

This chapter explores the characteristics of systems in the body that produce energy for human movement. You need to identify the characteristics of each energy system and use key terms such as rate and yield to explain their contribution to energy supply for physical activity, sport and exercise. You also need to demonstrate your understanding of which recovery strategy should be prescribed for different exercise intensities and link the strategy to the energy system that has provided the most energy. You will use a variety of sports and exercise examples to write energy system interplays that describe the way the systems work together in a particular context to supply required energy.

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 What are the names of the food fuels that can provide energy in the body?
- 2 Which of the food fuels mentioned above is the preferred source of energy during exercise?
- 3 **Identify** the names of the three energy systems that work together to provide energy in the body.
- 4 Provide two sporting examples where energy needs to be produced at a fast rate and two sporting examples that rely on energy being produced at a slower rate, but for a longer period of time.
- 5 **Describe** an active recovery and identify a sport or an event in which it might be prescribed or used.

## 6.1 FOOD FUEL FOR ENERGY PRODUCTION

In this module you will learn about:

- the three energy systems (ATP-CP, anaerobic glycolysis and aerobic) including their fuels (chemical and food) and learn to:
- perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery.

Before we deep dive into the cellular process that facilitates energy production, it is important to understand food fuels (macronutrients) and how these fuels become chemical fuels when transported and stored in our body. You also need to understand the exercise conditions that facilitate the use of different fuels. Later in this area of study we will examine nutritional strategies to enhance performance and recovery.

### LOOKING FORWARD

#### Fuel for performance

#### Chapter 7

In Chapter 7 we will investigate nutritional strategies to enhance performance, delay fatigue and improve recovery.

			
	CHO: e.g. rice	Fat: e.g. avocado	Protein: e.g. fish
<b>Food</b>	Carbohydrates Glucose	Fat Lipids	Protein
<b>Blood</b>	Glucose	Free fatty acid	Amino acid
<b>Muscle</b>	Muscle glycogen	Triglyceride	Amino acid
<b>Stored</b>	Liver glycogen	Adipose tissue	-

**FIGURE 6.02** The three food sources for energy are broken down and stored at various locations in the body.

## Carbohydrates

Carbohydrates are the body's preferred source of energy as they provide energy at a more rapid rate than the other macronutrients. A carbohydrate-rich diet of foods such as bread, fruit, vegetables and grains ensures that the body has sufficient stores to fuel physical activity. When carbohydrates are consumed, they are transported around the body in the blood as glucose, then stored in the muscle and the liver as the chemical fuel glycogen. Resting glycogen levels are relatively small and can, depending on the intensity worked at, be the major fuel for exercise bouts lasting between 90 minutes and 2 hours. Pre-loading of carbohydrate before an event or ingestion of carbohydrate during an event can support a longer duration of exercise where carbohydrate is the major contributor.



Casey B. Gibson/Alamy Stock Photo

**FIGURE 6.03** Carbohydrates such as those found in gels are the body's preferred source of energy.

## Fat

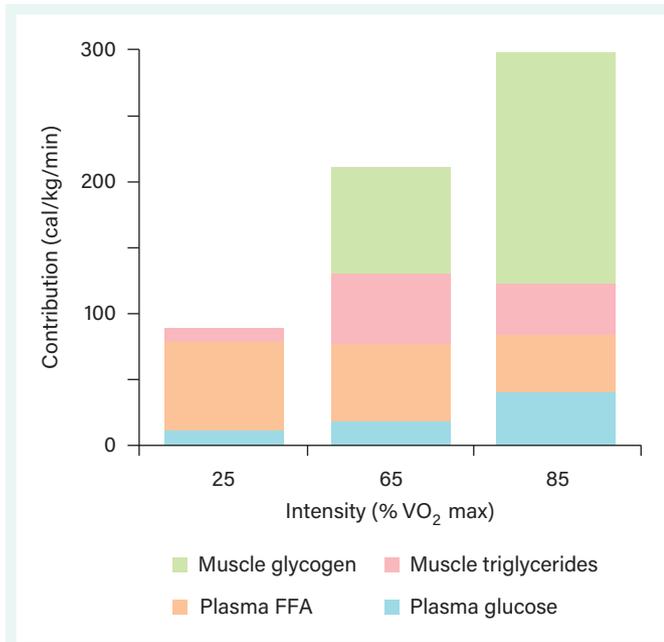
### LEARNING SHORTCUT

Excess carbohydrate that cannot be stored in the muscle or the liver is stored as triglyceride.

Consuming fat as part of our diet is vital as it helps nerve function and supports our immunity. Foods containing fat include various oils, dairy products and nuts. Fat is transported in the bloodstream as free fatty acid (FFA) and stored as triglyceride in the muscle and adipose tissue in other parts of the body. When energy demands are low, the body uses fat as its primary source of fuel. This includes when we are at rest and during very low intensity physical activity. While we have plentiful stores of fat in our body, it requires a large energy

investment and a large amount of oxygen to break down, proving less efficient in providing energy to fuel higher-intensity work.

At rest, the fat contribution (including triglyceride and FFA) to energy supply is high, as seen in Figure 6.04.



**FIGURE 6.04** At resting intensities, energy demands are low and fat sources including triglyceride and free fatty acids provide most of the energy. During exercise, when energy demands increase, there is a greater contribution from carbohydrate sources, including glycogen and glucose.

Source: Romijn, J.A. et al. (1993), 'Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration,' in *Am. J. Physiol.* 265, E380–E391, <https://journals.physiology.org/doi/epdf/10.1152/ajpendo.1993.265.3.E380>

## Protein

Protein is an important part of our nutritional intake as it supports muscle growth, rebuilding and repair and can be consumed through food such as lean meat, fish, eggs and lentils. It is transported in the blood and stored as the chemical fuel amino acid. Protein is a macronutrient that can be used for energy production but requires a large energy investment to break down. Therefore, it is not favoured by the body and would rarely be the primary source of energy during exercise. Having protein in your diet is important to sustain muscle mass, but too much can displace other macronutrients that the body prefers to use as fuel for exercise. This can compromise training and performance, particularly endurance work. Protein consumption by endurance athletes should be carefully monitored by coaching support staff via the use of training diaries.

## LOOKING FORWARD

### Training diaries

#### Chapter 11

Keeping a training diary is a way of monitoring subjective and objective data. Information is gathered regularly about such factors as nutrition (physiological), motivation (psychological) and the environmental conditions of training (sociological). This information helps coaches and athletes monitor their progress and may allow more appropriate progression to be applied. You will look at training diaries in more detail in Chapter 11.

## The CHO/fat relationship with intensity

**Incremental** physical activity occurs when someone starts out slowly, then gradually increases their intensity, often to exhaustion. Examples of this type of activity include the multistage fitness test and a laboratory test known as the  $\text{VO}_2$  max test.

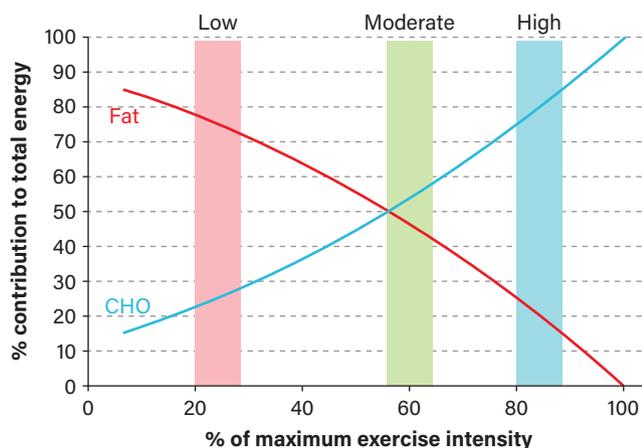
As intensity increases during the test, the percentage of energy obtained from carbohydrates and fats changes. At lower intensities, there will be a greater contribution from fats as energy is not required at a rapid rate. As intensity increases, there is a greater contribution from carbohydrates, which provide energy faster. The point where carbohydrate takes over from fat as the major contributor to energy production is known in the exercise physiology world as 'the crossover point'. Figure 6.05 shows the relationship each of the fuels has with exercise intensity.

### LOOKING FORWARD

#### Assessment of fitness

#### Chapter 10

In Chapter 10 you will investigate different types of fitness tests and perform a variety of different tests using reliable and accurate protocols.



**FIGURE 6.05** As intensity increases, there is a change in the contribution of different fuels used to provide energy to meet movement demands.

### LOOKING FORWARD

#### Fuel and glycogen sparing

#### Chapter 15

When exploring adaptations in Chapter 15, you will discover how trained athletes are able to use fat at a higher intensity, through the process of glycogen sparing and how this improves performance. This will result in a right shift in Figure 6.05.

#### incremental

Increasing in intensity over time

#### LEARNING HACK

You can use scientifically accepted abbreviations when writing answers to questions in the exam. For example, it is acceptable to use 'CHO' in place of 'carbohydrate'.

#### LEARNING SHORTCUT

When interpreting a graph, one variable influences the other, forming a relationship. As one variable changes, so, too, does the other. In Figure 6.05, as intensity increases, the percentage contribution from carbohydrate increases. You can also observe another relationship. As intensity increases, the percentage contribution from fat decreases.

## REAL WORLD APPLICATIONS

## Multistage fitness test

Table 6.01 shows likely fuel contribution during a multistage fitness test. This maximal test involves athletes moving between two sets of cones, 20 metres apart, and uses an audio recording. When they hear a beep, the athletes start jogging. The beeps get progressively closer together, meaning running pace, and therefore intensity, increases. The athlete stops when they fail to reach the cones before the next beep twice in a row. As the intensity increases, fuel contribution changes, as observable in Table 6.01, which displays likely results from a test.

**TABLE 6.01** As athletes progress through the levels of the multistage fitness test, there is an increase in intensity, shown by an increase in heart rate and a greater reliance on carbohydrate as a fuel source.

Level	RER	Fuel	Heart rate (bpm)
1	0.78	Fat	125
2	0.79	Fat	148
3	0.81	Fat	150
4	0.84	Fat	156
5	0.87	CHO	163
6	0.91	CHO	167
7	0.93	CHO	171
8	0.95	CHO	174
9	0.98	CHO	181
10	1.02	CHO	186
11	1.06	CHO	193
12	1.09	CHO	197

## LEARNING SHORTCUT

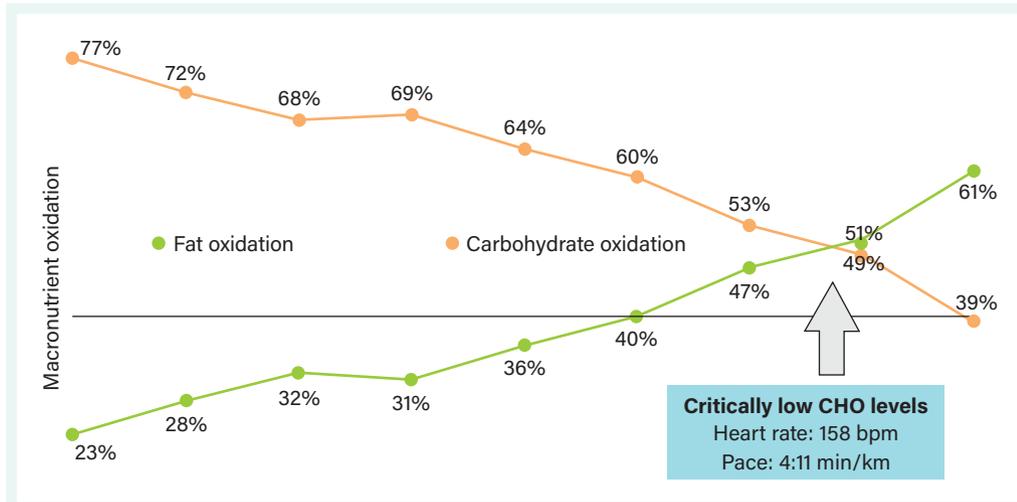
Respiratory exchange ratio (RER) refers to the ratio between  $\text{CO}_2$  produced by the body and the amount of  $\text{O}_2$  being used. It helps exercise scientists work out the fuel being used and if the body is working more aerobically or anaerobically.



**FIGURE 6.06** The multistage fitness test involves running between two cones at progressively shorter intervals.

## The CHO/fat relationship with duration

If specialised nutritional strategies are not employed during prolonged endurance events, CHO stores will begin to deplete. When CHO stores reach a critically low level, the body will turn to fat to provide most of the energy. As fat provides energy at a slower rate, intensity of performance must decrease. This concept is more casually known as 'hitting the wall' and will be explored in more detail when we discuss fatigue.



**FIGURE 6.07** This graph demonstrates two relationships: as duration increases, the percentage contribution of CHO decreases; as duration increases, the percentage contribution of fat increases.

Adapted from: McArdle, Katch & Katch, 2012

Importantly, all fuels contribute to energy supply, and athletes should work on developing strategies to drive metabolism of all fuel sources during training. The faster the rate of fuel breakdown, the faster the release of energy and the higher the intensity an athlete can work at.

### 6.1 CHECK-IN QUESTIONS

- 1 Identify** the names of the three food fuels that work together to supply energy for the body.
- 2 Explain** why carbohydrates are the preferred source of fuel during exercise.
- 3 State** the relationships shown in Figure 6.07.



**Assessment**  
6.1 Check-in questions

#### Command term

**state**  
Give a specific name or value or other brief answer without explanation or calculation

## 6.2 THE THREE ENERGY SYSTEMS

In this module you will learn about:

- the three energy systems (ATP-CP, anaerobic glycolysis and aerobic) including their fuels (chemical and food), rate and yield of each system, their contribution at rest and varying intensities and recovery rates associated with active and passive recovery and learn to:
- perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery.

**LEARNING  
SHORTCUT**

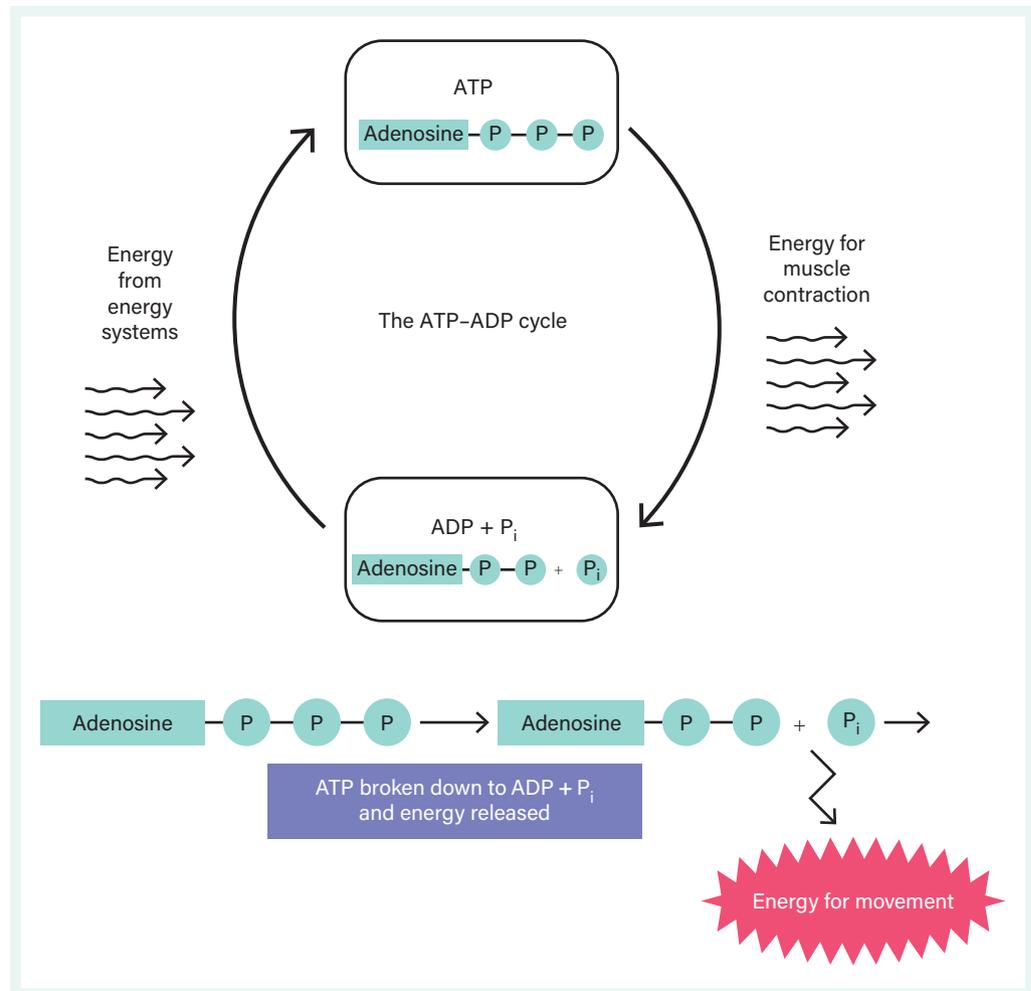
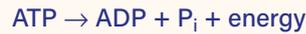
Exothermic reactions result in a net release of energy. In the case of the conversion of ATP to ADP and  $P_i$ , or ATP hydrolysis, the energy released is used for muscle contraction. The reactions also release heat, which contributes to the rise in muscle temperature when exercising.

Adenosine triphosphate (ATP) is a molecule in our muscles that stores energy and is responsible for the production of energy that fuels muscle contraction.

The structure of ATP consists of an adenosine molecule attached to three phosphate groups via bonds. The bond between the last two phosphate groups (the middle one and the one at the end) is relatively unstable and contains a large amount of stored energy.

When we need energy for muscular contraction, the bond connecting the middle and end phosphates breaks, producing energy and leaving behind adenosine diphosphate (ADP) and inorganic phosphate ( $P_i$ ). The energy that is released from this exothermic reaction is the energy that facilitates muscle contraction.

This energy-producing reaction can be summarised as follows:



**FIGURE 6.08** The breaking down of ATP to ADP and  $P_i$  releases energy for movement.

Our muscles have a limited (finite) amount of stored ATP, enough for one or two maximal contractions. ATP needs to be constantly rebuilt in a process known as ATP resynthesis. During this process, ADP and  $P_i$  are rejoined to form ATP, which then splits again to release more energy. The ATP-ADP cycle is constantly occurring, but the rate at which it occurs depends on our energy demands – in other words, how hard we are working. The key word used to describe how hard we are working is **intensity**.

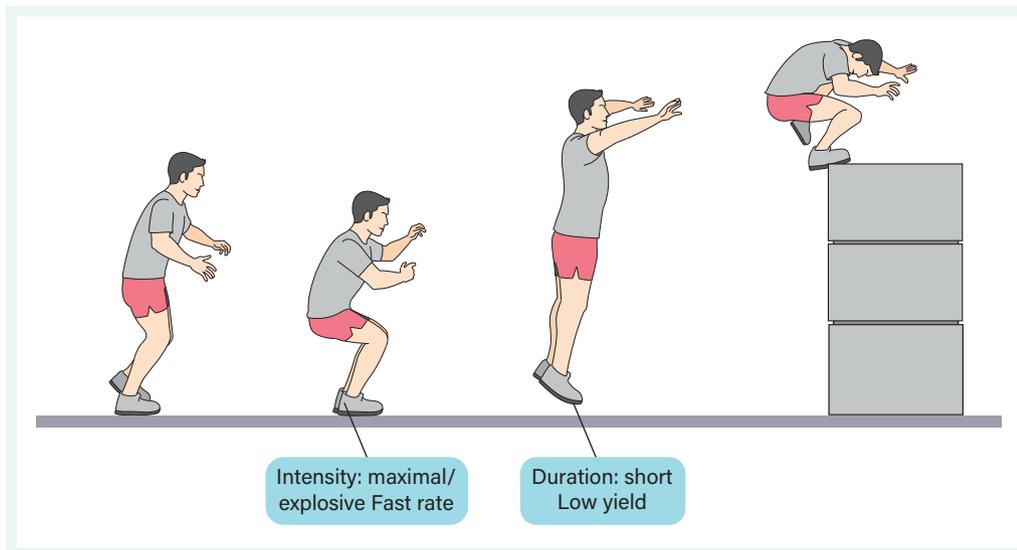
**intensity**

How hard we are working during exercise, and therefore how quickly we require ATP resynthesis

The resynthesis of ATP is a complex and dynamic process, facilitated by our body's three energy systems. It is important to note that all energy systems contribute to the resynthesis of ATP at all times; one, however, will be the major contributor, which primarily depends on how hard we are working (intensity) but is also influenced by how long we are working for (duration), the training status of the athlete and the availability of oxygen at the muscle site.

## Characteristics of performance

We can use the key terms **rate** and **yield** to link to performance. For example, Figure 6.09 demonstrates a jump that is a maximal-intensity exercise and requires energy at the fastest rate. However, as the jump is short in duration, a very low yield of energy is required. We can use these characteristics of performance to determine the contribution of the energy systems to the resynthesis of ATP.



**FIGURE 6.09** A jump is an explosive activity that requires energy at the fastest rate.

The muscles in our body are constantly breaking down ATP and resynthesising it from ADP. At rest, this cycle is relatively slow because we have a low energy demand. This means that a slower fuel and energy system can meet the demands easily, with ATP and ADP seesawing comfortably. When we start to work at a higher intensity, the breakdown of ATP occurs faster, so that our muscles can contract faster. There is a rapid rise in ADP, which signals to the body that resynthesis of ATP needs to occur faster, and so the body uses fuel and energy systems that better meet the new demands.

## The ATP-ADP cycle

We have discovered that all energy systems work together to supply energy, but there will always be one system that is contributing the most, depending on the demands of the task. There are three systems that work together to supply the energy required to resynthesise ATP. Two of these systems perform **anaerobic ATP resynthesis** – that is, they do not use oxygen in their reactions; these are the ATP-CP system and the anaerobic glycolysis system. Together, they form the anaerobic energy systems. The third system is the aerobic energy system, which performs **aerobic ATP resynthesis** – it uses oxygen to completely break down fuel to supply energy.

### rate

How quickly energy can be provided to resynthesise ADP to ATP. Energy is required at the fastest rate when exercise intensity is maximal.

### yield

The amount of energy required for a task. Activities shorter in duration require a small yield, while endurance work requires a larger yield of energy.

### LEARNING HACK

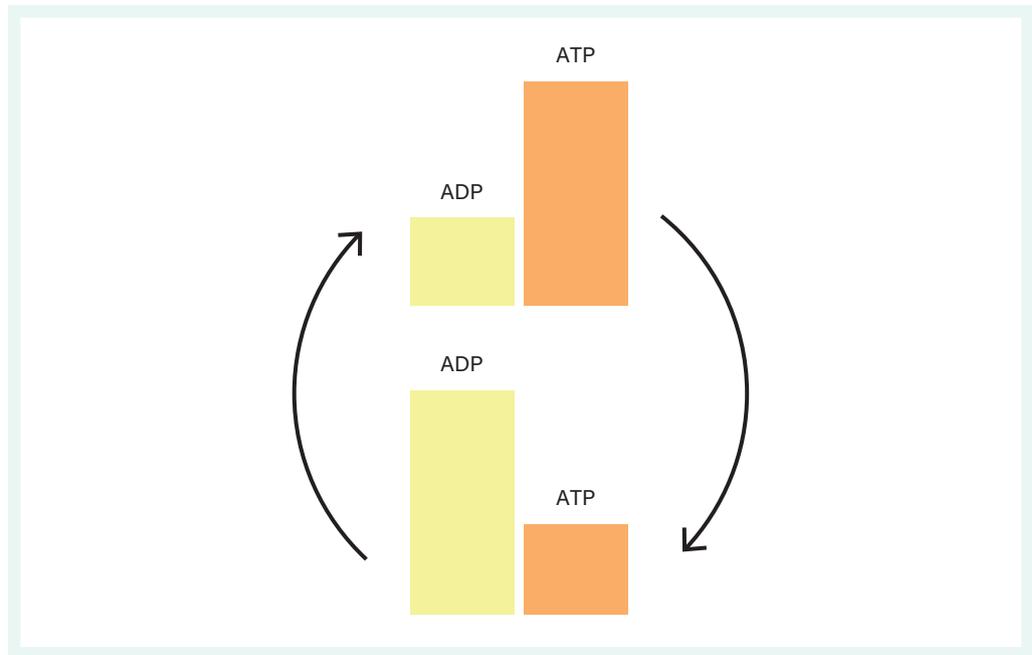
CP = creatine phosphate

### anaerobic ATP resynthesis

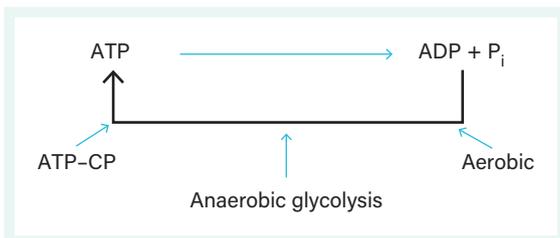
Reactions that resynthesise ATP without oxygen

### aerobic ATP resynthesis

Reactions that resynthesise ATP with oxygen



**FIGURE 6.10** In the ATP–ADP cycle, ATP is broken down to form ADP, which is then resynthesised to form ATP. This process is cyclic and constant. The rate at which it takes place is determined by how fast we need the energy.



**FIGURE 6.11** Energy to resynthesise ATP for movement comes from all energy systems.

### finite

Having a limit. The ATP–CP system is finite due to limited fuel, and the anaerobic glycolysis system is limited due to the accumulation of metabolic by-products.

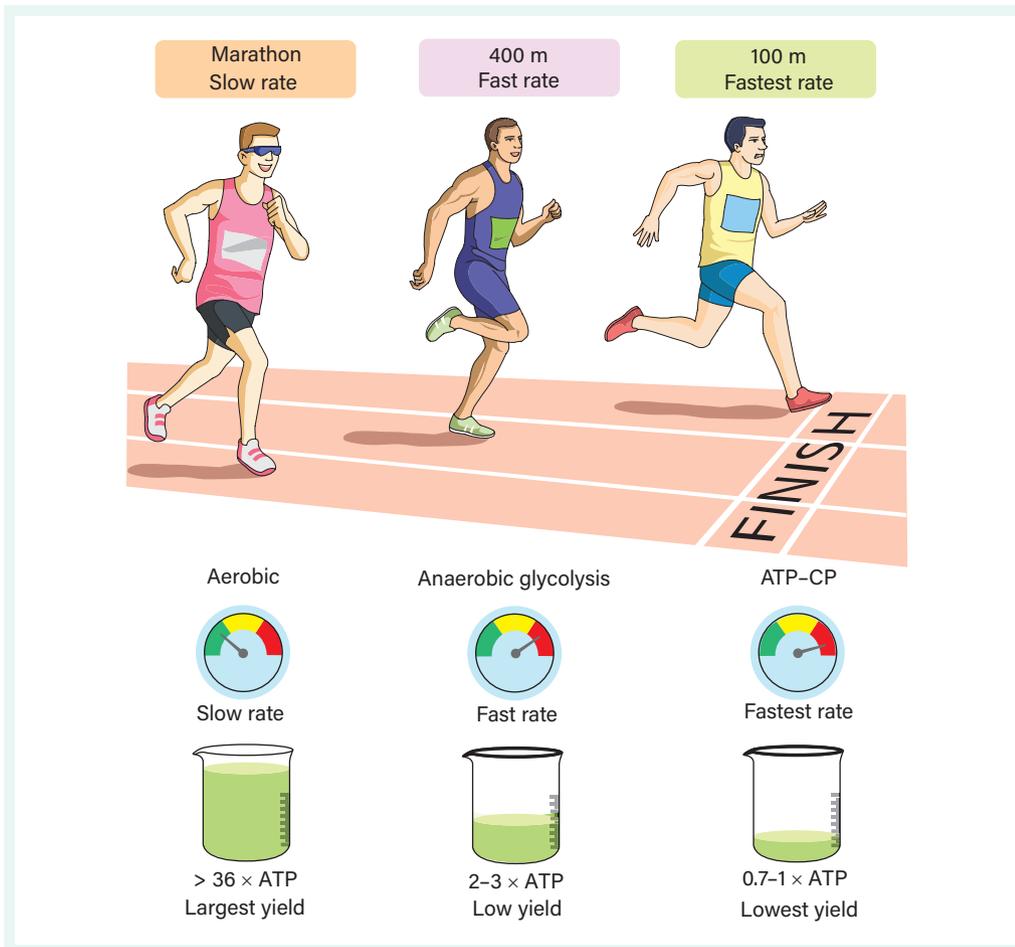
## Anaerobic energy systems

When energy is required quickly for explosive or maximal-intensity work, it is provided at a rapid rate by the anaerobic systems. These energy systems do not use oxygen to break down fuel and operate at a fast rate as they consist of relatively simple reactions. This means they can provide most of the energy we need for events such as sprinting, jumping and throwing. Although they provide energy quickly, the yield of energy they can provide is small (**finite**), which means there are limits to the duration of performances that are maximal.

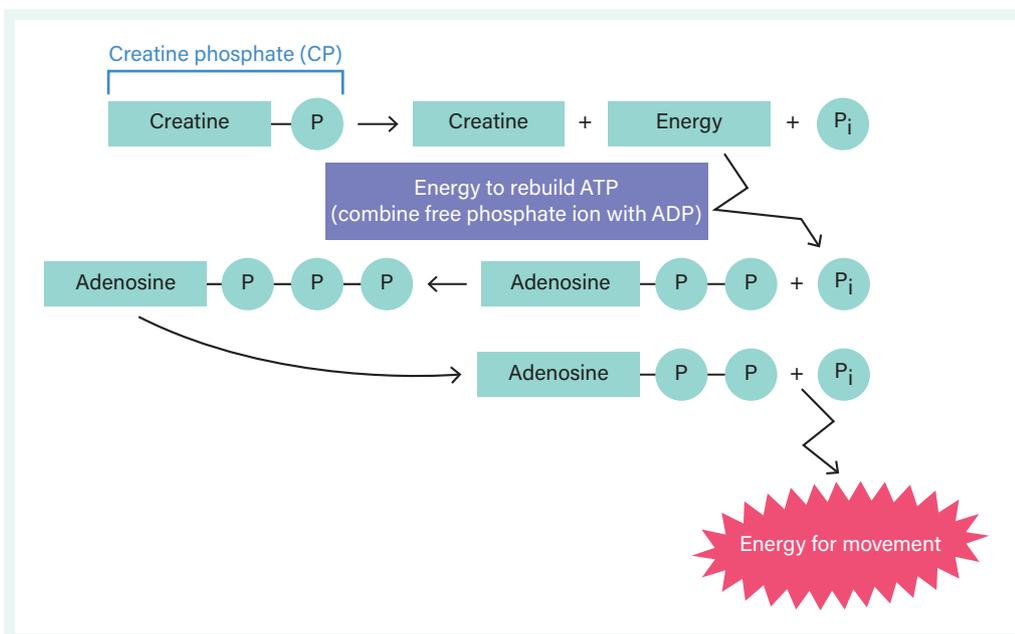
### ATP–CP energy system

We have discovered that we have a limited amount of ATP in our muscles, enough for a couple of maximal contractions. As ATP depletes, we get a rise in the amount of ADP and need the energy systems to work together to resynthesise ATP.

The ATP–CP system is the fastest system due to the simple reactions involved in releasing energy. This system uses the chemical fuel phosphocreatine, or creatine phosphate (CP), which is stored in the muscle. As shown in Figure 6.13, to provide the energy to resynthesise ATP from ADP, creatine phosphate splits. The bond energy from this splitting is used to rejoin a phosphate back to the middle phosphate and ATP is resynthesised. While stores of CP have some variability depending on the type of muscle an individual has and the training they have undertaken, it is always limited (finite). This means that, while the ATP–CP system has the fastest rate, it also has the lowest yield. For most people, when exercising maximally, CP will start to deplete after 6–10 seconds. Maximal exercise might include medicine ball slams, sprinting or clap push-ups.



**FIGURE 6.12** The anaerobic energy systems are quick to provide energy but there are limits on the amount of energy they can provide.



**FIGURE 6.13** The breakdown of creatine phosphate (CP) to produce energy to resynthesise ATP

**LEARNING SHORTCUT**

While we say that CP depletes quickly, it never completely runs out. It will reach critically low levels after 6–10 seconds of maximal activity. Athletes can train to increase their CP stores, which increases the capacity of the ATP-CP system.

## Links to performance

The ATP-CP system will be the major provider of energy for short-duration, maximal-intensity efforts – as in Figure 6.14, for example, which shows an elite baseball player hitting the ball.

To clearly justify why the ATP-CP system is the major provider, a 'fun fact' about the system can be identified and connected to the performance characteristics of the effort. For example, the ATP-CP system will be the major provider of energy for a baseball hit as it supplies energy at the fastest rate, allowing the effort to be powerful and explosive.

- Identify the energy system.
- Justify, using a 'fun fact'.
- Link to performance characteristics.



Yuki Taguchi/Major League Baseball/Getty Images

**FIGURE 6.14** A baseball hit relies on a rapid rate of energy, supplied by the ATP-CP system.

## Recovery of the ATP-CP system

To restore CP after it has been depleted, a rest or passive recovery is recommended so the aerobic system can facilitate restoration. It takes approximately 3 minutes to restore 98 per cent of CP, but up to 70 per cent can be restored with just 30 seconds of passive recovery. Studies have consistently shown that a passive recovery restores CP at the fastest rate, explaining why, in athletic events such as high jump or long jump, the athletes sit or lie down between attempts.

## REAL WORLD APPLICATIONS

### Field events

Most athletic field events require a maximal-intensity, short-duration effort. This means the ATP-CP system will contribute the most to energy production. In the sport of high jump, the athletes will have to perform this maximal effort many times over. To restore depleted CP at the fastest rate, so they can perform to their best in the next jump, athletes will use a passive recovery.



dpa picture alliance/Alamy Stock Photo

**FIGURE 6.15** Paris 2024 Olympic high jump champion Yaroslava Mahuchikh uses a passive recovery between jumps to restore CP at the fastest rate.

## LOOKING BACK

### Closing eyes to rest

#### Chapter 2

In Figure 6.15 you can see the athlete closing their eyes during a time of rest. This may be to enhance concentration and strengthen neural pathways by practising mental imagery or to optimise arousal through meditation or deep breathing.

**TABLE 6.02** Characteristics of the ATP-CP system

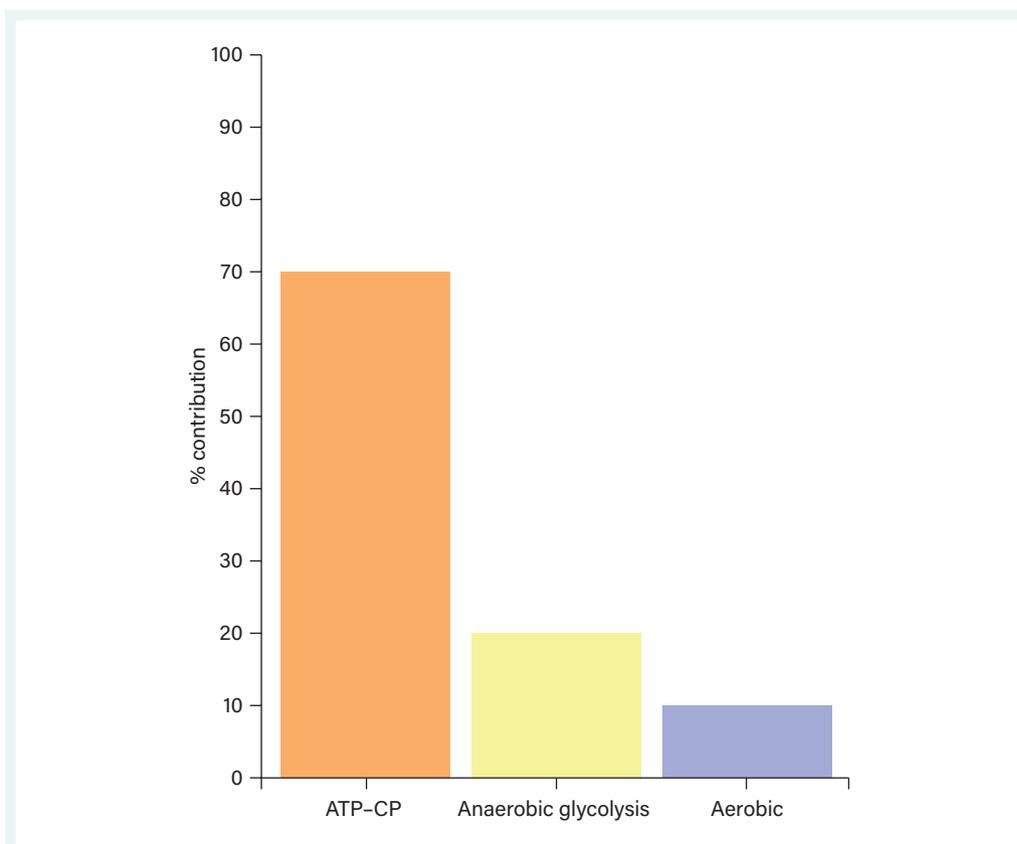
	Characteristics
Rate	Fastest rate of ATP resynthesis due to simple reactions
Yield	Lowest due to limited fuel
Fuel/substrate	CP
Performance	Maximal-intensity, short-duration exercises provided CP stores are present – for example gymnastics vault
By-products	P <sub>i</sub> , C

It is important to emphasise that, although the ATP-CP system will provide the greatest amount of energy for short-duration, maximal-intensity tasks when CP stores are available, all systems will always contribute. Figure 6.17 indicates the likely contribution of energy systems for a gymnastics vault that lasts approximately 5 seconds.



GABRIEL BOUYS/AFP/Getty Images

**FIGURE 6.16** A gymnastics vault uses all energy systems to provide energy.



**FIGURE 6.17** All energy systems contribute to the maximal-intensity, short-duration gymnastics vault.

## Anaerobic glycolysis energy system

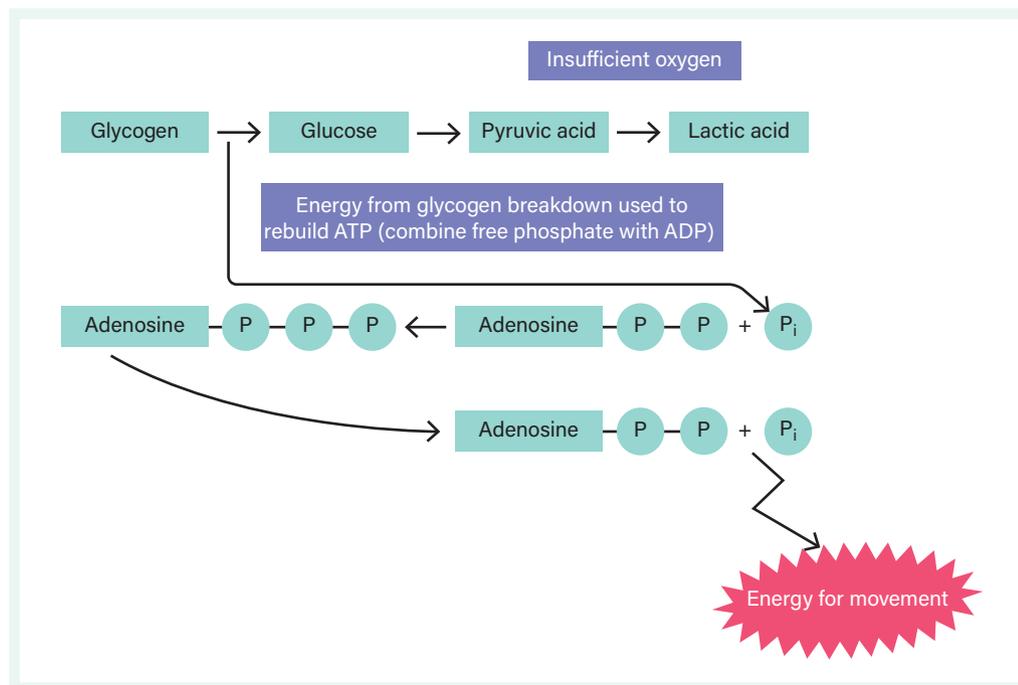
The anaerobic glycolysis energy system involves the incomplete breakdown of glycogen without oxygen. While it is slightly more complex in its reactions than the ATP-CP system, it still provides energy at a fast rate. To release the energy required to resynthesise ATP from this system, glycogen is broken down into glucose and then pyruvic acid. Energy is released, as seen in Figure 6.18.

When energy is required at a faster rate than it takes to completely break down glycogen with oxygen, it takes a 'short cut' and lactic acid is formed. Immediately, lactic acid dissociates to form lactate and  $H^+$  ions, which together form metabolic by-products. When these metabolic by-products, specifically  $H^+$  ions, are produced faster than they can be removed, they accumulate and cause the muscles to become acidic, which inhibits the enzymes responsible for breaking down glycogen. This means muscle contraction slows down, and accounts for the burning feeling you might feel during slightly longer or repeated maximal-intensity efforts.

### LEARNING HACK

#### The burn! Lactate or lactic acid?

Often, these terms are used interchangeably in the sports world, but they are slightly different. Lactic acid is produced during anaerobic glycolysis but, at normal body pH, it quickly turns into lactate and  $H^+$  ions. So lactic acid and lactate are closely related, but slightly different in molecular structure.



**FIGURE 6.18** Anaerobic glycolysis is the incomplete breakdown of glycogen without oxygen.

### Links to performance

When very high intensity is sustained, beyond the capacity of the ATP-CP system, there will be an increased reliance on the anaerobic glycolysis system. There will be a slight decrease in power or intensity since the anaerobic glycolysis system provides energy at a slightly slower rate. It can remain the major contributor for up to 60 seconds of very high-intensity activity before the impact of accumulated metabolic by-products will force the athlete to slow down. A 400-metre sprint is an example of an event that requires a large contribution from this system.

If repeated very high-intensity efforts are undertaken with very little rest for CP restoration – for example, when a centre in a netball match sprints from one end of the court to the other after an intercept – the anaerobic glycolysis system will also make a large contribution to energy supply.

The anaerobic glycolysis system will also increase its contribution during endurance events when energy demands suddenly increase – for example, a surge when overtaking an opponent or sprinting to the finish. This concept will be explored further when we look at energy system interplay, later in the chapter.

## Recovery of the anaerobic glycolysis system

An active recovery has been shown to support the body's return to pre-exercise conditions fastest when the anaerobic glycolysis system has made a large contribution to energy supply. An active recovery maintains circulation, and therefore blood flow, to the muscles. The oxygen delivered to the muscles oxidises the  $H^+$  ions to reduce muscle acidosis. Moreover, lactate is shuttled to other muscles and even the heart, where it is oxidised and broken down completely via the aerobic system, turning it into a valuable fuel. This is still a growing area of research in the exercise physiology world. Studies are looking at the differences in individuals and exercise intensities as key variables that affect the removal of, and recovery from, lactate and  $H^+$  accumulation.

**TABLE 6.03** Characteristics of the anaerobic glycolysis system

	Characteristics
Rate	Fast rate (second-fastest) of ATP resynthesis due to simple reactions
Yield	Low (due to accumulation of metabolic by-products)
Fuel/substrate	Glycogen/glucose
Performance	Increased reliance during sustained/repeated maximal efforts – for example 100 m swim or repeat sprints
By-products	$H^+$ , lactate



ANP/Alamy Stock Photo

**FIGURE 6.19** The anaerobic glycolysis system will increase its contribution during a surge to the finish line in an endurance event such as the 10,000 metres.

### 🚩 SIGNPOST

Watch the video *Haile Gebrselassie – 10,000 m Olympic Champion at Sydney 2000* on the Olympics channel on YouTube. Although this took place more than 20 years ago, it is a classic finish to the 10,000 metres. For these athletes, it is important to 'kick' at the right time. Too early, and they will fatigue; too late, and their finish will not be optimal. This video shows an example of both.



#### Weblink

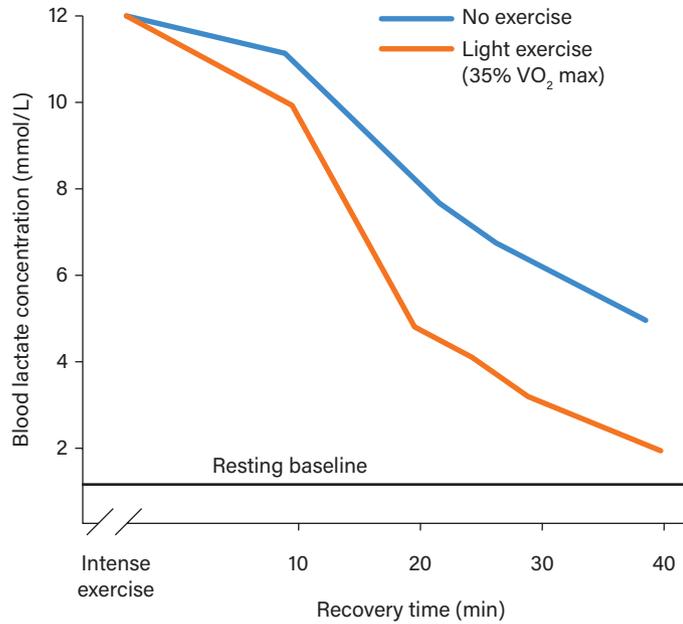
Haile Gebrselassie – 10,000 m  
Olympic Champion at  
Sydney 2000

**WORKED EXAMPLE**

**DIAGRAMS/GRAPHS**

©VCAA Exam 2022, Section B, Q7

The graph below shows blood lactate concentration over time, comparing different recovery methods following intense exercise.



Ensure you specifically refer to data from the graph.

If there are two variables in the question, discuss both of them in your answer.

Adapted from: Powers, S.K., Howley, E. & Quindry, J. (2009), *Exercise Physiology: Theory and application to fitness and performance*, McGraw-Hill, New York, p. 54

**a** With reference to the graph above, explain whether passive recovery or active recovery is more beneficial following intense exercise.

Faster removal is key here. This first sentence also compares both types of recovery, ensuring you address what is being asked in the question.

**Sample response**

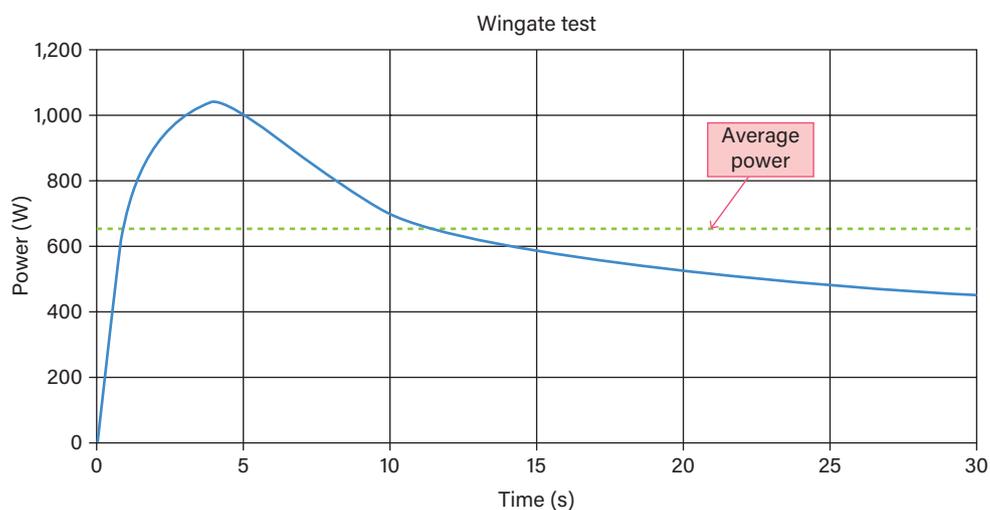
Active recovery is better as it allows faster removal of blood lactate than passive recovery. The data demonstrates that after ~30 minutes, blood lactate concentration was ~3 mmol/L when undertaking an active recovery compared to ~6 mmol/L with no exercise (passive recovery).

Using data strengthens your response and ensures you get the mark allocated to your graph reference. The tilde (~) means 'approximately' and is appropriate to use in exams.

## CASE STUDY 30-SECOND WINGATE TEST

The 30-second Wingate test, which is a recognised test to indirectly measure the capacity of the two anaerobic systems, explicitly shows the performance consequences of attempting to meet maximal power output for an extended time. Over a period of 30 seconds, the athlete pedals as hard as they can, and their power output is measured in watts.

At the beginning, the ATP-CP system supplies most of the energy as it provides energy at the fastest rate; however, CP stores quickly become depleted and the body increases its reliance on the anaerobic glycolysis system. As this system has slightly more complex reactions, and therefore a slower rate, the athlete is unable to sustain the power output, which is evident by the gradual decline displayed in the graph.



**FIGURE 6.20** Graph showing results for a Wingate 30-second bike test

### QUESTIONS

- Which energy system is providing the most amount of energy at the 30-second point in this all-out sprint test?
- Use the graph in Figure 6.20 to **identify** the approximate time of peak power during the Wingate anaerobic capacity test.
- Identify** the energy system that would be the major contributor at the time of peak power.
- Explain** why the energy system you identified in Question 3 is the major contributor at that time, using the concept of rate to **justify** your answer.
- Explain** the limitation of this system.
- Justify** why a 200-metre runner might perform better on this test than a 100-metre runner.
- Use data to **discuss** the difference between power at the 5-second mark and at the 30-second mark with reference to the major provider of energy at each point.

## SIGNPOST

## 30-second Wingate test

Watch a clip of an athlete undertaking the 30-second Wingate test in the video *30 Second Wingate* on the McAuslanPerform channel on YouTube. The athlete pedals as fast as possible without any resistance, then a fixed resistance is added and the athlete sprints for 30 seconds. Their power output is measured.



**Weblink**  
30 Second Wingate

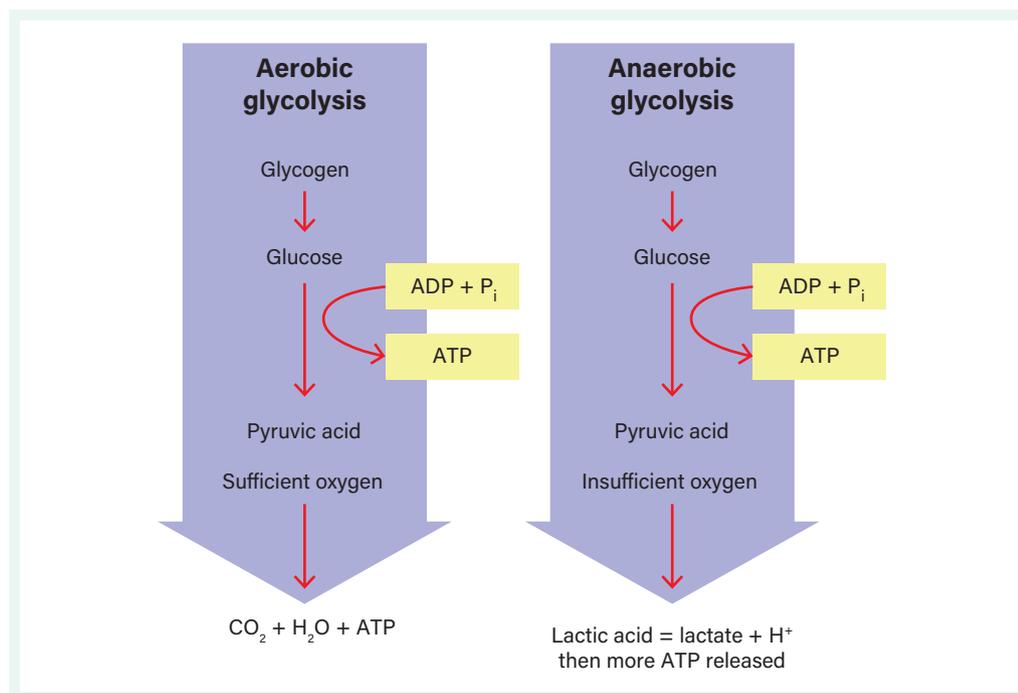
## LEARNING SHORTCUT

An easy way to remember how fast an energy system can provide energy is to think about the complexity of its reactions. Simple reactions mean the system can produce energy at a fast rate; more complex reactions result in a slower rate of energy production.

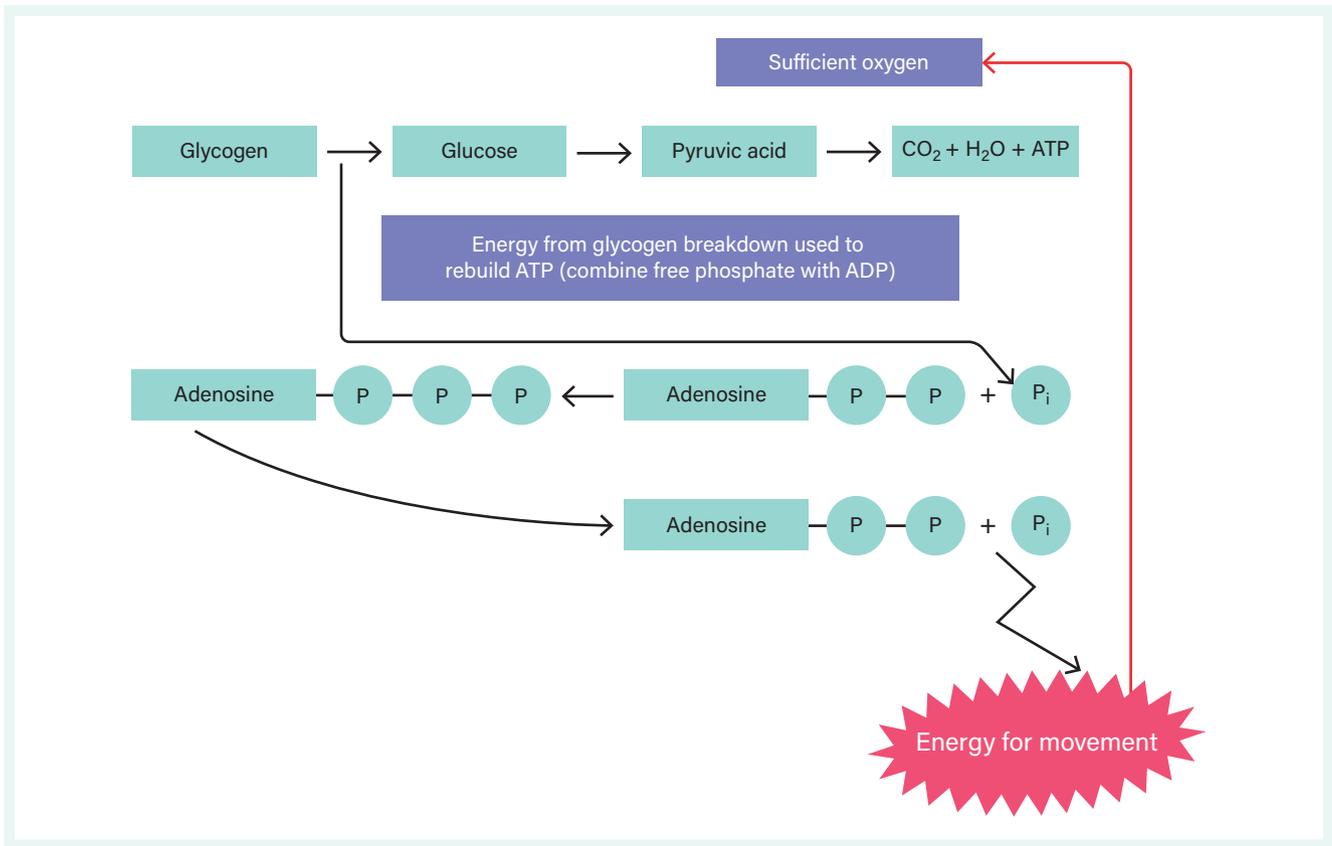
## Aerobic energy system

The aerobic energy system uses oxygen to completely break down glycogen/glucose and triglyceride/FFA. It can also break down amino acids (stored protein) but as they are much more complex the process is very slow. Amino acids make very little contribution to energy supply during exercise.

The aerobic system has the capacity to produce the most amount of energy, meaning it has the greatest yield. However, it also relies on the most complex reactions of the three systems, resulting in a slow rate of energy production. The initial pathway in which glycogen is broken down to pyruvate is the same as that used by the anaerobic glycolysis system; however, to release more energy and break down completely, the fuel enters the mitochondria. Similarly, a broken-down form of triglyceride can enter the mitochondria. This complex process produces metabolic by-products, including water ( $H_2O$ ), heat and carbon dioxide ( $CO_2$ ). The body can efficiently remove these by-products through processes such as gas exchange by transporting them from the muscle in the blood, then exchanging them for oxygen ( $O_2$ ) via the gas-exchange process in the lungs.



**FIGURE 6.21** The aerobic and anaerobic pathways of glycogen breakdown



**FIGURE 6.22** The aerobic system uses oxygen (O<sub>2</sub>) to completely break down fuel.

### Links to performance

The aerobic system will provide the greatest amount of energy for lower-intensity work when energy is not required as a fast rate. It provides the most energy for longer-duration endurance events as well as contributing overall during team sports due to its large yield. Once oxygen uptake is high, the aerobic system is also capable of providing the majority of energy for high-intensity demands. However, an increase in contribution from the anaerobic systems will support a maximal or higher-intensity effort such as a sprint to the ball or a maximal jump. Similarly, a sprint finish to a half marathon will mostly be fuelled by the aerobic system, but there will be an increase in contribution from the anaerobic systems to meet the increase in energy demands.

### Recovery of the aerobic system

An active recovery is generally recommended for events where the aerobic system is the major contributor as it maintains circulation, helps to thermoregulate and reduces the risk of venous pooling.

### DID YOU KNOW?

VO<sub>2</sub> max is a measure of the maximal intensity that can be obtained aerobically. It indicates the maximal amount of oxygen the body can take in, transport and utilise, and it will be different for each individual, depending on a variety of factors, including age, sex and genetics. While VO<sub>2</sub> max is obtainable, it is not possible to hold this intensity. Interestingly, while the aerobic system provides energy at a slower rate, some research has shown that 90 per cent of an athlete's VO<sub>2</sub> max can be reached in only 30–60 seconds.

**TABLE 6.04** Characteristics of the aerobic system

	Characteristics
Rate	Slowest (due to complex reactions)
Yield	Largest due to abundant fuel
Fuel/substrate	Glycogen/glucose, triglyceride/free fatty acid, amino acid
Exercise	Long duration, submaximal intensity
By-products	CO <sub>2</sub> , H <sub>2</sub> O, heat, ADP



Albert Perez/Getty Images Sport/Getty Images

**FIGURE 6.23** A sprint in an aerobic sport such as an AFLW game requires an increase in contribution from the anaerobic systems.

## COLLABORATIVE TASK

### Prac activity

#### Relative energy system contribution

In pairs or small groups, select and undertake three of the practical examples from the table below and estimate the contribution each energy system makes during the activity. Weblinks on Nelson MindTap will help you with some of these activities. Present your data in three pie charts. You do not need to identify the exact percentage contribution: as each person is different, an estimate will be more appropriate.

A sample (Figure 6.24), showing the energy systems' relative contributions during the 400-metre track event, has been completed for you. Include your pie charts in the write-up in your reflective folio.

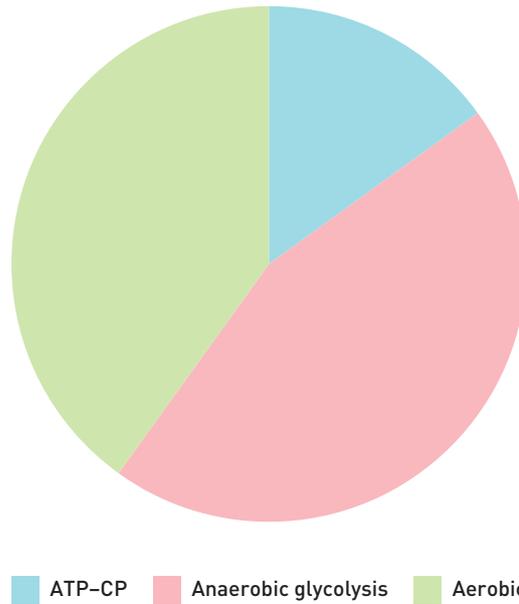
Javelin/discus throw	100 m sprint	10 burpees
90 s wall sit	1 km jog	Just Dance
10 min resistance band workout	5 min basketball 1v1 game	10 tennis serves



**Weblinks**  
Just Dance

10-minute resistance  
band workout

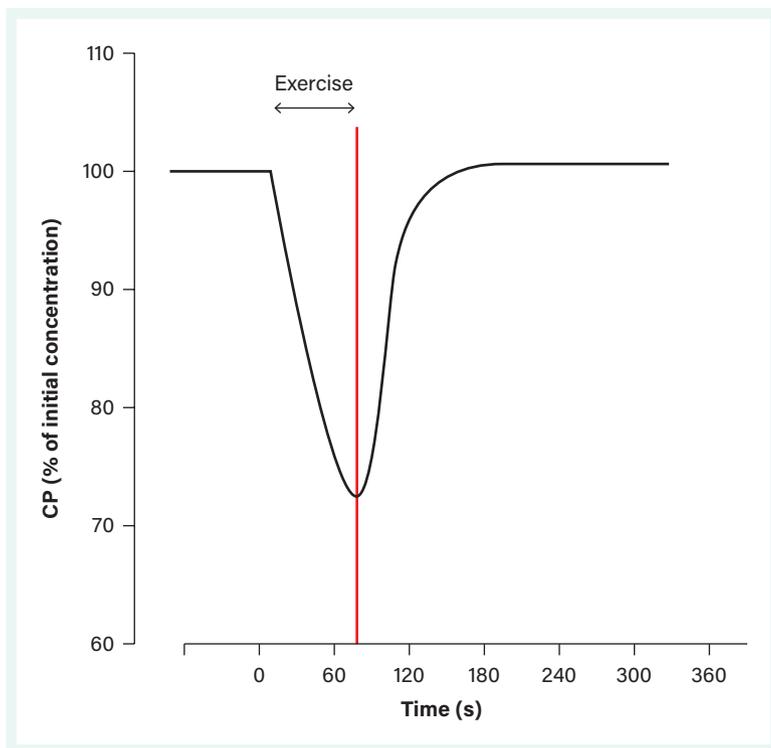




**FIGURE 6.24** Estimated energy system contributions during a 400-metre track event

## Recovery rates

Through our investigation of each energy system, we have discovered that it is important that athletes use an appropriate recovery strategy. They may need to perform again very quickly after their effort – for example, the repeat sprints required in a tennis rally – or recover properly for a training session the next day. The type of recovery prescribed can be linked to the major energy system that has contributed to the task as well as the time available for recovery.



**FIGURE 6.25** The aerobic system restores CP at a rapid rate during a passive recovery.

### Passive recovery

A passive recovery occurs when the athlete rests or moves at a low intensity – for example, walking. This type of recovery allows the aerobic system to restore CP, and it is the strategy advised when rest time is short and the following movement is of maximal or very high intensity. An example of when a passive recovery is used is during a 3-metre springboard dive. While 3 minutes is the recommended time to restore 98 per cent of CP, up to 70 per cent can be restored with just 30 seconds of passive recovery. Figure 6.25 shows the restoration of CP when passive recovery is undertaken.



AP Images/Matt Dunham

**FIGURE 6.26** A diver consults with his coach during a passive recovery.

## Active recovery

An active recovery involves the athlete maintaining a similar type of movement at a lower intensity than during their performance. It might include a slow swim following a 400-metre swim or a jog following a netball match. An active recovery maintains circulation, and therefore blood flow. This supports the fastest removal of metabolic by-products, such as the fatiguing H<sup>+</sup> ions produced by the anaerobic glycolysis system. The circulation also helps restore fuel to the muscles, prevents venous pooling and removes heat, assisting with thermoregulation.

There is some evidence to support a decrease in the likelihood of experiencing DOMS (delayed onset muscle soreness) if an active recovery is used.

Therefore, an active recovery is recommended when the anaerobic glycolysis system or the aerobic system makes a large contribution to energy supply. It must, of course, be balanced with the athlete’s future needs and environmental conditions. An active recovery would not be recommended after an athlete has run a marathon in warm conditions!



### ABOVE AND BEYOND THE STUDY DESIGN

Delayed onset muscle soreness (DOMS), page 268

**TABLE 6.05** Energy system comparison

	ATP-CP	Anaerobic glycolysis	Aerobic
Advantages	Fastest rate	Fast rate	Greatest yield
Limitations	Lowest yield (fuel depletion)	Low yield (accumulation of by-products)	Slow rate
Performance examples	Soccer penalty	50 m swim	Most team games
Recovery	Passive	Active	Active



### Command term

#### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

## COLLABORATIVE TASK

### Prac activity

#### Energy systems and athletics

The data below shows track and field events and the time taken to complete each event at a local carnival. Try these events in class and use the information below to answer the questions.

Event	Time taken (s)
Javelin	3.61
Long jump	4.16
100 m	11.65
400 m	58.0

#### DISCUSSION

- 1 **Identify** the three events in which the greatest percentage contribution comes from the ATP-CP system.
- 2 **Identify** the event in which the greatest contribution comes from the aerobic system.
- 3 **Justify** your selection from Question 2.
- 4 **Identify** the event after which the athlete should undertake an active recovery. **Justify** your selection.

## LOOKING BACK

### Augmented feedback

#### Chapter 2

In Figure 6.26 the coach is giving the athlete augmented feedback (knowledge of performance) as they are looking at and discussing a video review of his technique while he undertakes a passive recovery.

## 6.2 CHECK-IN QUESTIONS

- ©VCAA Exam 2020, Section A, Q10

The energy system with the highest yield of ATP but slowest rate is the:

  - ATP–CP system.
  - aerobic system.
  - anaerobic system.
  - anaerobic glycolysis system.
- Which of the following characteristics is true of the ATP–CP system?

  - Peak power occurs at 5 seconds.
  - A limitation is CP stores.
  - It involves the incomplete breakdown of glycogen.
  - It has the slowest rate.
- Define** the term 'finite.'
- Explain** why a passive recovery would be the most suitable recovery strategy for a pole vaulter between efforts.
- The following questions relate to a class game of tchoukball. The game was played over 4 × 4-minute rounds, with a minute recovery between. The fast-paced game is played on a 27-metre-long court between two teams of six. To score a point, the ball must be thrown forcefully by an attacking player, hit the rebounder and be caught by the attacking team on the full. Physical contact is prohibited. Players may take three steps with the ball and may hold the ball for a maximum of 3 seconds when in possession. The game is characterised by short, repeated sprints, explosive jumps and short rests.

  - Identify** the major fuel used for higher-intensity efforts towards the end of each intermittent 4-minute round.
  - Explain** when each of the anaerobic systems increases in its contribution to energy production during the 4-minute block. **Justify** your selection with links to the characteristics of the game. (4 marks)



**Assessment**  
6.2 Check-in questions

### Command terms

#### define

Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity

#### identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

## 6.3 INTERPLAY OF ENERGY SYSTEMS

In this module you will learn about:

- interplay of energy systems in relation to the intensity and duration of physical activity, sport and exercise and learn to:
- participate in a variety of physical activity, sport and exercise and describe, using appropriate terminology, the interplay and relative contribution of the energy systems.

All energy systems work to provide energy to resynthesise ATP at all times. Which energy system is the major contributor depends on the demands of the task and the training status of the athlete.

**Video**

In focus: Energy system  
interplay

## Energy at rest

The body's energy demands at rest are low, which means the more complex aerobic system provides most of the energy. At rest, two-thirds of the energy provided by the aerobic system is provided via the breakdown of fat and one-third via the breakdown of carbohydrate.

## Energy during physical activity

Which energy system provides most of the energy required at any time during physical activity depends on:

- the intensity of the movement
- the duration of the movement
- the training status of the person.

Ideally, the body would provide most energy via the aerobic system as it has a large yield and its metabolic by-products can be dealt with relatively easily. However, the limitation of the aerobic system is that it is slow to meet energy demands once they rise above rest, and it requires a large oxygen uptake. This is a time-consuming process and, while the body begins to make the acute responses to increase oxygen uptake, including increasing heart rate and respiratory rate, there is an increased reliance on the anaerobic systems to provide energy. This period, during which oxygen supply does not equal demand, is known as oxygen deficit. For very short duration, maximal-intensity movement, the aerobic system will never meet the demands of the task, so the anaerobic systems will provide most of the energy to fuel the movement.

Knowing and understanding energy system contribution, and being able to identify when each energy system is making the greatest contribution to the resynthesis of ATP, is especially useful for coaches and trainers. It allows them to design a specific training program that develops the energy system performance requirements for that athlete.

### LOOKING FORWARD

#### Specificity

##### Chapter 12

Specificity is one of the most important training principles for enhancing performance. In this context it refers to the way the training program mimics the performance requirements of the sport or event, such as fitness components, energy systems, muscle groups and actions. In Chapter 12 you will explore this concept in depth.

### LOOKING BACK

#### Oxygen deficit

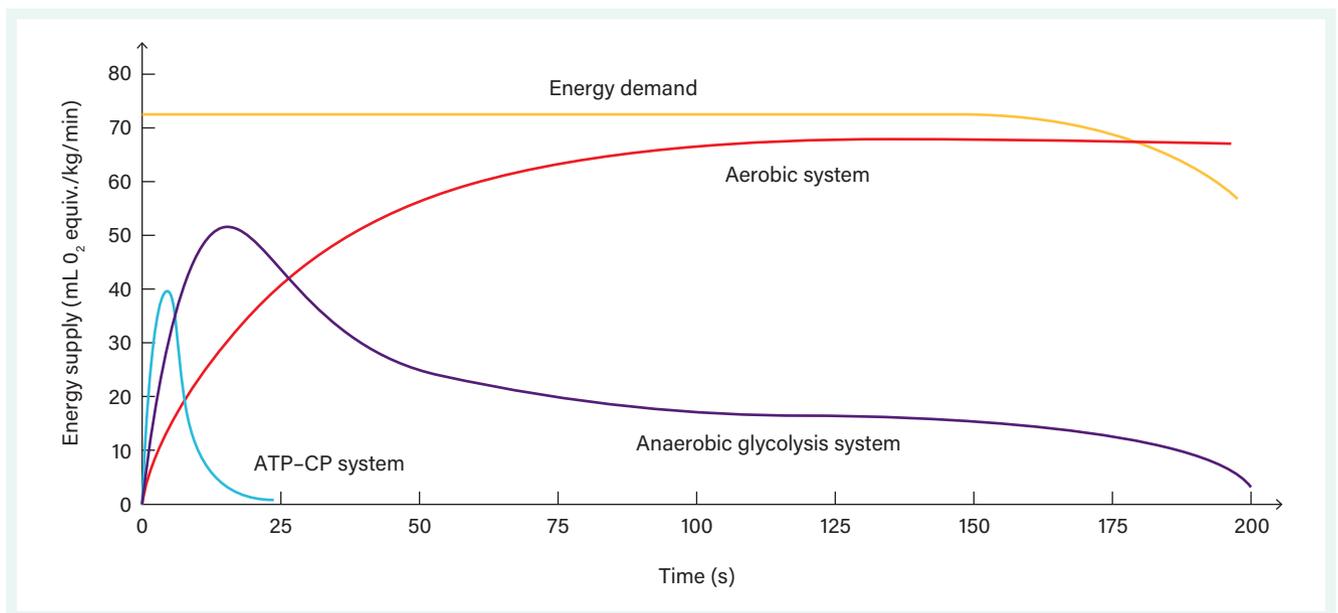
##### Chapter 4

You will remember discussing the concept of oxygen deficit in Chapter 4. During this period of time, when energy demands rise, the aerobic system is unable to immediately meet the new energy demands. This is due to the complex reactions it must undertake to provide energy. This is also known as a lag time. Once the body makes the necessary acute responses to increase oxygen consumption, the aerobic system increases its contribution, reducing oxygen deficit.

## The time–energy continuum

There are some movement examples that require maximal intensity from the onset and there is a well-recognised energy system continuum that demonstrates the interaction between energy systems for these types of movements. Examples include a 50-metre swim, a long jump and a hammer throw. Most sports, including team sports such as hockey or lacrosse, will have fluctuating energy demands and therefore their energy system contribution will not always be reflected in this graph.

Nevertheless, the graph shown in Figure 6.27 is important to understand as it demonstrates the rise and fall of the anaerobic systems and the slower rise of the aerobic system, thus displaying the interrelationship of the energy systems for maximal-intensity movement. This graph can be helpful in working out the system that is contributing the most for a set time frame. For example, you can use it to determine that, for a 5-second effort such as a hammer throw, the ATP–CP system will contribute the most. During a hockey game, when there are repeated maximal sprints, each lasting around 20 seconds, this graph can be used to identify the anaerobic glycolysis system as the major contributor.



**FIGURE 6.27** The energy system–time continuum for maximal-intensity activity

## REAL WORLD APPLICATIONS

### Anaerobic capacity as a determinant of performance in sprint skiing

We often think of cross-country skiing as being an endurance event, but sprint events are popular too.

In the 1924 Winter Olympics there were two cross-country events, which grew to 12 at Beijing in 2022 – six each for men and women.

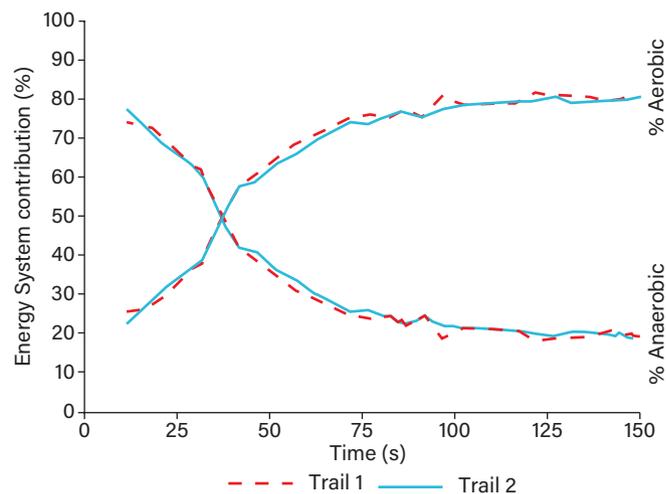
The Sprint Classic is a race of 1.4 kilometres for men and 1.2 kilometres for women. In 2023, the winner of the men's Sprint

Classic at the Nordic World Ski Championships was Johannes Klæbo from Norway, with a time of just over 2 minutes 56 seconds.

While the greatest contribution in this event comes from the aerobic system, the anaerobic systems will play a large role in providing energy. There has been much interest in developing the total amount of energy the anaerobic systems can provide, known as anaerobic capacity. In a testing lab in Norway, athletes were required to ski as fast as possible on a roller-ski treadmill. A variety of measurements were taken, one of which informed the laboratory testers about the relative contributions of anaerobic and aerobic energy. The graph below shows this contribution for the first 150 seconds, similar to the time taken to ski the Sprint Classic.



**FIGURE 6.28** Anaerobic energy is still vital in aerobic-based events.



**FIGURE 6.29** The relative contribution of aerobic and anaerobic energy systems during 150 seconds of performance

Source: Losnegard, T., Myklebust, H. & Hallen, J. (2012), 'Anaerobic capacity as a determinant of performance in sprint skiing', in *Medicine and Science in Sports and Exercise*

**QUESTIONS**

- 1 Referring to the graph in Figure 6.29, **identify** which energy system or systems contribute the most at the 25-second mark.
- 2 **Identify** which energy system or systems contribute the most at the 100-second mark.
- 3 **Explain** why the system or systems you chose in Question 1 make the greatest contribution, referencing one of the key terms – rate or yield.
- 4 **Discuss** why there is a gradual decrease in the energy production from these systems as the duration of the test increases.
- 5 The study discusses the impact of anaerobic capacity in cross-country skiing, which can be developed through training. Develop a training session that might support this development, drawing on your understanding of the contribution of the anaerobic energy systems for various intensities and durations.

**LOOKING FORWARD****Training methods****Chapter 13**

Training methods will be discussed in Unit 4. You will need to be able to link each training method to the energy system that it targets, and identify adaptations (changes) that occur to an athlete as a result of participating in an effective training program and how these adaptations improve performance.

**🚩 SIGNPOST**

To learn more about training links, refer to the interval resource on the VCAA website.

**🚩 SIGNPOST**

Come up with a checklist of items you should consider when writing an energy system interplay. Check your own list against our recommended list on Nelson MindTap.

**ABOVE AND BEYOND THE STUDY DESIGN**

The lactate shuttle, page 269



**Weblink**  
VCAA interval resource

**Resource**  
Energy system checklist

## WORKED EXAMPLE

### ENERGY SYSTEM CONTRIBUTION FOR BREAKING

Breaking, or breakdance, is a dance style characterised by acrobatic movements. During a breakdance effort you might observe the following series:

- The athlete will start with a series of small jumps and sideways movements, then stand still and use their arms to create stylish hand movements.
- They then move to the 'down rock', which involves explosive arm jumps, rotations and powerful spins on the ground.
- In the middle of the routine the athlete will freeze on their head or arms for a few seconds, then propel into more explosive work. The entire effort will last about 50 seconds. Use this information to **discuss** the energy requirements of this effort.



**FIGURE 6.30** The Olympic/Paralympic movement is conscious of the rise in recreational and informal sport participation. Breaking was chosen as a feature sport for the Paris Olympics in 2024.

chacassart/Adobe Stock

### Sample response

To build your confidence, use a starter sentence acknowledging that all systems contribute.

Reference specific words from the example and link explicitly to each system.

Use the key term 'rate' to justify why the ATP-CP system increases contribution.

All energy systems will contribute to the breakdance effort. Initially, for the jumps and for the explosive arm jumps and powerful spins, the ATP-CP system will be the major contributor as it provides energy at the fastest rate. There is the opportunity to restore some CP via the aerobic system when they stand still or freeze and perform the lower-intensity hand movements. Here the aerobic system will work to restore CP as it is not required at a fast rate. However, it is unlikely to be fully restored and the down rock efforts will likely see CP depletion. This results in an increase in contribution from the anaerobic glycolysis system (which will have a large role due to the 50-second effort and the fact that it has a slightly higher yield than the ATP-CP system) to maintain the high-intensity movements as it produces energy at a fast rate.

Another way to demonstrate how the systems work together is to use CP depletion to explain its reduction in energy and the consequent increase in anaerobic glycolysis contribution.

Keep referring to the key terms 'rate' and 'yield' to justify your energy systems contribution.

Rather than mention each system separately, try to link the systems. A great way to do this is to link the aerobic system to the recovery of the anaerobic systems.

## Links to performance

When considering which energy system is making the greatest contribution to ATP resynthesis, many factors need to be taken into account. A sprint to the ball during the first kick-off at the centre mark in soccer will have different contributions from the various energy systems than a surge to overtake an opponent at the end of a 5-kilometre run.

When thinking about energy system interplay, it is important to acknowledge that all systems contribute to the supply of energy, the major contributor depending on the intensity and duration of the task. During a relatively long match of hockey or netball, the greatest supplier of energy will be the aerobic system; but during those matches when energy demands rise – for example, during a sprint or a fast pass – the anaerobic systems will increase their contribution to meet the higher energy demands.

Consider a basketball match, immediately after the ball goes out of court. The aerobic system will provide the most energy setting up for the sideline throw-in, as energy is not required at a fast rate. If there is an explosive sprint after the sideline throw-in, the ATP-CP system will provide most of the energy for the maximal-intensity movement as it provides energy at the fastest rate. Energy for an immediate sprint after the initial sprint would also be met by the ATP-CP system. If the maximal-intensity efforts were sustained, CP would start to deplete, and the anaerobic glycolysis system would take over as the major provider. When the player is resting – for example, during a time out – the aerobic system will be the major contributor as it works to provide energy and restore CP. A maximal effort, such as a lay-up following rest, would again use the ATP-CP system as CP is likely to be partially restored. As the match progresses, oxygen uptake will increase and the aerobic system will increase its contribution. This means that, late in the match, the aerobic system is likely to contribute the most energy to a sprint, with a top-up of energy supplied anaerobically.



**FIGURE 6.31** A basketball team has time for a short passive recovery when the ball goes out of court.

### LEARNING SHORTCUT

The aerobic system increases its contribution to ATP resynthesis as oxygen uptake increases. Be careful not to always link the increase in aerobic energy supply to the accumulation of by-products associated with the anaerobic glycolysis system. It is not always the accumulation of by-products that 'causes' the aerobic system to increase contribution; otherwise events such as the 400-metre freestyle swim would see a dramatic drop in intensity at around the 60-second mark.

Mr. Anthony Nesmith/Icon Sportswire/Getty Images



**FIGURE 6.32** A basketball player will use a combination of the three energy systems to provide energy for ATP resynthesis during a match.

Consider a 5-kilometre run with a competitive sprint finish, such as the Parkrun, shown in Figure 6.33. The aerobic system will be the major contributor due to the long duration and its large yield. However, as the run begins, energy demand lifts above that which the aerobic system can provide. The anaerobic energy systems (ATP-CP and anaerobic glycolysis) will increase their contribution during the period of oxygen deficit as they provide energy at a faster rate. Once oxygen uptake has increased, the aerobic system will be able to meet energy demands. This is known as steady state. It may take a few minutes before oxygen supply matches oxygen demand. For any lifts in intensity, the anaerobic glycolysis system will increase its contribution, but the aerobic system will remain the major contributor.



**FIGURE 6.33** Parkrun has become a popular recreational pursuit.

### DID YOU KNOW?

Parkrun is a free community event held in 484 locations worldwide on Saturday and Sunday mornings. There are various modes of movement available, including walking, jogging and running, and the atmosphere is welcoming and inclusive. It can also be competitive: the current world record is held by Andy Butchart, who ran the 5-kilometre event in 13 minutes 45 seconds at Silverknowes, in the north-west of Edinburgh, Scotland. Andy sprinted to the finish to achieve the world record.

## COLLABORATIVE TASK

### Prac activity

#### Energy systems in team sports

##### AIM

To collect data while undertaking a team sport to determine the energy system requirements of the sport. Use the data collection template on Nelson MindTap to record your data.

##### METHOD

- 1 As a class, select a sport. Split the class into two groups: one half will play, the other half will collect data.
- 2 Make a list of the skills that are important to the sport and put them in a table.
- 3 Make a list of the movement patterns – for example, run, sprint, jog, sidestep – and put them in a table.
- 4 The group collecting the data should select a couple of pieces of data – a skill and a movement – to record during the game.
- 5 After conducting an effective warm-up, play the game for 5 minutes.
- 6 Select one player and note down each time they execute the skill or perform the movement.
- 7 Swap over so each person experiences the practical activity and the process of data collection.
- 8 Use a central document to collect all data.

##### DISCUSSION

As a group, make a list of the skills that might rely on each energy system as the major provider of energy. Use this information to discuss the following questions as a group.

- 1 Which skills are likely to rely on the ATP–CP system? Why?
- 2 What are some of the limitations of the ATP–CP system in providing energy to all the movements listed in the previous question?
- 3 **Describe** when the anaerobic glycolysis system might increase its contribution.
- 4 As a player, what were your physical observations when performing? Did you notice a drop in power or playing intensity at any time? Did you feel the acute responses your body was making to try to increase oxygen uptake?
- 5 What role did the aerobic system have in providing energy during the practical session?
- 6 How does the aerobic system complement the anaerobic systems when considering interplay?



**Template**  
Data collection

#### Command term

##### describe

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way



## COLLABORATIVE TASK

### Prac activity

#### Finite capacity of the anaerobic energy systems

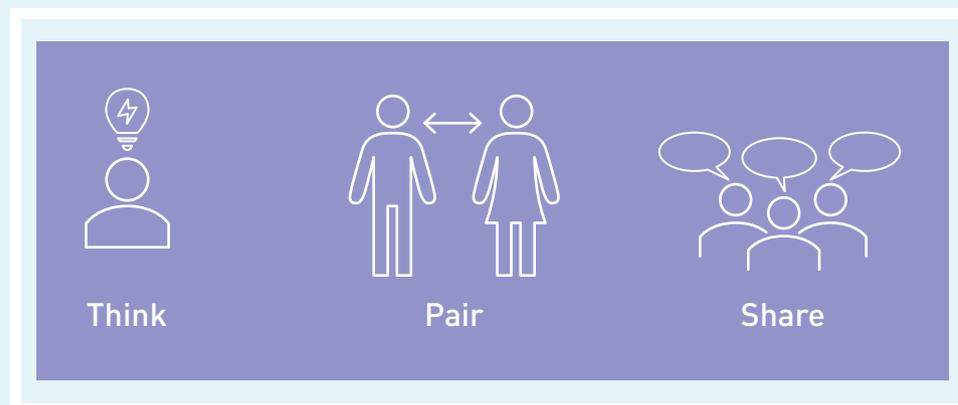
##### AIM

To consider how to use the energy from the anaerobic systems for a variety of activities of different intensities and durations

##### METHOD

Use a Think-Pair-Share routine for the four activity examples:

- Think – consider the question individually.
- Pair – discuss ideas with a classmate.
- Share – in a larger group or whole class, share your responses.



In pairs or small groups, imagine you have \$100, broken into 20 × \$5 notes. You can use small pieces of paper to represent each \$5 note. This money represents total anaerobic energy supply. It is limited (finite). For any event undertaken without a break (when you can recover your anaerobic energy systems and therefore get some cash back), you must spend the money wisely. The more you spend at any given point, the faster you will go – but don't let the cash run out too early!

Use the three sample activities below, or create your own event, to map out how you will spend your energy:

- long jump
- 800 metres race
- 5-kilometre run.

When considering the longer events, draw out stages, either every 100 metres for the 800 metres, or every 500 metres for the 5 kilometres.



##### Resource

How to write an energy system interplay response

### 🚩 SIGNPOST

For information about how to write an energy system interplay, see the resource available on Nelson MindTap.

**WORKED EXAMPLE**

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Water polo is a pool-based sport that involves two teams of seven players attempting to score goals by throwing a ball into the opposing team's net. A water polo match consists of four 7-minute quarters and 2 minutes of rest. Each quarter, players use a combination of swimming, treading water, throwing, catching and shooting to beat the opposing team by scoring more goals. Players are not allowed to touch the bottom of the pool or hold on to the lane ropes.



In each quarter, a water polo player:

- completes a 'swim off', where they maximally swim 10–15 m to gain possession of the ball and pass it back to teammates
- swims and moves to a position where they can score
- holds their position against an opposing player
- catches the ball, then propels themselves out of the water and shoots at the goal net
- will repeat several intervals with little rest in between, resulting in back-to-back intense swims that may total 25–30 seconds.

**a** Using the information above, analyse the relative contribution of the three energy systems with specific reference to fatigue and recovery. 6 marks

**Sample response**

Use a starter sentence to build confidence. You may not need this for the marks, but it's a good way to get started.

Use specific examples from the stimulus in your wording.

*While all systems will contribute throughout the water-polo game, each system will have a major contribution, depending on the energy demands of the movement. Overall, the aerobic system will be the greatest provider of energy due to its large yield, which is required for the duration of the game (4 × 7-minute quarters). For maximal explosive efforts that are short in duration, such as the initial swim-off, the ATP-CP system will increase its contribution due to its rapid rate of energy supply. While the player holds their position against an opposing player, the energy demands are lower and the aerobic system is likely to be the major provider of energy. During this time, the aerobic system also works to restore CP so that the ATP-CP system can again provide energy for the explosive effort required when propelling out of the water. As there are several repeated intervals with little rest, it is likely CP will deplete, so there will be an increased reliance on the anaerobic glycolysis system, which provides energy at a fast rate to meet the high energy demands.*

Show the interplay of the systems and how they impact each other. You could use CP depletion to explain why the anaerobic glycolysis system increases contribution or discuss how the aerobic system restores CP.

'Increased reliance' sounds sophisticated and clearly demonstrates your understanding of the rise in energy demands and the impact it has on energy system contribution.

Acknowledge why each system has the greatest contribution using key terms/'fun facts' - 'rate' and 'yield'.



## Assessment

## 6.3 Check-in questions

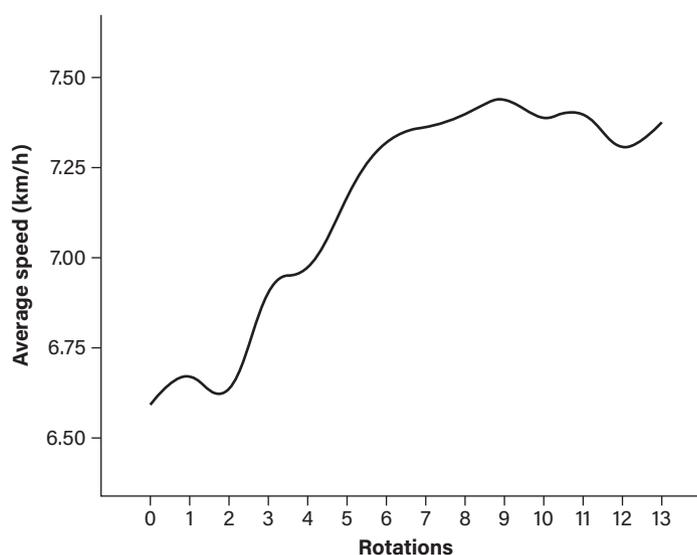
## Command term

## explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

## 6.3 CHECK-IN QUESTIONS

- 1 **Identify** three factors that determine which system is the major contributor to ATP resynthesis during physical activity, sport and exercise.
- 2 **Explain** why the anaerobic systems increase in contribution at the start of an aerobic event such as a 10-kilometre run.
- 3 **Explain** why having a strong aerobic system is important for a team sport such as hockey.
- 4 The graph below shows sample data collected from AFLW practice matches. It compares the number of rotations during a practice match with the average speed of players during the game. The more often they are rotated, the more players are able to rest on the sideline. It can be observed that in general, as rotations increase, the average speed increases. Using your understanding of energy systems and passive recovery, **explain** why this might be the case.



Source: AFL Player Fitness Ratings/Facebook



## ABOVE AND BEYOND THE STUDY DESIGN

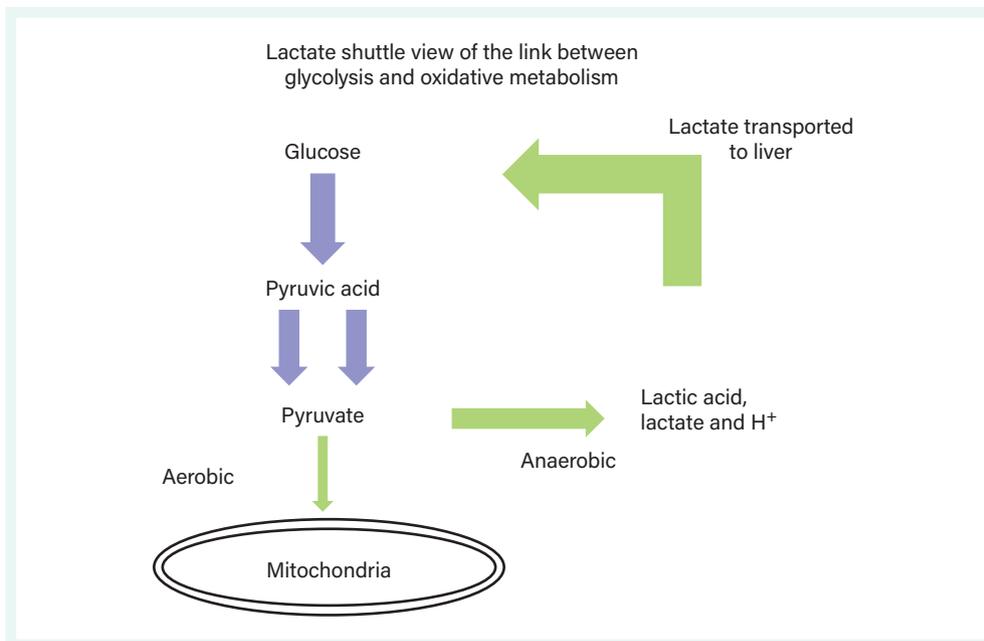
MODULE 6.2, PAGE 255

## Delayed onset muscle soreness (DOMS)

After explosive or unaccustomed physical activity, we often feel muscle soreness that peaks about 48 hours after exposure to the exercise and can last up to 5 days. It occurs more often after eccentric exercise (in which the muscle lengthens while contracting). A variety of ideas have been proposed as to what causes DOMS, and it is likely that multiple factors are involved. Most of these ideas centre on damage to the microscopic muscle cells, which causes inflammation and a feeling of pain. Such is the interest in DOMS that several commercial providers of clothing have created bespoke collections that claim to reduce the likelihood and severity of DOMS. Training recommendations to decrease the impact of DOMS include starting an exercise program slowly to allow the body to adapt over time, rather than commence with an explosive, high-intensity program.

## The lactate shuttle

We have established that during exercise the anaerobic glycolysis system produces lactic acid, and therefore lactate and  $H^+$  ions, as a by-product. It was long considered that it was lactic acid that was responsible for the punishing 'burn' athletes felt in their body during very high-intensity exercise. This may occur during an all-out effort or during a surge in a race, when an athlete surpasses lactate inflection point (LIP). While it certainly is the case that lactate levels rise as lactate production exceeds removal, and that the associated decrease in pH in working muscle impacts metabolic processes, which slows down muscle contraction, more recent research refutes these claims. Some research indicates that lactate can actually have a beneficial role and can be used as a fuel source. This concept is demonstrated in Figure 6.34. Here you can see that lactate can enter the mitochondria in muscle cells and be broken down completely via oxidation. Indeed, lactate can travel in the blood and be taken up by the surrounding muscle tissue, in a process known as the lactate shuttle. Importantly, most (75–80 per cent) of lactate is disposed of immediately, within the tissue, or after release and re-uptake by working muscle. Some other lactate is transported to the liver via the blood and is converted to glucose in a process known as gluconeogenesis, or taken up by the heart. It is then transported back to working muscle to be used as a fuel. Undertaking an active recovery can be beneficial in supporting this transfer of lactate to surrounding muscles and the liver as circulation remains higher than resting levels.



**FIGURE 6.34** The lactate shuttle

Source: George A. Brooks (2018), 'The science and translation of lactate shuttle theory', in *Cell Metabolism*

# CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 6

## 6.1 Food fuel for energy production

- ATP is a molecule, found in muscle cells, that consists of adenosine and three phosphate molecules attached with high-energy bonds.
- ATP is broken into ADP and  $P_i$  and the energy released is the energy for movement during physical activity, sport and exercise.
- The ATP–ADP cycle is constant; how fast it is undertaken depends on the energy demands of the task.

## 6.2 The three energy systems

- The three energy systems work together to resynthesise ATP from ADP.
- The primary factor that determines which energy system is contributing the most is intensity.
- Other factors that impact energy system contribution include duration, availability of oxygen and status of the athlete.
- The ATP–CP system provides energy at the fastest rate due to simple reactions.
- One limitation of the ATP–CP system is fuel supply (lowest yield).
- Events that are short in duration and maximal in intensity will likely have a great contribution from the ATP–CP system.
- The aerobic system will work to restore CP fastest during passive rest.
- The anaerobic glycolysis system breaks down glycogen without oxygen and produces energy at a fast rate due to relatively simple reactions.
- One limitation of the anaerobic glycolysis system is the accumulation of metabolic by-products (low yield).
- Events that require sustained maximal intensity will likely have a large contribution from the anaerobic glycolysis system.
- The metabolic by-products associated with the anaerobic glycolysis system are removed fastest with an active recovery.
- The aerobic system completely breaks down fuel with oxygen and provides energy at a slow rate due to the complex reaction involved.
- The aerobic system has the largest yield.

## 6.3 Interplay of energy systems

- Events that are long in duration will have a large contribution from the aerobic system.
- An active recovery is recommended for events that have the greatest contribution from the aerobic system.
- Energy system interplay refers to the way in which the energy systems work together to provide energy, each taking an important role throughout an event.

# CHAPTER REVIEW

- 1 Use the table below to answer the following question:

	Limitation	Advantage
Energy system A	Rate	Yield
Energy system B	By-product accumulation	Rate
Energy system C	Fuel	Rate



**Assessment**  
Chapter 6 Review

**Identify** which of the following correctly identifies each of the three energy systems:

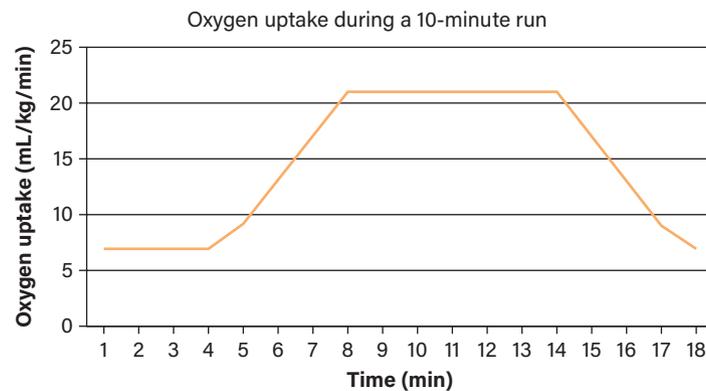
- A** A = ATP-CP                      B = anaerobic glycolysis              C = aerobic  
**B** A = anaerobic glycolysis      B = ATP-CP                              C = aerobic  
**C** A = aerobic                        B = ATP-CP                              C = anaerobic glycolysis  
**D** A = aerobic                        B = anaerobic glycolysis              C = ATP-CP

- 2 **Identify** the fuel source that has the capacity to produce the greatest amount of ATP.
- A** triglyceride  
**B** glycogen  
**C** ATP  
**D** CP
- 3 Complete the following sentence. When lactic acid is produced, it is immediately broken down into:
- A** glycogen and ATP.  
**B** glycogen and H<sup>+</sup> ions.  
**C** glycogen and lactate.  
**D** lactate and H<sup>+</sup> ions.
- 4 In elite swimming competitions, in which freestyle swimming event are athletes likely to use a relatively even contribution from anaerobic and aerobic energy sources?
- A** 50 metres  
**B** 100 metres  
**C** 400 metres  
**D** 1,500 metres
- 5 **Identify** the energy system that is making the greatest contribution in the sprint finish to the line in a 1,500-metre track race.
- A** aerobic  
**B** anaerobic glycolysis  
**C** ATP-CP  
**D** anaerobic lipolysis

- 6 **Identify** the major energy system being used for the work periods of the training session below:

Reps	Work time	Rest time	Intensity
12	60 seconds	60 seconds	80% max HR

- A ATP-CP  
 B aerobic  
 C anaerobic  
 D anaerobic glycolysis
- 7 Taekwondo matches are contested over 3 × 2-minute rounds with a rest of 1 minute between rounds. Each fighter attempts to score points by landing explosive blows on their opponent's torso or head. Kicks are allowed to the torso and head, while punches are only allowed to the body.  
**Discuss** how energy system interplay would occur during the taekwondo match, using the data above to support your response.
- 8 The graph below demonstrates oxygen consumption for a student, Sammi, before (minutes 1–4), during (minutes 4–14) and after (minutes 14–18) a 10-minute run. The run commences at the 4-minute mark.

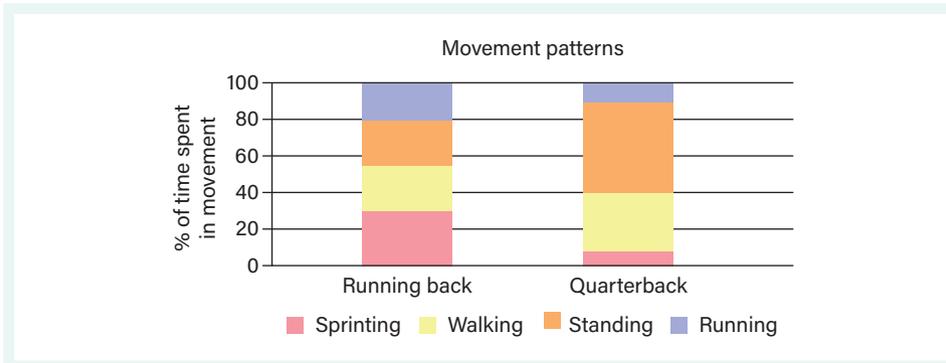


Two students undertook this run. Both students ran together for the first 9 minutes. Sammi jogged at a steady pace for the whole run, while Ashley jogged with Sammi for the first 9 minutes, then 'surged' and pushed hard for the last minute. Below are the distances they covered in 10 minutes:

- Sammi: 2.2 km
- Ashley: 2.8 km.

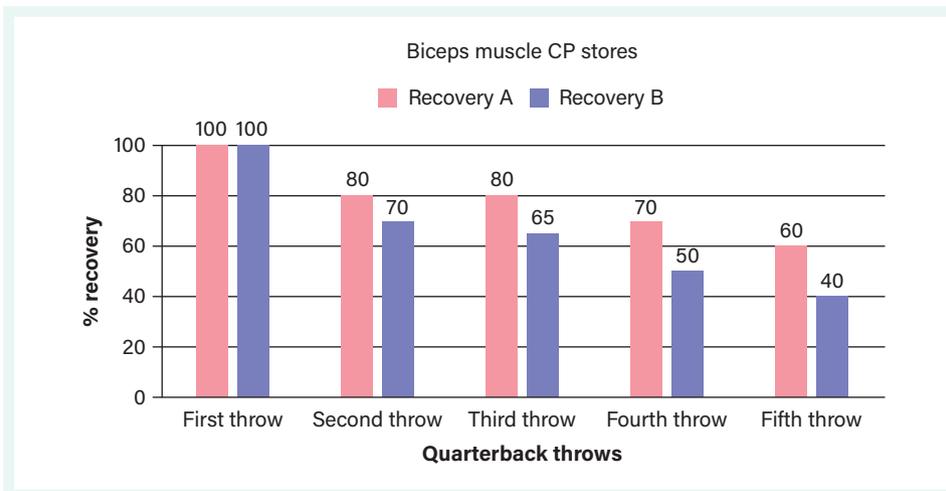
Using the information provided, **discuss** the similarities and differences in energy system contribution for Sammi and Ashley during the 10-minute run.

9 In 2023, the Super Bowl was played between the Philadelphia Eagles and the Kansas City Chiefs. The graph below displays percentage time at various intensities for two different players. Both players spent approximately 60 minutes on the field.



**Discuss** the similarities and differences in the energy system requirements for both players, referring to data.

10 When preparing for the match, the teams undertake a series of throwing drills. The following graph demonstrates CP recovery levels in the biceps muscle after an explosive throwing training drill with two different types of recovery. There were 30 seconds of recovery between throws.

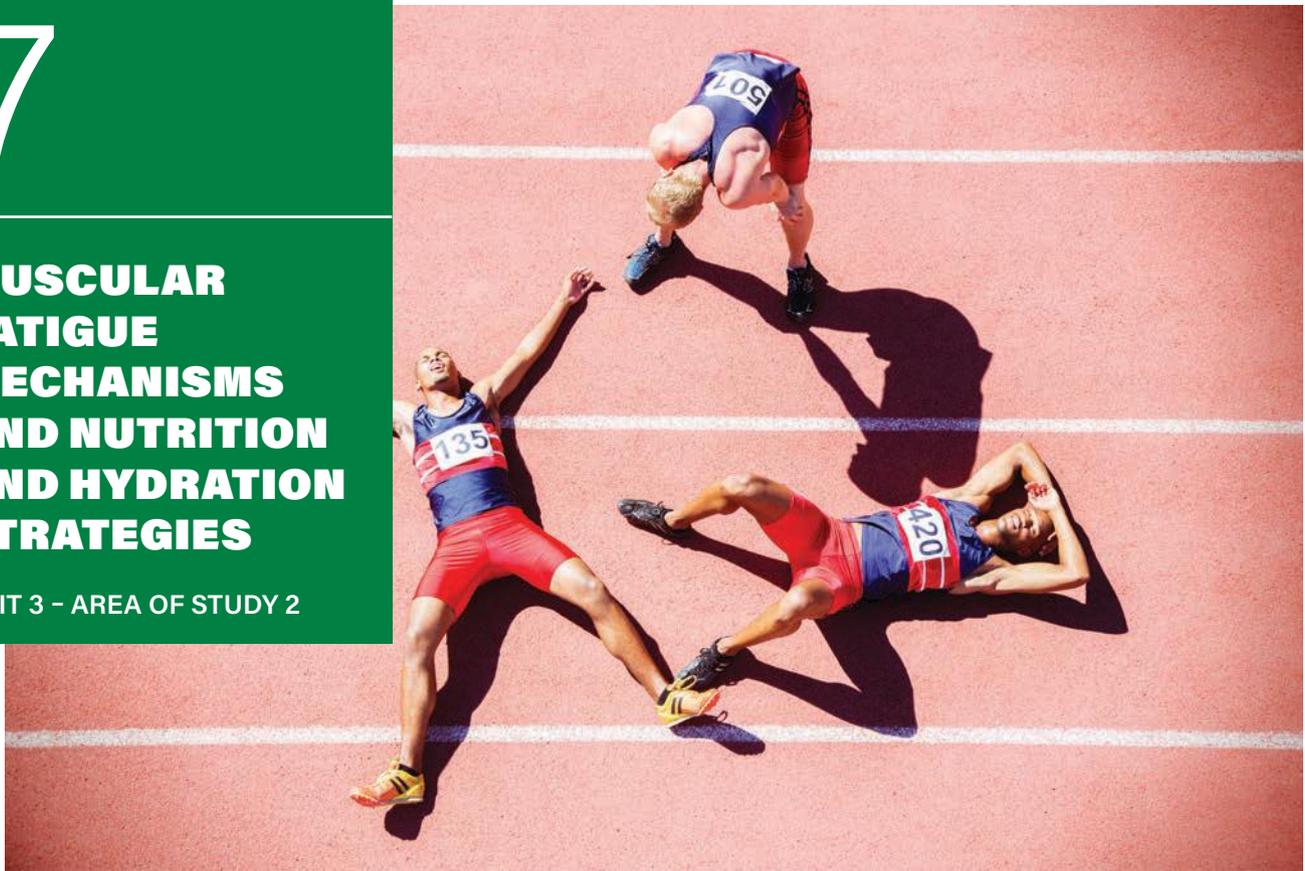


- a Which letter (A or B) represents an active recovery?
- b **Explain** the benefit to performance in the explosive training drill of the recovery shown as recovery A.

# CHAPTER 7

## MUSCULAR FATIGUE MECHANISMS AND NUTRITION AND HYDRATION STRATEGIES

UNIT 3 - AREA OF STUDY 2



KOTOIWA GES/Shutterstock.com

**FIGURE 7.01** Fatigue is multifactorial and results in the loss of power output.

### Quizzes

Chapter 7 Pulse check

- 7.1** Check-in questions
- 7.2** Check-in questions
- 7.3** Check-in questions
- 7.4** Check-in questions
- 7.5** Check-in questions

Chapter 7 Review

### Videos

Masterclass: Chapter 7

- 7.3** In focus: Accumulation of metabolic by-products

### Resources

Chapter 7 Self-Assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



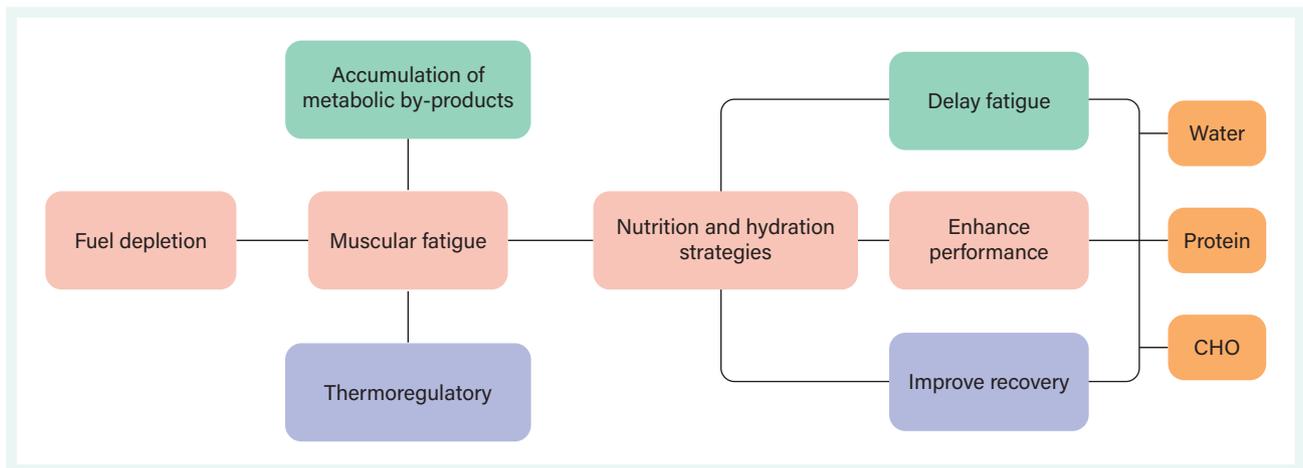
- » muscular fatigue mechanisms including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations
- » nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery including carbohydrate ingestion, protein and water

## KEY KNOWLEDGE

- » explain the muscular fatigue mechanisms associated with the use of the three energy systems under varying exercise conditions
- » develop nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)





Video

Masterclass: Chapter 7

Assessment

Pulse check

In this chapter you need to be able to identify the major cause of fatigue in a variety of sporting and exercise scenarios, justifying why this is the fatigue mechanism and explaining how it physiologically impacts the athlete. Often data will be presented to interpret and you will need to apply your knowledge to demonstrate your understanding. You will also need to explain nutritional and hydration strategies to enhance performance, delay fatigue and optimise recovery.

## PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- 1 **Identify** three key fatigue mechanisms studied in senior Physical Education.
- 2 **Name** three factors that influence the rate of fatigue.
- 3 **Identify** a nutritional strategy that could be undertaken after resistance training to support repair of muscle.
- 4 **Explain** how consuming extra carbohydrate a few days before a marathon (carbohydrate loading) could delay fatigue.
- 5 **Explain** why an athlete should consume carbohydrate immediately after an endurance event lasting over 90 minutes.

## 7.1 INTRODUCTION TO FATIGUE

In this module you will learn about:

- muscular fatigue mechanisms and learn to:
- explain the muscular fatigue mechanisms associated with the use of the three energy systems under varying exercise conditions.

### isometric

The muscle length remains constant while force is developed



INDRANIL MUKHERJEE/AFP/Getty Images

**FIGURE 7.02** Australian cricket player Glenn Maxwell scored 201 runs in one innings during the 2023 One Day International World Cup, struggling through cramp and fatigue over his 187-minute innings in humid temperatures.

Exercise-induced fatigue can be observed when there is an inability to maintain a given force production or power output. It might be observed when an athlete slows down when running or swimming, when they are unable to kick the ball as far later in the game during an AFL or AFLW match, or when they are unable to complete a set during resistance training.

There are a variety of factors that influence the time and rate of muscle fatigue, including:

- intensity and duration
- type of muscle contraction (due to occlusion of blood flow, **isometric** contractions induce fatigue the fastest)
- training status
- nutritional status
- environmental conditions, including temperature and humidity.

## SPOTLIGHT

**Enhancing recovery through nutritional and hydration methods**

In Units 3 and 4 we study nutritional and hydration methods to enhance recovery. In the sports world this recovery process is far more complex, and many physiological strategies are used, including ice baths, sleep and lightened training load. To see this holistic approach in action, go behind the scenes of AFL recovery with the Crows' Tom Doedee and veteran high-performance manager Darren Burgess.

**Weblink**

How AFL players repair and prepare between games

## Fatigue is multifactorial

Many factors contribute to **fatigue**, often at the same time. However, there will always be one major factor that impacts performance. The three major fatigue mechanisms we will cover are:

- fuel depletion
- accumulation of metabolic by-products
- thermoregulatory fatigue.

**fatigue**

A decreased capacity, or an inability, to maintain a given force production or power output

## REAL WORLD APPLICATIONS

### Pole vaulters share gold

Fatigue was cited as the major factor influencing the unusual decision to share gold in the 2023 World Athletic Championships. Australian Nina Kennedy and American Katie Moon both cleared 4.90 metres on their third attempt in the pole vault, but missed on their three attempts at 4.95 metres and tied for first place. They were offered the opportunity to jump again to determine a winner, but opted to share the gold medal. The two defended their decision against critics, citing fatigue and a high risk of injury as major factors informing their choice. Towards the end of the event, the two athletes observed a change in their run-up pattern, and their take-off steps moved further away from the pit – two clear signs of fatigue. Pole vault is a high-risk sport, as athletes propel themselves almost 5 metres in the air and must manipulate their bodies carefully to land safely. The loss of force production and power output as a result of fatigue might cause a change in technique or a mistimed movement that could have catastrophic consequences.



**FIGURE 7.03** Nina Kennedy and Katie Moon share gold in the 2023 World Athletic Championships.

Tim Clayton – Corbis/Corbis Sport/Getty Images

## Observing fatigue

While fatigue can be described as a reduction in force production and power output it can be observed during performance in a variety of ways. Some ways fatigue can be observed include:

- an increase in time taken to complete a distance
- a decrease in the distance covered in a particular time.

### An increase in time taken to complete a distance

Some events are measured in splits, which is a set distance that is covered many times during the performance. For example, a 400-metre swim can be measured in 50-metre splits. A marathon is often measured in 5-kilometre splits. While athletes train specifically to try to avoid fatiguing too early in an event, an increase in the time taken to complete a split can indicate fatigue.

To minimise the likelihood of fatigue, athletes will often work with their coach to pace themselves to achieve a predetermined goal. While there will be outside variables that influence the result such as temperature and nutrition, most elite athletes will use a monitoring system such as a smart watch to maintain an optimal pace to achieve their goal.

**TABLE 7.01** The calculated average splits to achieve a set time in a marathon

Marathon pace chart	
Finishing time (h:min)	1 km split times (min:s)
5:00	7:06
4:30	6:23
4:00	5:41
3:30	4:57
3:00	4:15
2:30	3:33
2:00	2:51

Adapted from <https://marathonhandbook.com/marathon-pace-chart-km/>

## REAL WORLD APPLICATIONS

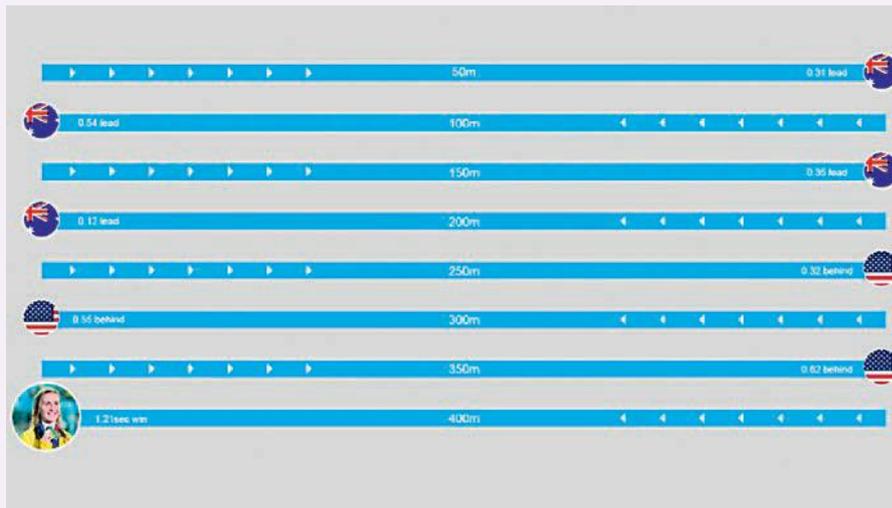
### Pacing a 400-metre swim

Table 7.02 lists the time Ariarne Titmus took for each split in the 400 metres freestyle at the Tokyo Olympics. The split times from the last 100 metres indicate she speeds up. It is through careful management of fatigue and energy system contribution that this performance outcome can be achieved.

**TABLE 7.02** Ariarne Titmus's split times in the 400 metres freestyle at the Tokyo Olympics

Distance (metres)	Time (seconds)
50	27.88
100	29.86
150	30.09
200	30.27
250	30.02
300	30.15
350	30.13
400	28.67

&gt;



Quinn Rooney/Getty Images

**FIGURE 7.04** This graphic displays the leading swimmer at each split and the time they are leading by.

Source: Tom Decent, 'Lap-by-lap: The breakdown of Titmus's brilliant win over US legend Ledecky', in *The Sydney Morning Herald*, 26 July 2021. The use of this work has been licensed by Copyright Agency except as permitted by the Copyright Act, you must not re-use this work without the permission of the copyright owner or Copyright Agency

## LOOKING BACK

### Acceleration and energy system contribution

#### Chapters 3, 6

During the last 50 metres of her 400 metres final, Ariarne Titmus increased her power output and experienced positive acceleration, which means she swam faster. Acceleration is the rate of change of velocity over time. As she began to swim faster, she would have had an increase in contribution from the anaerobic energy systems – more specifically, the anaerobic glycolysis system, which produces energy at a faster rate – so she could increase her pace and sprint to the finish, winning the race and breaking the world record.

## A decrease in the distance covered in a particular time

This is often observable in team sports such as Australian Rules football, where players cover large distances in the first two quarters but the distance they cover drops significantly in the last quarter.

**TABLE 7.03** Time spent at different intensities during the first and fourth quarters in a sample Australian Rules football match, as well as other variables including distance covered and average speed (mean  $\pm$  SD)

Variable	First quarter	Fourth quarter
<b>Game movements (time)</b>		
Stand (s)	179 $\pm$ 116	221 $\pm$ 259
Walk (s)	955 $\pm$ 152	1010 $\pm$ 185
Jog (s)	422 $\pm$ 75	371 $\pm$ 95
Run (s)	156 $\pm$ 41	119 $\pm$ 33
Higher-speed running (s)	44 $\pm$ 17	36 $\pm$ 13
Sprint (s)	25 $\pm$ 10	18 $\pm$ 10
<b>Game movements (distance)</b>		
Walk (m)	1130 $\pm$ 201	1130 $\pm$ 228
Jog (m)	1121 $\pm$ 267	1049 $\pm$ 242
Run (m)	675 $\pm$ 158	525 $\pm$ 145
Higher-speed running (m)	242 $\pm$ 95	198 $\pm$ 74
Sprint (m)	168 $\pm$ 73	121 $\pm$ 66
<b>Match distances</b>		
Total distance (m)	3463 $\pm$ 403	3058 $\pm$ 433
High-intensity running distance (m)	1090 $\pm$ 212	844 $\pm$ 198
Low-intensity activity distance (m)	2380 $\pm$ 324	2210 $\pm$ 352
<b>Other</b>		
Average speed (m/min)	117 $\pm$ 14	103 $\pm$ 14
Sprint number	7.7 $\pm$ 2.6	6.2 $\pm$ 2.8
Peak speed (km/h)	29.1 $\pm$ 1.9	28.4 $\pm$ 2.0

Source: Coutts, A. et al. (2009), 'Match running performance in elite Australian Rules Football', in *Journal of Science and Medicine in Sport*

## LOOKING FORWARD

### Activity analysis

#### Chapter 9

Movement patterns, as well as skill frequency and work-to-rest ratio, will be further explored in Chapter 9. You will analyse data to determine the physiological requirements of the sport including energy systems, fitness components, muscle groups and actions.

## Rating of perceived exertion

A more subjective way to measure fatigue is on a scale known as rating (or rate) of perceived exertion (RPE). There are a few models used in the exercise science world, including a numerical rating of 1–10. A rating of 1 would indicate that the workload is very light, whereas 10 would indicate the athlete is working as hard as they can and fatigue is imminent. RPE is highly subjective (open to personal interpretation), and it can take an athlete some time to get used to associating these feelings with a number. The table in Figure 7.05 uses descriptors to support beginners in matching their physiological and psychological feelings with the scale.

## Borg's 1–10 RPE scale

RPE = rating of perceived exertion

My number	My face	Description	What I may be thinking ...	What my body may be feeling ...
1		Very light/easy	This is super easy and relaxed.	I don't feel any different from rest.
2		Fairly light/easy	This exercise isn't hard.	Comfortable. Can maintain this pace all day. Can talk in complete sentences.
3		Easy/light	I'm just beginning to feel like I'm exercising, but could keep going for hours.	Light rhythmic breathing. My body temperature has increased.
4		Moderate	I'm exercising and I feel good.	Talking is starting to become uncomfortable.
5		Somewhat hard	This is a good workout. I'm working hard.	Breathing more heavily and sweating is starting to increase.
6		Moderately hard	This is getting hard to do.	I can talk, but I don't want to.
7		Hard	This is pretty hard. I'll keep going for a bit longer, but I'm not sure for how much longer.	I am getting really sweaty. Talking becomes a 'grunt'.
8		Very hard	This is really hard.	Cannot talk. Sweating is next level.
9		Extremely hard	I'm close to stopping.	My face is like a beetroot and my heart is pumping hard.
10		Maximal	My body is making me stop now!	I can't do this any more.

**FIGURE 7.05** Borg's rating of perceived exertion is a subjective measure of performance and fatigue. It is often used in resistance training.

**Assessment**

7.1 Check-in questions

**Command term****name**

Provide a word or term (something that is known and distinguished from other people or things) used to identify an object, person, thing, place etc

**LOOKING FORWARD****Monitoring training****Chapter 11**

RPE is a subjective variable that is often tracked in training diaries or apps. Athletes and coaches use the information to determine the effectiveness of training and track progress, and it may help prevent overtraining. If an athlete is recording a higher RPE than the previous identical session, the coach may need to investigate other factors that may be impacting training – for example, sleep, nutrition or stress.

**7.1 CHECK-IN QUESTIONS**

- 1 **Define** 'fatigue'.
- 2 **Name** three ways in which fatigue can be identified during a game of soccer.
- 3 **Explain** why RPE can take some time to understand and use effectively.

**7.2 FUEL DEPLETION**

In this module you will learn about:

- muscular fatigue mechanisms, including fuel depletion linked to varied sport and exercise intensities and durations and learn to:
- explain the muscular fatigue mechanisms associated with the use of the three energy systems under varying exercise conditions.

**DID YOU KNOW?**

While a fuel will never completely deplete, it may reach critically low levels, which will compromise performance. This is known as fuel depletion.

We discovered in Chapter 6 that the body uses the energy systems, and therefore the fuel, that best meets the energy demands of the task. We explored the limitations and advantages of each system and identified performance examples where each energy system provided the most energy. We will now explore some of the limitations in more detail.

**ATP**

When energy demands increase, the rate of ATP breakdown increases. The drop in ATP levels (ATP depletion) causes a small drop in power output while the body works to resynthesise ATP. It is difficult to observe, as an athlete is often building momentum and pace is often increasing at that time, but it is important to identify this as a contributing factor to fatigue.

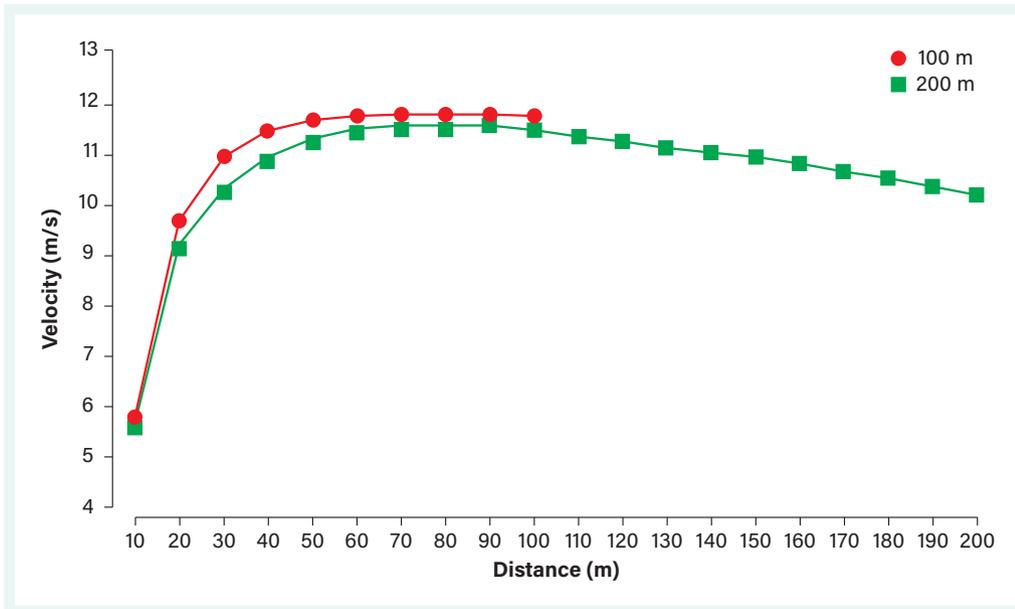
**Creatine phosphate (CP)**

When working maximally, the ATP-CP system can be the major provider of energy for the first 6–10 seconds of exercise. How long this lasts depends on the athlete's muscle fibre type and training status. As creatine phosphate (CP; also known as phosphocreatine) depletes, there is an increase in contribution from the anaerobic glycolysis system. As this system uses more complex reactions to produce energy, it provides energy at a slower rate and the athlete

experiences a decline in power. The graph in Figure 7.06 looks at velocity decline over 100-metre and 200-metre sprint efforts. It clearly demonstrates a loss of power as the athlete sprints towards the 200-metre mark, showing the impact of CP depletion.

## DID YOU KNOW?

The rate of CP depletion will be slower during exercise that is not performed at maximal intensity.



**FIGURE 7.06** The performance impact of CP depletion is evident in a decrease in velocity between 100 and 200 metres.

Source: Girard, O. et al., (2011), 'Repeated-sprint ability – Part I', in *Sports Med* 41, pp. 673–694

## LOOKING BACK

### Muscle fibre type

#### Unit 1

Muscle fibres can be classified either as fast-twitch or slow-twitch fibres. The ratio of fast-twitch and slow-twitch muscle a person possesses depends on their genetics and body composition. Fast-twitch fibres will produce more force and have the capacity to store more CP, but are quick to fatigue. Slow-twitch fibres take longer to fatigue but do not have the capacity to store as much CP.

## LOOKING FORWARD

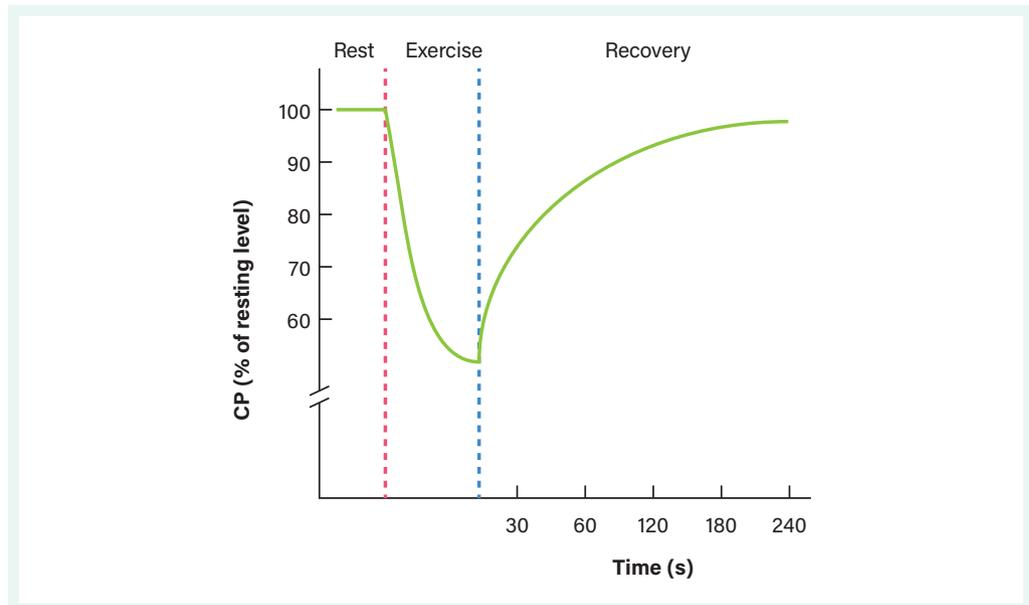
### Training methods

#### Chapter 13

When exploring different training methods, including resistance and plyometrics training, in Chapter 13, you will explore the preferential recruitment of muscle fibres based on the needs of the exercise. You will also explore the adaptations of each of the muscle fibres and how this enhances performance.

## Recovery strategies

Creatine phosphate is restored fastest by a passive or rest recovery via the aerobic system. Each person will differ slightly in their recovery rate, but it takes approximately 3 minutes to restore 98 per cent of CP, while 30 seconds generates 70 per cent restoration (see Figure 7.07).



**FIGURE 7.07** It takes approximately 3 minutes to restore 98 per cent of CP in the muscle.

Source: Szendroedi, J. & Roden, M. (2008), 'Mitochondrial fitness and insulin sensitivity in humans', in *Diabetologia* 51, pp. 2155–67



### COLLABORATIVE TASK

#### Prac activity

##### CP recovery

###### AIM

To investigate the impact of different recovery strategies on repeated sprints

###### EQUIPMENT

- cones
- stopwatch
- pen and paper

###### METHOD

- 1 Use the protocols on page 428 (Chapter 10) to set up the phosphate recovery test.
- 2 Select at least three students to undertake the test with the recommended protocols (passive recovery).
- 3 Select at least three students to undertake the test with an active recovery. Here, students will jog at a moderate pace between efforts with no rest.
- 4 Record the results, using the protocols.
- 5 Calculate the decrement for each student.





## DISCUSSION

Use the results to facilitate a discussion around the differences in decrement between students. Use the data to create an average decrement for each group. In your discussion, explore the differences between the sets of data. Consider the following:

- Were there any trends in the data gathered?
- What were your observations of running velocity for each group as the sprints progressed?
- What did each group experience physiologically?
- Are there any other factors, other than the type of recovery, that might impact results? What are they?

## Glycogen

Glycogen depletion occurs during sustained aerobic work associated with endurance events. When an athlete is well nourished, resting glycogen levels can support continuous exercise for somewhere between 90 minutes and 2 hours. After this time, glycogen starts to deplete, and the body turns to fat (stored as triglyceride) as the major provider of energy. As triglyceride provides energy at a significantly slower rate than glycogen, the athlete will experience fatigue and will be forced to slow down. This phenomenon is casually known as 'hitting the wall' and typically occurs around the 35-kilometre mark of a marathon.

**TABLE 7.04** Fuel depletion

Major fuel	Next available fuel	Outcome
ATP	CP	Slower rate of energy production Reduced force production and power output
CP	Glucose/glycogen	Slower rate of energy production Reduced force production and power output
Glucose/glycogen	Triglyceride	Slower rate of energy production Reduced force production and power output



Boston Herald /MediaNews Group/Getty Images

**FIGURE 7.08** A marathon runner is supported to the finish line in the Boston Marathon as they experience the multifactorial impact of fatigue, including glycogen depletion.



## Web link

Marathon Runner Hayley Carruthers Collapses Just Before Finish

## SIGNPOST

Watch the video *Marathon Runner Hayley Carruthers Collapses Just Before Finish* on the Latest News channel on YouTube to see Hayley Carruthers succumb to sudden fatigue just before the finish line.

## WORKED EXAMPLE

## GLYCOGEN DEPLETION

©VCAA Exam 2013, Section B, Q8

Brett, a 37-year-old male, completed a marathon. His split times are shown below.

Distance	Time (hours:minutes:seconds)
10 km	0:48:20
20 km	0:48:21
30 km	0:48:40
40 km	1:00:19
<b>Total</b>	42.195 km

Provide a physiological explanation as to why the final 10 km split was slower than the previous three split times.

## Sample response

Any question that requires an explanation about why an athlete slows down or has a reduction in power output needs a fatigue mechanism identified.

The physiological consequence of glycogen depletion is explained.

Brett experienced glycogen depletion. This means that there is an increase in contribution from fat as a fuel source. Fat provides energy at a slower rate and therefore the final 10 km was run at a slower pace.

The outcome of the fatigue mechanism is explained through the link to the key term 'rate', then clearly linked to the performance outcome – slower pace. Think: 'What does this look like?'



## Assessment

7.2 Check-in questions

## Command term

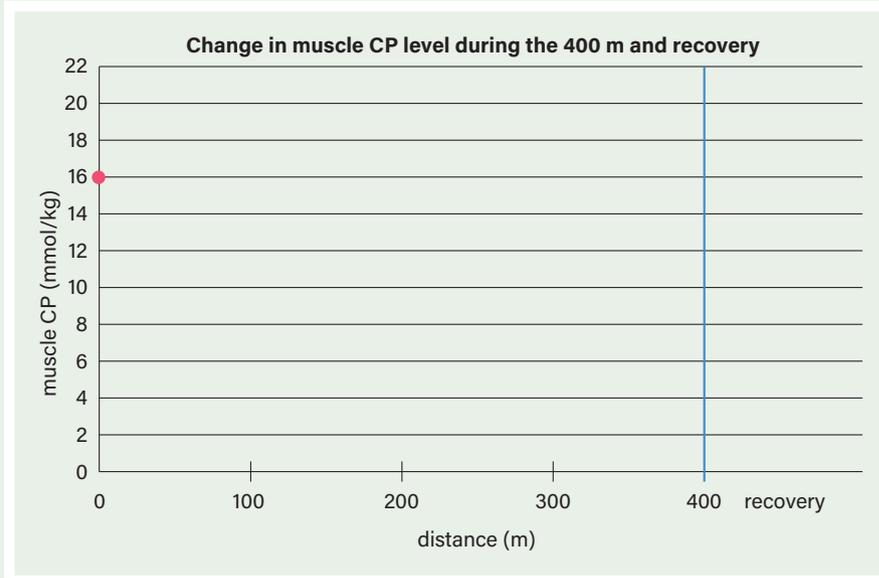
## identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

## 7.2 CHECK-IN QUESTIONS

- 1 **Identify** a fuel that is likely to deplete in:
  - a 50-metre swim
  - an open water 20-kilometre swim.
- 2 **Explain** why there is a decline in power as CP depletes.
- 3 **Identify** the duration of an event that might be impacted by glycogen depletion and explain your selection.
- 4 ©VCAA Exam 2019, Section B, Q3 d  
Complete the following graph to show the change in muscle creatine phosphate (CP) level during a 400 m sprint and passive recovery. The initial muscle CP level was 16 mmol/kg.





## 7.3 ACCUMULATION OF METABOLIC BY-PRODUCTS



### Video

In focus: Accumulation of metabolic by-products

In this module you will learn about:

- muscular fatigue mechanisms, including accumulation of metabolic by-products linked to varied sport and exercise intensities and durations and learn to:
- explain the muscular fatigue mechanisms associated with the use of the three energy systems under varying exercise conditions.

A metabolic by-product is something that is produced when fuel in the body breaks down. The body deals effectively with most metabolic by-products – for example, carbon dioxide (CO<sub>2</sub>), which is a by-product of aerobic energy production, is expelled in air as we exhale. However, when some metabolic by-products are produced faster than they can be removed, and therefore **accumulate**, they can impair muscle contraction and result in fatigue.

### accumulate

To build up in the body

## ADP and P<sub>i</sub>

Inorganic phosphate (P<sub>i</sub>) is a performance-limiting by-product that often accumulates during maximal-intensity work, when the ATP–CP system is the major contributor. P<sub>i</sub> is produced when CP splits and, when it accumulates, it slows down the release and uptake of calcium ions (Ca<sup>+</sup>), which enable muscle contraction. Hence the build-up of P<sub>i</sub> slows down muscle contraction and causes a reduction in force production and power output.

Some research has also supported a similar limiting factor when ADP accumulates.

## Lactate and H<sup>+</sup> ions

In Chapter 6 we explored the by-products of the anaerobic glycolysis system and identified these as a limiting factor for the use of this system.

When glycogen is incompletely broken down without oxygen via the anaerobic glycolysis system, lactic acid is produced in the muscle. Lactic acid immediately dissociates (splits) into lactate and  $H^+$  ions. Lactate is effectively moved into the blood and taken up by the surrounding muscles, where it can be processed back into a usable fuel by the aerobic system. It is also taken up by the liver and heart and turned into glycogen in a process known as gluconeogenesis. In low levels,  $H^+$  can also be effectively removed via the aerobic system. However, when lactate and  $H^+$  ions are produced at a rate faster than they can be removed during high-intensity exercise, a build-up of  $H^+$  ions lowers the pH of the muscle and causes the muscles to become acidic (muscle acidosis). This acidic environment impairs the capacity of the body to break down glycogen by inhibiting the enzymes responsible for glycogen breakdown, a natural protective mechanism.

### DID YOU KNOW?

The process of  $H^+$  production and removal is constantly occurring and we always have lactate in our blood – even when we sleep!

## Measuring lactate

While it is widely recognized that it is  $H^+$  ions that cause fatigue, they are difficult to measure in the body. Instead, blood lactate is measured, which is an indirect measure of  $H^+$  ions. An exercise physiologist can use a device such as a Lactate Pro. This device quickly pricks the skin, often in the fingertip or the ear, and the blood taken is used to

measure lactate levels. Coaches will use this data to devise training strategies or review adaptations such as lactate tolerance. Training adaptations will be explored in Unit 4.

## LOOKING FORWARD

### Lactate tolerance

#### Chapter 15

The ability to continue to work with high levels of lactate is known as lactate tolerance and is a long-term change (chronic adaptation) as a result of effective training. Having a high lactate tolerance allows the performer to continue to use the anaerobic glycolysis system, which provides energy at a fast rate, and therefore there is less of a decline in power output and force production.

## Links to performance

The build-up of lactate and  $H^+$  can be observed in many different performance contexts. The common observation of each is that intensity is very high, there is an increased reliance on the anaerobic glycolysis system and the aerobic system is unable to remove the associated metabolic by-products as fast as they are being produced.

## Maximal or very high intensity exercise

During very high intensity exercise such as the 100 metres freestyle, which takes elite athletes under a minute to complete, the ATP-CP system will provide the most energy initially, when energy demands rapidly increase during the explosive dive and the first few strokes. CP will deplete and the anaerobic glycolysis system will take over as the major contributor. As the event is short in duration, the anaerobic glycolysis system is likely the major provider for the remainder of the race. Energy demands are very high and, due to the large amount of energy that is being supplied via the anaerobic glycolysis system, a large amount of lactic acid (and therefore lactate and  $H^+$  ions) is produced. These by-products cannot be removed as fast as they are produced. For any person – an elite athlete or someone in the general population – when there is an accumulation of these metabolic by-products, they must slow down. They simply can't continue at that intensity.

## CASE STUDY

## BLOOD LACTATE RESPONSES TO 25-METRE, 35-METRE AND 50-METRE SWIM SPRINTS

Data on maximal lactate levels collected at the conclusion of three swim sprints demonstrated a significant difference depending on the duration of the effort. Table 7.05 shows the maximal blood lactate levels reached following 25-metre, 35-metre and 50-metre swims. This data demonstrates the accumulation of metabolic by-products (lactate and  $H^+$  ions) when the anaerobic glycolysis system has a large role in energy supply (Mavroudi et al., 2023).

**TABLE 7.05** Blood lactate response to sprints

Distance (m)	$La_{max}$ (mmol/L)
25	7.0 (1.5)
35	9.3 (2.2)
50	13.8 (2.6)

Source: Mavroudi, M. et al. (2023), 'Blood lactate and maximal lactate accumulation rate at three sprint swimming distances in highly trained and elite swimmers', in *Sports* (Basel)11(4): 87. CC BY 4.0

## QUESTIONS

- Identify** if the maximal sprints have a greater contribution from the aerobic or the anaerobic energy systems.
- State** the relationship between the duration of swim sprints and maximal blood lactate levels.
- Discuss** why there is an accumulation of metabolic by-products during these maximal efforts.
- Explain** the physiological impact of the accumulation of metabolic by-products ( $H^+$ ) during the swim sprints.
- Analyse** why there is an increase in blood lactate levels as the duration of the swim sprints increases. **Predict** what would happen to blood lactate levels for a 100-metre swim sprint and **explain** your prediction.

## Command terms

**state**

Give a specific name or value or other brief answer without explanation or calculation

**discuss**

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

**analyse**

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

**predict**

Give an expected result of an upcoming action or event; suggest what may happen based on available information



Abdul Razak Latif/Shutterstock.com

**FIGURE 7.09** All three energy systems are working together, but one is producing most of the ATP.

## A surge within longer-duration events

Events such as the 5,000 metres or 10,000 metres track race require a large yield of energy due to their duration. This means that the aerobic system will provide most of the energy and the athlete will be in steady state for much of the event. Towards the end of the race, it is common to observe an increase in running pace as the runners accelerate towards the finish line. This is commonly known as 'kicking', and it brings with it a rapid increase in energy demands. The aerobic system is too slow to provide all the energy to meet this intensity increase, so the anaerobic glycolysis system increases its contribution, and the athlete will enter oxygen deficit. During this time, although there is an increase in anaerobic energy supply, the aerobic system will remain the major contributor. There will be an accumulation of metabolic by-products as they are produced at a faster rate than they can be removed, which will result in fatigue. The challenge for athletes is to correctly judge the point where they need to accelerate: too soon, and they will fatigue before the finish; too late, and they may not catch the other athletes. The link (see Signpost box below) provides an opportunity to observe different athletes accelerating (and fatiguing) at different times during the 2020 Olympic Games men's 10,000 metres event. The accumulation of metabolic by-products will occur in this manner in other aerobic events, too – for example, during repeated lifts in intensity while running in a soccer or hockey match (see Figure 7.10).



Bryn Lennon/Getty Images Sport/Getty Images

**FIGURE 7.10** During lifts in intensity, such as those from hockey player Joel Carroll, there may be an accumulation of metabolic by-products.



### Weblink

Medal Moment | Tokyo 2020:  
Men's 10,000m

### 🚩 SIGNPOST

Watch the video *Medal Moment | Tokyo 2020: Men's 10,000m* on the Tokyo Olympics YouTube channel to see an Olympic track event that demonstrates the variety of strategies athletes use to manipulate intensity. Some athletes timed the point of acceleration successfully and were able to sprint towards the finish line, while others suffered visible fatigue and one athlete fell over. While fatigue is multifactorial, one of the main causes of fatigue in this event is the accumulation of  $H^+$  ions as intensity lifts towards the end of the race.

## Incremental tests

Maximal field tests for aerobic power will result in an accumulation of by-products. These tests include the multistage fitness test and the 'Yo-Yo' intermittent shuttle run. As we explored in Chapter 6, in these tests the intensity starts low and gradually increases. Using the multistage fitness test as a specific example, as the levels and therefore the intensity increases, oxygen uptake increases to enable aerobic energy production. As the participant heads towards, and exceeds, the maximal rate of energy production via the aerobic system, the anaerobic glycolysis system increases contribution. This results in lactate production exceeding removal, and the accumulation of metabolic by-products. The primary fatigue mechanism that causes fatigue in these aerobic-based maximal fitness tests is the accumulation of metabolic by-products.

## Recovery strategies

In Chapter 6 we determined that an active recovery was recommended to return the body to pre-exercise conditions fastest when the anaerobic glycolysis system has made a large contribution to energy supply. This is also true when the major fatigue factor is accumulation of metabolic by-products ( $H^+$ ). We discovered that an active recovery maintains circulation, and therefore blood flow to the muscles, which removes the metabolic by-products at a faster rate. In some sports, coaches use an active recovery, when players are substituted, to maintain oxygen uptake and promote a faster removal of metabolic by-products, as in Figure 7.11.



Simon Bruty/Sports Illustrated/Getty Images

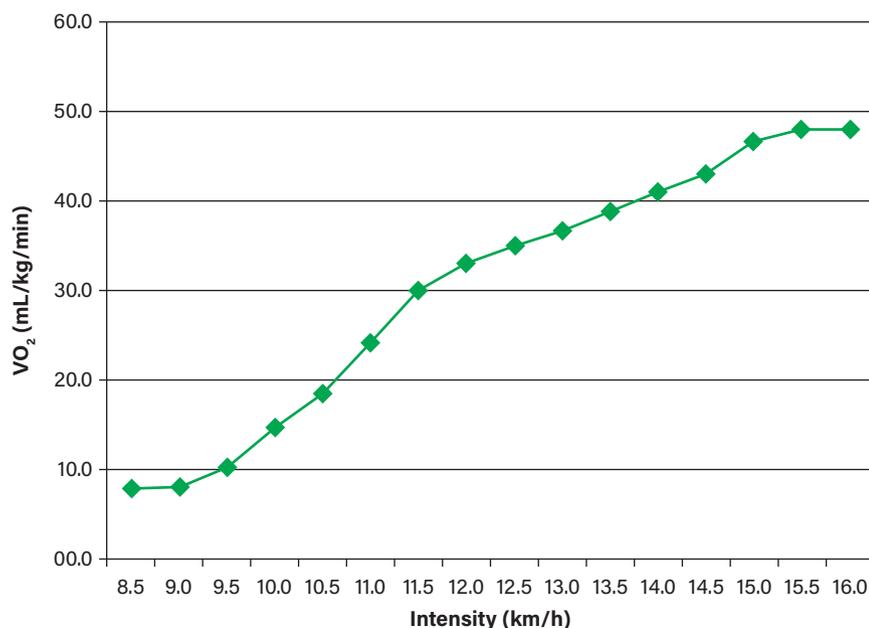
**FIGURE 7.11** An active recovery promotes faster removal of metabolic by-products.

## CASE STUDY

VO<sub>2</sub> MAX TEST

The VO<sub>2</sub> max test is a maximal, incremental laboratory test to directly measure the maximal amount of oxygen that can be taken in, transferred and utilised. It measures the rate of energy that can be produced aerobically. In a similar manner to the field tests, it starts off at a low intensity, then gradually increases in intensity. In this sample test, each intensity is held for 3 minutes.

Once intensity is high and the maximal rate of aerobic energy production is reached, any lift in intensity must be supplied by the anaerobic glycolysis system. Therefore, lactate production will exceed removal and the athlete will fatigue due to accumulation of metabolic by-products. A plateau in oxygen consumption in a maximal test indicates maximal aerobic energy production has been reached. This occurs after 15 kilometres/hour in Figure 7.12. It is important not to confuse the plateau in this test with steady state, which is also represented by a plateau in oxygen consumption. In this test, peak oxygen consumption is reached just after 15 kilometres/hour but intensity continues to increase to 16 kilometres/hour, which would not allow a steady state to be reached.



**FIGURE 7.12** Relative oxygen uptake during a VO<sub>2</sub> max test

## QUESTIONS

- 1 **Identify** the energy system that contributes the most during the VO<sub>2</sub> max test.
- 2 **Identify** a common field test that indirectly measures VO<sub>2</sub> max and might have a similar energy system contribution.



&gt;

- 3 **Explain** why oxygen consumption increases as the test progresses. **Identify** three acute responses that occur to increase oxygen consumption.
- 4 **Discuss** why the test requires each level to be held for 3 minutes before intensity increases and what might happen if each level was only held for 1 minute.
- 5 Using your understanding of energy systems and fatigue, **explain** why the athlete was unable to reach 17 kilometres/hour.
- 6 Use data to **justify** the observation that  $\text{VO}_2$  max has been reached in this test.

**Command term****justify**

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

**LOOKING BACK****Acute responses during a  $\text{VO}_2$  max test****Chapter 5**

As the test continues, the responses from the respiratory, cardiovascular and muscular systems increase to increase oxygen uptake. These responses include an increase in pulmonary diffusion from the respiratory system, an increase in cardiac output from the cardiovascular system and an increase in oxygen extraction from the muscular system. These responses occur to meet the increased demand for oxygen during the test.

**LOOKING FORWARD****Maximal fitness tests****Chapter 10**

A laboratory test such as the  $\text{VO}_2$  max test will be explored in more detail in Chapter 10. There you will learn about maximal and submaximal tests, the protocols to ensure the test is conducted successfully and how to increase accuracy and reliability of the testing process.

## Lactate inflection point

**Lactate inflection point (LIP)** is the name given to the final steady state someone can hold – when lactate production is matched by lactate removal. Once LIP is surpassed, the aerobic system can no longer remove lactate as fast as it is produced, there is an increase in contribution from the anaerobic glycolysis system and there is a rapid rise in blood lactate – and therefore an accumulation of metabolic by-products and fatigue. The point where blood lactate begins to accumulate is also known as the ‘onset of blood lactate’ (OBLA). LIP is often observed at around 4 mmol/L of lactate in the blood (see Figure 7.14). To specifically identify LIP, blood lactate must be taken at various stages in a test such as the  $\text{VO}_2$  max test. Some coaches find this beneficial for endurance athletes as LIP can be aligned to a percentage of maximal heart rate. This supports prescription of training to enhance LIP as the higher the LIP, the higher the intensity the athlete can work at (and hold) aerobically, such as the Para cross-country skiers in Figure 7.13.

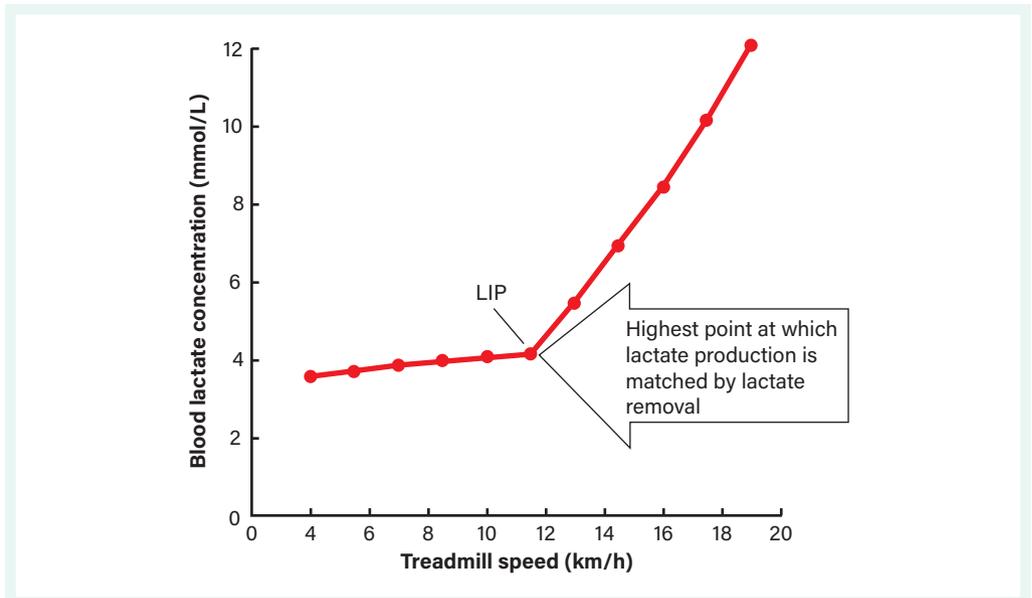
**lactate inflection point (LIP)**

The final point that can be held where lactate production equals lactate removal

Moto Yoshimura/Getty Images Sport/Getty Images



**FIGURE 7.13** An endurance event such as Para cross-country skiing requires a high LIP to work at a higher aerobic intensity for longer.



**FIGURE 7.14** The lactate inflection point (LIP) is the final point at which lactate production matches removal. Beyond LIP, lactate production exceeds removal and there is a sharp rise in blood lactate.

## COLLABORATIVE TASK

### Prac activity

#### Burpees active/passive recovery

##### AIM

To observe performance outcomes of different recovery strategies while completing burpees

##### METHOD

- 1 In pairs, allocate one person to undertake an active recovery and one to undertake a passive recovery.
- 2 Each personal completes 45 seconds of burpees – no push-up but with an explosive jump.
- 3 After the 45 seconds, one student jogs and completes arm circles for 1 minute while the other students crouches in a low squat position for 1 minute.
- 4 At the conclusion of 1 minute recovery time, repeat the 45 seconds of burpees.

##### OBSERVATIONS

As a class, list and record the physiological feelings of each student. This may include RPE, muscle tightness or coordination. Ensure this is completed in your reflective folio.

##### DISCUSSION

Use the results to facilitate a discussion around the difference in fatigue experienced during the second round of burpees. Using your understanding of recovery and considering the limited blood supply to the lower legs during the crouch recovery, consider the following:

- Were these results as expected?
- What did each group experience physiologically?
- Why was the crouch position specifically chosen, rather than just standing still?
- Are there any other factors, other than the type of recovery, that might impact results? What are they?



### 🚩 SIGNPOST

To learn more about one strategy for delaying fatigue during high-intensity exercise, read the fact sheet 'Sports supplement framework: sodium bicarbonate' from the AIS.



**Weblink**  
Sports supplement framework:  
sodium bicarbonate

## LOOKING FORWARD

### Lactate tolerance

#### Chapter 15

Lactate tolerance and buffering will be explored as adaptations to different training methods in Unit 4.



## ABOVE AND BEYOND THE STUDY DESIGN

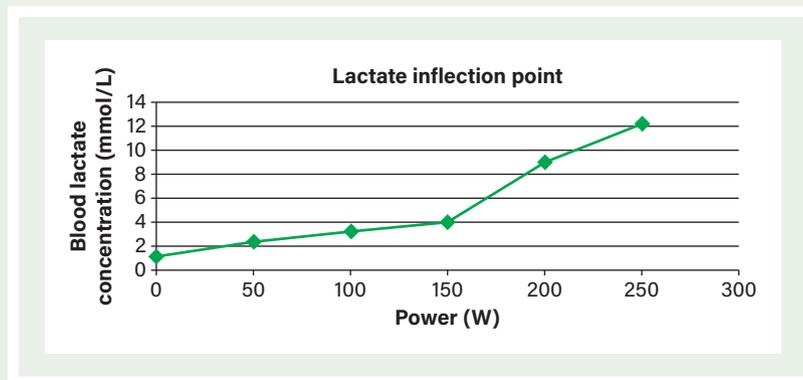
Effect of sodium bicarbonate on energy metabolism, page 311



**Assessment**  
7.3 Check-in questions

## 7.3 CHECK-IN QUESTIONS

- 1 What are metabolic by-products?
- 2 Why is it that some metabolic by-products cause fatigue and others do not?
- 3 Identify three metabolic by-products that are responsible for fatigue.
- 4 Define 'LIP'.
- 5 Circle LIP on the graph below.



- 6 The graph represents an athlete who has undertaken successful aerobic-based training for 6 months. Draw a line on the graph to represent the likely lactate response from an untrained person who undertook the same test.
- 7 Explain what occurs physiologically when an athlete exceeds LIP.

## 7.4 THERMOREGULATION

In this module you will learn about:

- muscular fatigue mechanisms, including thermoregulatory fatigue linked to varied sport and exercise intensities and durations and learn to:
- explain the muscular fatigue mechanisms associated with the use of the three energy systems under varying exercise conditions.

### thermoregulatory fatigue

Fatigue that results from an inability to maintain a stable body temperature

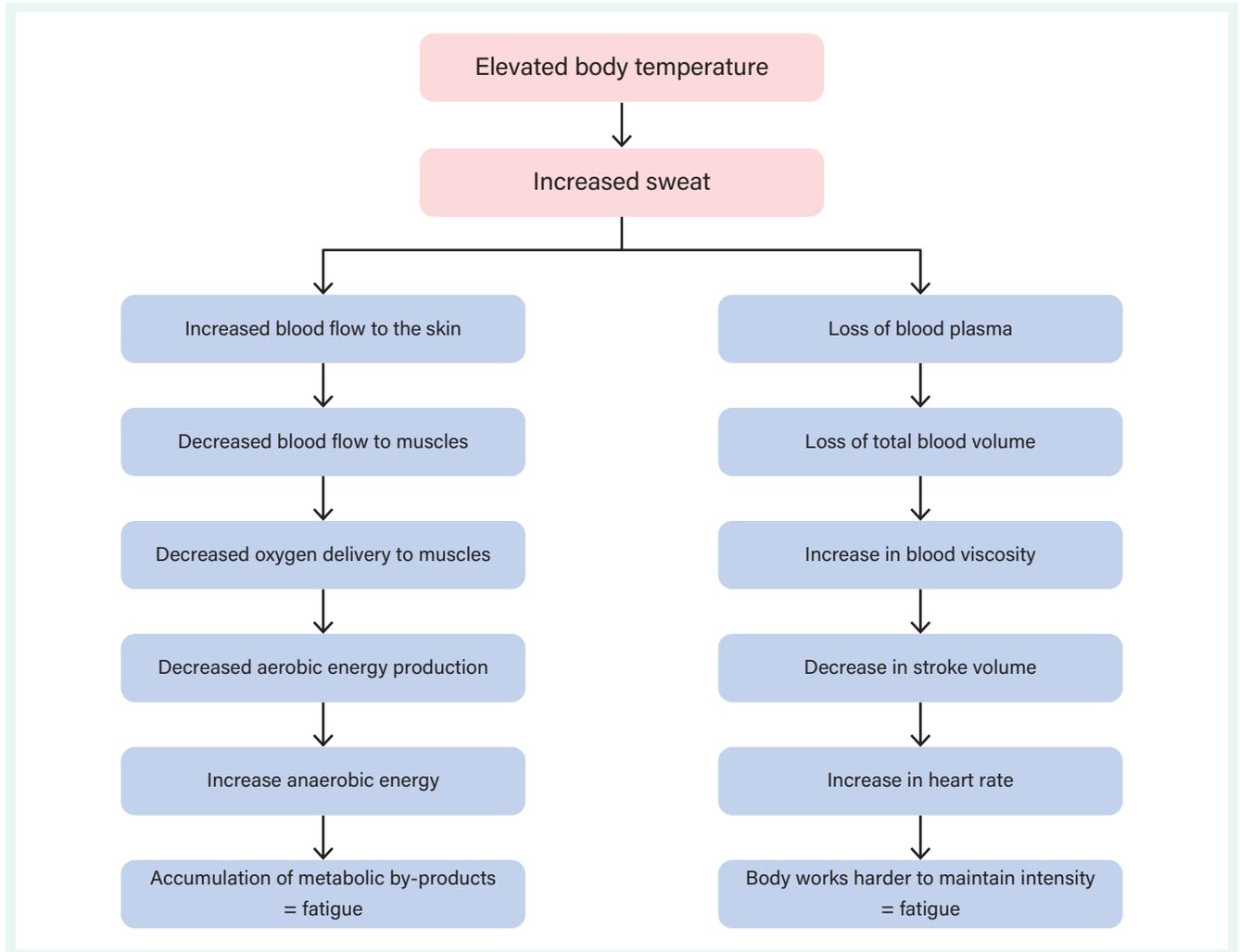
### redistribution of blood flow

A physiological process that involves vessels widening (vasodilation) to increase blood flow to a particular site in the body and vessels narrowing (vasoconstriction) to decrease blood flow elsewhere

Regulating body temperature during exercise is critically important as metabolic pathways and enzymes only function effectively within a small temperature range. To effectively regulate body temperature, the body is well equipped with strategies to support appropriate heat loss in response to changes in temperature. Contracting skeletal muscles produce a large amount of heat during exercise, and, for the body temperature to remain relatively constant, heat loss must match the heat gained/produced. If core temperature is not well regulated, the person may suffer **thermoregulatory fatigue**.

The body uses blood to regulate temperature as blood has the capacity to store heat. When skeletal muscles increase their heat production, blood will carry the heat produced to the surface of the skin, where it attempts to lose the heat by mechanisms such as radiation and evaporation. During exercise of shorter duration or when the outside temperature is relatively cool, this redistribution of blood flow is effective. However, during exercise of longer duration, or when the ambient temperature is warm, there is a large **redistribution of blood flow** towards the skin – away from working muscles. This reduces the delivery of oxygen to working muscles and, therefore, their capacity to produce aerobic energy. There is an increase in contribution from the anaerobic systems and an accumulation of metabolic by-products.

The body also sweats to maintain a stable body temperature. This sweat comes from blood plasma, and, when more sweat is lost than fluid put in, there is a loss of blood plasma, which causes a slight thickening of the blood (increased viscosity). This reduction in total blood volume results in a reduction in stroke volume, and this, in turn, causes heart rate to increase. The body works harder to push the thicker blood through the vascular system, also contributing to an increase in heart rate. This means the body is working harder with no increase in pace, resulting in fatigue.



**FIGURE 7.15** Two thermoregulatory pathways to fatigue

## REAL WORLD APPLICATIONS

### Cardiac drift

When taking part in a long-duration event such as the ultramathon in Figure 7.16, or when exercising in warm or hot environments, heart rate increases due to a loss of blood plasma (through sweat). This loss of blood plasma results in a loss of total blood volume, which in turn decreases stroke volume. To maintain a stable cardiac output, heart rate drifts upwards, a phenomenon known as cardiovascular drift (commonly called cardiac drift). There is no change to the athlete's pace or workload but, as heart rate increases, the body works harder to maintain a set pace. Cardiac drift can occur within 10 minutes of exercising in temperatures over 32°C. It has been found to be performance-limiting when 10–16 per cent decrease in stroke volume results in a heart rate increase of





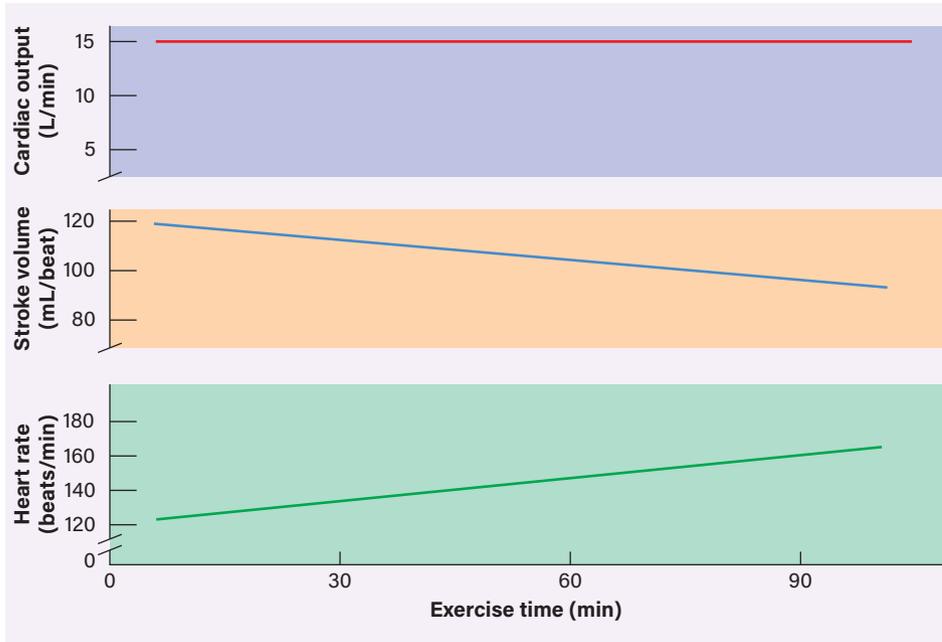
11–16 per cent over 45 minutes of exercise in a warm to hot environment (Powers et al., 2024). This consistently results in a substantial decrease in  $VO_2$  max.

To reduce the risk of cardiac drift, athletes are advised to exercise in optimal temperatures, as well as beginning exercise hydrated. In the case of marathon running, consuming fluid is recommended before and during the event to limit the impact of dehydration.

iStock.com/simonkr



**FIGURE 7.16** Participants in events such as an ultramarathon require extreme endurance and may be affected by cardiac drift.



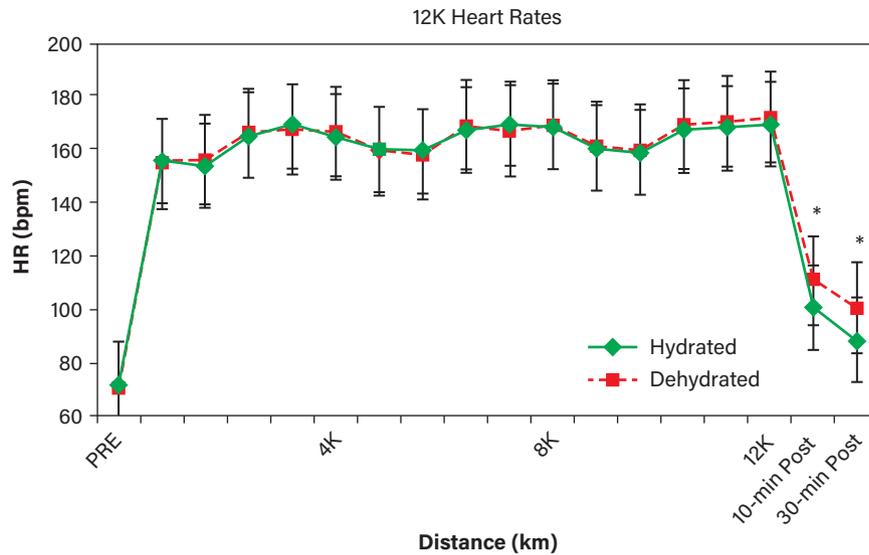
**FIGURE 7.17** Exercise lasting 90 minutes results in a significant drop in stroke volume and rise in heart rate to maintain cardiac output, demonstrating the concept of cardiac drift.

Source: Powers, S.K, Howley, E. & Quindry, J. (2024), *Exercise Physiology: Theory and application to fitness and performance*, McGraw-Hill, New York

**WORKED EXAMPLE**

©VCAA Exam 2022, Section B, Q11

The graph below shows heart rate data from a highly trained amateur trail runner who has completed two 12 km training sessions on different training days, on a trail-running track in an area with frequent uphill and downhill sections. The trail runner's heart rate was recorded every four minutes. The trail runner completed the two training sessions in approximately 64 minutes each.



\* Significant main effect for condition;  $p < 0.05$

On both training days, the temperature was above 27°C but the trail runner was well hydrated. Identify and discuss a likely cause of fatigue for the trail runner.

**Sample response**

When exercising in warm temperatures, even when well hydrated, athletes can have elevated body temperatures. You could also have identified accumulation of metabolic by-products as the fatigue mechanism.

The runner experienced *thermoregulatory fatigue*. This results in blood flow away from the working muscles, reducing oxygen available for aerobic ATP production.

Discussing the reduction in available oxygen as a result of blood being redistributed away from working muscles and linking to the aerobic system explores the process of the fatigue mechanism.

## WORKED EXAMPLE

©VCAA Exam 2022, Section B, Q8

The Ironman Triathlon is usually scheduled to be held at a time when athletes will not have to compete in high temperatures.

Explain, physiologically, what occurs when exercising in high temperatures and **suggest** what implications this could have on an athlete's performance.

### Sample response

Identify the consequence of the response.

Identify the physiological response to an increase in body temperature.

When core body temperature increases, the body sweats in an attempt to thermoregulate (cool down). This results in a reduction in blood plasma and the body works harder to maintain blood flow to the muscles. Additionally, there is a redirection of blood towards the skin in an attempt to cool down, and consequently away from the muscles. This vasoconstriction results in a decrease in oxygen delivery to the muscles and therefore an increase in the contribution of anaerobic energy, resulting in an accumulation of metabolic by products and fatigue resulting in the athlete slowing down.

Clearly link what has happened in the body to the performance, i.e. what does it look like?

### Command term

#### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer

## DID YOU KNOW?

The Berlin Marathon is run over the fastest marathon course in the world and has seen 11 world records since it was first held in 1974. The ideal environmental conditions for world-record performances for men have been temperatures of 18.61°C and sunny, mostly dry days, with little cloud cover. For women, ideal conditions for world-record performances are temperatures of 13.07°C with no sunshine and significant cloud cover (Scheer et al., 2021).

## Energy systems and fatigue

Table 7.06 summarises the fatigue mechanisms associated with each energy system as well as recovery strategies recommended to return the body to pre-exercise condition as quickly as possible.

**TABLE 7.06** The three energy systems and the major associated fatigue factors

Energy system	Associated fatigue mechanism	Recovery strategy
ATP-CP	Fuel depletion: <ul style="list-style-type: none"> <li>ATP</li> <li>CP</li> </ul> Accumulation of metabolic by-products: <ul style="list-style-type: none"> <li>ADP</li> <li>P<sub>i</sub></li> </ul>	Physiological: <ul style="list-style-type: none"> <li>passive</li> </ul>
Anaerobic glycolysis	Accumulation of metabolic by-products: <ul style="list-style-type: none"> <li>H<sup>+</sup> ions</li> </ul>	Physiological: <ul style="list-style-type: none"> <li>active</li> </ul>
Aerobic	Fuel depletion: <ul style="list-style-type: none"> <li>glycogen</li> </ul> Thermoregulatory	Dietary: <ul style="list-style-type: none"> <li>carbohydrate</li> <li>protein</li> </ul> Hydration: <ul style="list-style-type: none"> <li>water</li> </ul> Physiological: <ul style="list-style-type: none"> <li>active</li> </ul>

## Delaying fatigue

In most competitive events, delaying fatigue and minimising the impact of the factors that are responsible for fatigue and impaired performance is an important goal. Some of the factors that can support this goal will be discussed in this chapter and in Unit 4. They include:

- developing training adaptations
- nutrition
- sleep
- acclimatising to performance conditions.

### REAL WORLD APPLICATIONS

#### World Athletics Cross Country Championships

A dramatic finish to the 2023 World Athletics Cross Country Championships in Bathurst demonstrated the impact of fatigue. The 10,000-metre women's race was held in the afternoon, when the temperature on course surpassed 36°C. Many runners struggled to finish, including race leader Letesenbet Gidey, who stumbled and fell within 50 metres of the finish line. She was supported to the finish by officials and subsequently disqualified. Australian Leanne Pompeani also collapsed with 20 metres to go to the finish line. She was reported to have a core body temperature of 41.7°C in the medical tent shortly after the conclusion of the event. The body's ability to thermoregulate is challenged when exercising in warmer temperatures, hastening the impact of fatigue.



**FIGURE 7.18** Letesenbet Gidey falls agonisingly short of victory in the final 50 metres of the World Athletics Cross Country Championships in Bathurst.

AAP Image/Dean Lewins

**Weblink**

Women's Senior Race: World Athletics Cross Country Championships

**Assessment**

7.4 Check-in questions

**Command term****describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

## 🚩 SIGNPOST

See the dramatic finish to the women's senior race at the World Athletics Cross Country Championships on the World Athletics feed on X (formerly Twitter).

## 7.4 CHECK-IN QUESTIONS

- 1 **Define** 'thermoregulatory fatigue'.
- 2 **Explain** why the body redistributes blood flow to the skin when core temperature increases.
- 3 **Explain** why significant sweating without adequate hydration strategies is associated with fatigue.
- 4 Using your understanding of the redistribution of blood flow, **describe** the physiological process that occurs when an athlete is well hydrated, but still suffers from thermoregulatory fatigue.

# 7.5 NUTRITIONAL AND HYDRATION STRATEGIES

In this module you will learn about:

- nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery, including carbohydrate ingestion, protein and water and learn to:
- develop nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery.

There are very few concepts in sport that have caught the attention of the general population like nutrition and performance. In this key knowledge point, you need to describe the various strategies someone might use before, during and after participation in physical activity and how these enhance performance, delay fatigue and optimise recovery. There will be a focus on aerobic and anaerobic athletes in competition and training as well as on resistance exercise. Overarching the science that will be explored in this module is the understanding that nutrition must be personalised to support performance and training, promote recovery and enhance adaptations.

While the general population eat for optimal physiological and psychological functioning, the primary goals of sports nutrition are to enhance performance, minimise the impact of fatigue and optimise recovery. This means that bespoke short-term nutrition and hydration strategies are used, many of which may not be recommended for long-term use. It is important to know that these strategies are recommended for athletes in the context of specific exercise and sport performance.

# Enhancing performance and delaying fatigue

One of the primary goals of nutrition and hydration during performance is to delay fatigue. As we have explored earlier in the chapter, two of the fatigue mechanisms that impact performance are fuel depletion (glycogen) and thermoregulatory fatigue. While fatigue cannot always be prevented, there are some nutrition and hydration strategies that can be undertaken before an event, as well as during an event, that act to minimise the impact of these fatigue mechanisms.

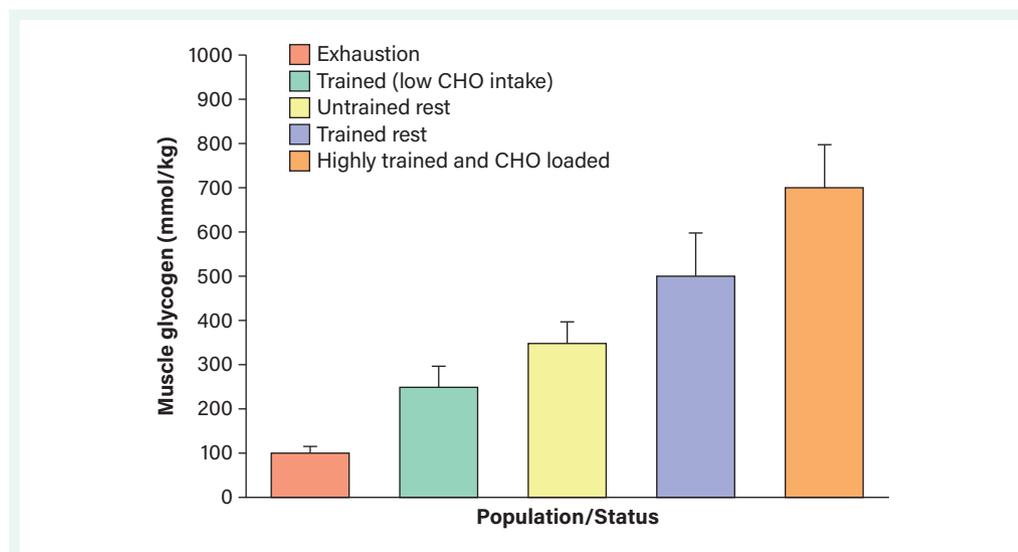
## Carbohydrate loading

Preloading of carbohydrate (CHO) involves ingesting more CHO than would be considered part of a regular nutrition plan with the aim of maximising the body's glycogen stores. This may be beneficial in longer-duration events – such as those lasting 90 minutes or longer of continuous performance. As a general guide, CHO intake should be increased for 24–48 hours before the performance and should consist of 8–12 grams/kilogram body mass. The graph in Figure 7.19 compares muscle glycogen levels in different population groups. Note the very high levels of glycogen in the highly trained athletes who have CHO loaded.

When investigating CHO loading and intermittent sport, research has been challenging. In their book *Clinical Sports Nutrition*, Louise Burke et al. state:

Typically CHO loading will postpone fatigue and extend the duration of steady state by ~20% and improve performance over a set distance or workload by 2–3%. While team sports often extend for longer than 90 minutes of playing time, there are complexities in gathering research due to the intermittent and unpredictable nature of team sport. Some preloading of carbohydrate may be beneficial for these athletes, but research is challenging due to a high level of variability between athletes and games.

Source: Burke, L. et al. (2021), *Clinical Sports Nutrition* sixth edition, McGraw-Hill



**FIGURE 7.19** The benefits of training and CHO loading for muscle glycogen levels

Source: Hearn, M.A. et al. (2018), 'Regulation of muscle glycogen metabolism during exercise: Implications for endurance performance and training adaptations,' in *Nutrients* 10(3): 298. CC BY 4.0

## LOOKING FORWARD

### Tapering

#### Chapter 12

It is important to reduce training volume in the lead-up to a competition. This ensures physiological and psychological recovery. For endurance athletes, it also gives them the opportunity to optimise stores of fuel, such as glycogen, in the muscle. This may help delay glycogen depletion and thus fatigue. The reduction in training volume is known as tapering, and will be explored in Unit 4.

#### LEARNING HACK

There are clear links between simulation and specificity throughout the VCE PE Study Design. Train the way you want to perform: this can be linked to the performance environment – for example temperature, nutritional status and specificity of training activities.



#### Weblinks

Sports Dietitians Australia road cycling fact sheet

Sports Dietitians Australia fact sheets

## During exercise

The consumption of carbohydrate during an endurance event can help delay muscular fatigue. There is some evidence to suggest that even in an event lasting only 60 minutes, which is unlikely to be impacted by glycogen depletion, improved performance levels are possible when carbohydrate is consumed during the event. However, more research has been conducted for endurance events lasting over 90 minutes. When carbohydrates such as glucose or sucrose, which are found in gels, sports drinks and lollies, are consumed during such an event, the muscle is provided with additional fuel to use and the muscle maintains oxidation of carbohydrate fuel stores, which can delay fatigue. How much is required depends on the performance characteristics of the event (intensity and duration) the athlete's ability to tolerate eating food during an event and the environmental conditions. What is most important is that event strategies are planned and practised in the performance environment to simulate the requirements of the event.

### 🚩 SIGNPOST

Sports Dietitians Australia (SDA) has produced fact sheets on nutrition and hydration for a variety of different sports, including one on road cycling. Explore your own sport's recommendations, whether it be snowboarding, rowing, V8 supercars or netball.

## Hydration

Inevitably, loss of fluid occurs during physical activity. We explored the impact of this fluid loss earlier in the chapter and have linked this loss to thermoregulatory fatigue. How much fluid is lost depends on a variety of factors, including:

- sweat rates of the athlete
- environmental conditions such as temperature and humidity
- intensity and duration of work.

Most athletes will find it challenging to consume as much fluid as they lose while participating in training or an event. Therefore, it is important to commence a session well hydrated. This balance can be tricky for athletes to achieve as they wish to avoid an increase in urination during an event, which is the consequence of consuming a lot of fluid. There are companies that offer sweat testing through collection of sweat via a patch. These patches can link to apps that give specific information on the composition of the sweat for a customised hydration strategy (see Figure 7.20). A more accessible and straightforward way to monitor hydration is a urine check; dark urine indicates more fluid is required for optimal hydration.



**FIGURE 7.20** An athlete uses a sweat patch to monitor the composition of their sweat.

## REAL WORLD APPLICATIONS

### Complexities when hydrating

While most sports give athletes opportunities to take fluid during regular breaks such as 'half time,' some sports are more complex. Sports where toilet access is challenging due to location or clothing requirements, and those in which slowing down to receive fluid and drink it is time-consuming, have to develop specific strategies to ensure athletes can get the fluid they need. The table below lists several of these sports and the complexities associated with hydration.

**TABLE 7.07** The complexities associated with hydration in various sports

Sport descriptor	Complexity
Land-based endurance events	<ul style="list-style-type: none"> <li>Stopping to collect fluid can slow the athlete</li> <li>Drinking while running can be difficult to coordinate</li> <li>Some competitions have limited stations to collect fluid from</li> </ul>
Swimming	<ul style="list-style-type: none"> <li>Open water swimming does not have water stations and requires a support team to facilitate opportunities for delivery of fluid (see Figure 7.21)</li> <li>Athletes must stop or slow down when consuming fluid</li> <li>An aquatic environment can psychologically mask the need for fluid intake</li> </ul>
Distance kayaking	<ul style="list-style-type: none"> <li>Fluid access can be challenging due to difficulty in creating hydration stations</li> <li>Both hands are required to kayak</li> <li>Bathroom facilities are difficult to create, and using them is time-consuming (includes getting into and out of boat)</li> </ul>
Snow sports	<ul style="list-style-type: none"> <li>The drinks can freeze!</li> <li>Bathroom facilities are difficult to create, and using them is time-consuming (due to type and volume of clothing worn)</li> </ul>

Adapted from: Burke, L. & Deakin, V. (2015), *Clinical Sports Nutrition* fifth edition, McGraw-Hill Education



Sebastian Kahnert/picture alliance/Getty Images

**FIGURE 7.21** Ensuring access to fluid is more challenging in water-based sports.



**Weblink**

IOC consensus statement on recommendations and regulations for sport events in the heat

**SIGNPOST**

Read the article 'IOC consensus statement on recommendations and regulations for sport events in the heat' for everything from mist sprays, ice and shade to athlete acclimatisation.



**ABOVE AND BEYOND THE STUDY DESIGN**

Electrolyte drinks, page 311

## Improving recovery

The aim of nutritional and hydration strategies post-exercise is to optimise recovery so that an athlete can participate in the next bout of exercise at the required intensity. Additionally, some nutritional strategies are used to promote adaptations to the training undertaken.

Regardless of the goal of nutrition, each individual will respond differently and require an individualised/tailored strategy that meets their personal needs, likes/dislikes and tolerances.

Recently, there has been great interest in strategies to optimise recovery for athletes and the general population. It is an area of science that has been investigated heavily and one that has seen a rapid increase in the availability of commercial products, including drinks, bars and powders, all claiming to support recovery. While there are some underlying principles of science that underpin selection of nutritional strategies to enhance recovery, many factors will influence what, when and how much is consumed. Elite athletes may face added constraints when competing in international competitions.

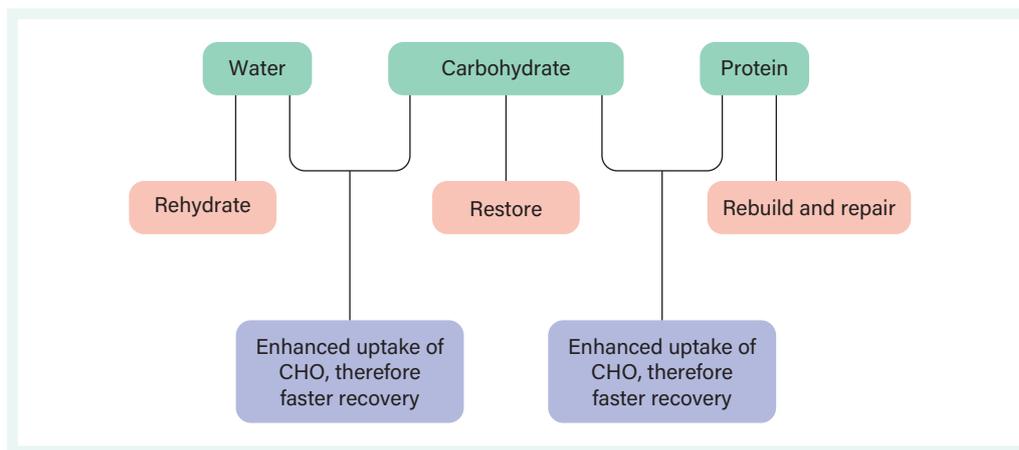
The factors that may impact an athlete's consumption of food after training or an event include:

- access to appropriate food stations
- likes and dislikes of available food
- media commitments
- doping control protocols.

Canetti/Shutterstock.com



**FIGURE 7.22** Food offered to runners during a marathon



**FIGURE 7.23** The recovery benefits of water, CHO and protein and the added benefits of co-ingestion

## Water

Rehydrating after exercise is an important part of returning the body to pre-exercise conditions. As individual sweat rates and thirst drives are different, each person will require a slightly different strategy. In many cases, particularly after a local or club training session, water alone will support rehydration. Water works to restore blood plasma, which optimises blood flow and therefore recovery. In cases where considerable sweat has been lost, the individual may wish to include electrolytes, which may enhance fluid consumption and retention.

## Carbohydrate

Following exercise, the muscles are hungry for glycogen. The uptake of glycogen is highest immediately post-exercise, which has led sports dietitians to believe that there is a 'window of opportunity' of 30 minutes to 1 hour after exercise to maximise muscle glycogen restoration and allow the athlete to return to their pre-exercise condition fastest. This will be especially important for events where the athlete needs to perform again the next day – for example, when riding in a 3-week stage race such as the Tour de France or the Giro d'Italia (Figure 7.24).



**FIGURE 7.24** Long-duration events performed over many days, such as the Tour de France (left) or the Giro d'Italia (right), require athletes to consume a large amount of carbohydrate to optimise recovery.

## Protein

Protein ingestion after exercise should also be considered an important recovery strategy for athletes. Similar to carbohydrate, the rate of protein resynthesis and thus muscle rebuild and repair is enhanced post-exercise. Therefore, consuming protein becomes important to those athletes wishing to recover from a heavy load or generate appropriate adaptations to training. While it is widely accepted that anabolic sensitivity is highest immediately after exercise, athletes can experience benefits from consuming protein every 3 or 4 hours post-exercise, as well as straight after their session.

## Co-ingestion of carbohydrate and protein

There is evidence to suggest that, in some circumstances, co-ingestion of carbohydrate and protein may enhance the uptake of glycogen at the muscle site, which will allow the athlete to recover at a faster rate than by consuming carbohydrate alone. This concept of co-ingestion is an area that has gained significant attention in the sports world, and then the commercial world, and studies are continuing. The diagram in Figure 7.22 shows the benefits of this co-ingestion.

**LEARNING HACK**

When considering the consumption of nutrients and fluid in recovery, link each strategy to a term beginning with 're':

- CHO – refuel
- protein – rebuild/repair
- water – rehydrate.

## Co-ingestion of carbohydrate and water

There is also evidence to suggest that consuming carbohydrate and water together enhances recovery. This concept is complex and multifaceted. At a level specific to the requirements of VCE, having carbohydrate within fluid can enhance the absorption rate of the carbohydrate and thus faster restoration of muscle glycogen. Additionally, such fluids are often more palatable than water alone, supporting more voluntary fluid intake and therefore carbohydrate ingestion.

### REAL WORLD APPLICATIONS

#### Ask an expert: Dr Louise Burke

Leading Australian sports nutritionist Dr Louise Burke has 40 years' experience working with elite athletes. She was Head of Sport Nutrition at the AIS and worked with Australian athletes at multiple Olympic Games.

**Q:** What aspect of sports nutrition do athletes find the hardest to manage – prior to an event, during, or in recovery? Could you explain a little about your selection?

**A:** I think the most challenging aspect of eating around competition is the 'during event' menu because it requires the athlete to integrate several factors into their plan. The first step is to consider the physiological and psychological limitations to the specific event and how nutritional strategies can address these. Common factors – depletion of muscle fuel, dehydration, sub-optimal function of the central nervous system, and gastrointestinal discomfort – might be experienced by the athlete each time they compete, so that they learn how to address the challenges. But in some sports, the event can change from one competition to the next – for example, two tennis matches are never the same, the length of each cycling road race is different, and a marathon might be held in different weather conditions. This might require a different approach for each version of the event. The second step is to recognise that the during-race nutrition plan needs to fit event rules or practical considerations. Even if two events share the same theoretical nutrition plan (i.e. to replace a certain amount of fluid, to benefit from caffeine intake and to require extra carbohydrates as a brain and muscle fuel), there may be different opportunities for the athlete to consume fluid and food during the competition. Some events have stoppages (e.g. half-time breaks, substitutions), which allow the athlete to consume their nutrition support. However, in continuous events like marathons, triathlons and cycling races, the athlete must literally 'eat on the run'. Whether the athlete can carry their own race supplies (on their bike or in a race jersey), whether there is a network of aid stations, or whether a support team can take the nutrition supplies to the athlete will vary across sports. Therefore, the athlete needs to examine all the features of their event to match their needs to the opportunities. The final step is to master the behaviour and gut tolerance to consume drinks and foods while exercising. It takes skill to grab a cup/bottle and drink from it while moving at a swift pace. The gut must also be trained to feel comfortable and be able to process (empty and absorb) nutrients while exercise is causing most of the body's blood supply to be shunted to the muscles. The final plan needs to be individualised to the athlete and can take time and effort to master. Luckily, the sports industry has created special drinks and sports foods that have characteristics to assist the process.

**Q:** For recovery that aims to restore muscle glycogen, what sort of foods do you recommend?

**A:** At the simplest level, any carbohydrate-rich food will contribute to muscle glycogen storage after exercise. However, training and competition scenarios can create different contexts that favour different approaches. For example, if an athlete has finished one session and needs to refuel as quickly as possible, it can be useful to choose sources that are easy to consume and digest. Drinks – juices, sports drinks, flavoured milk/smoothies – can provide a rapid carbohydrate source, and sugar-rich or processed foods may offer practicality and ease of consumption. Alternatively, when the focus is on the training diet, where the athlete also needs to consider a range of nutrition goals, carbohydrate-rich foods or meals that can provide other nutrients are more valuable. Grains, fruits or starchy vegetables can form the basis of meals to provide carbohydrate as well as protein, vitamins, minerals, fibre and micronutrients.





**Q:** There is great interest in protein in the sports and commercial worlds. What sort of exercise (type, intensity/duration) might someone undertake to require extra protein? What are some of the issues with consuming extra protein?

**A:** When exercise is undertaken at a 'serious' level of commitment – for example, it is undertaken daily, sessions might last an hour or more, and it has goals of creating adaptation in the body (increased strength, power, endurance etc.) – it is likely to create an increased protein requirement. This includes resistance training, endurance training or combined training (e.g. team sport). Generally, there is no problem with the opportunity to consume extra protein, because the athlete/exerciser is also creating extra energy needs. However, sometimes there is a practical problem with understanding how to best integrate protein-rich foods into the daily nutrition plan. This includes over-estimating the importance of protein and thinking that you can only achieve your new needs with expensive supplements. But it can also include not recognising practical ways to include protein-rich foods into post-exercise recovery snacks or meals across the day. Many everyday plant-based and animal foods can be included in eating occasions to achieve a good daily spread and overall protein target. And there are times when a simple protein powder (or even skim milk powder) has value as an easy-to-prepare protein boost when everyday foods aren't available.

**Q:** What characteristic of exercise (type, intensity/duration) would benefit from additional CHO support to enhance recovery?

**A:** The fuel cost of exercise can be derived in different ways. Muscle (and blood) carbohydrate contributes to higher-intensity exercise of short duration, as well as more moderate intensity exercise of longer duration. Muscle glycogen can be largely depleted by a range of exercise scenarios due to the interaction of type, intensity and duration (e.g. a soccer match, a 60-minute maximal-intensity cycling time trial or a 2-hour training run). What also creates the need for specific strategies for recovery of carbohydrate stores is when the athlete needs to train or compete again. When athletes are training twice a day, or competing in a sport with multiple substantial events (e.g. a team tournament or cycling stage race), planned replacement of carbohydrate between sessions becomes important.

**Q:** How does CHO consumption during an event potentially delay fatigue from glycogen depletion?

**A:** Carbohydrate consumption during exercise can have a number of different benefits for performance. Some of them are related to muscle fuel use. In some situations, the ingested carbohydrate takes over the role of providing a muscle fuel when the muscle's own glycogen stores are becoming depleted. In other situations – and this is a bit controversial – the ingested carbohydrate might restore glycogen concentrations in the muscle for later use during the event. Another benefit is via the support for liver glycogen stores. Ingested carbohydrate supports the liver in being able to keep blood glucose concentrations high, to fuel both the muscles and the central nervous system and to prevent the fatigue associated with hypoglycemia. A final role is via a direct effect on the brain and central nervous system, that actually doesn't even involve fuel use. There are receptors in the mouth and throat that respond to carbohydrate exposure. Simply tasting carbohydrate – just by swilling it around your mouth – sends messages to the reward centres in the brain to make you feel better. This plays a role in making the athlete feel like they have the energy to exercise at their highest pace or output. Different scenarios of exercise draw on these different benefits of carbohydrate intake.

## 🚩 SIGNPOST

Listen to Dr Burke advise how to eat like an athlete in the radio segment 'Eat like an athlete,' on ABC Listen.



**Weblink**  
Eat like an athlete

## WORKED EXAMPLE

©VCAA Exam 2020, Section B, Q8 d and e

d Explain, physiologically, why carbohydrates are beneficial for the athletes within the first 30 minutes of finishing the Ironman Triathlon.

CHO ingestion needs to be linked to the physiological recovery of restoring muscle glycogen.

**Sample response:** Consuming carbohydrate within the first 30 minutes will enable a quick restoration of muscle glycogen, which will allow the athlete to return to pre-exercise condition faster.

Linking the time frame of the nutritional strategy to the outcome (faster recovery) explains why the athlete would benefit from this approach.

e Suggest why an athlete would ingest protein in combination with carbohydrates after a race to aid recovery.

Identify the recovery benefit of protein.

**Sample response:** Protein helps with muscle repair, and combining it with carbohydrate assists with a more rapid rate of glycogen absorption.

Using terms such as 'more rapid' ensures the co-ingestion strategy is clearly linked to the physiological advantage.



### Assessment

7.5 Check-in questions

### Command term

#### analyse

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

## 7.5 CHECK-IN QUESTIONS

- 1 **State** the primary goals of sports nutrition.
- 2 Which fatigue mechanism may carbohydrate loading delay?
- 3 **Explain** how an athlete can ensure they are able to tolerate their nutrition and hydration strategy during an event.
- 4 **Explain** two purposes of using successful nutritional strategies in recovery.
- 5 **Analyse** the benefit of co-ingestion of carbohydrates and protein, rather than just carbohydrate alone.

MODULE 7.3, PAGE 295

## Effect of sodium bicarbonate on energy metabolism

A recent review of literature on the impact of consuming sodium bicarbonate found that it had an impact on events with a large contribution from the anaerobic energy systems. One of the natural buffer systems in the body is bicarbonate ions. These ions make the blood more alkaline, which balances out the acid from the  $H^+$  ions. This allows the athletes to continue to work with higher contributions from the anaerobic glycolysis system, allowing a very high intensity of effort to be held for a longer time and decreasing the performance impact of fatigue. Consuming sodium bicarbonate as a tablet can increase alkalinity in the blood, which may have a positive impact on performance. However, as with all supplements, there are side effects that may limit or discourage use. These include gastric upsets, headaches and fluid retention. All ergogenic aids (dietary supplements etc.) must be used carefully and with the approval of coaches and the governing bodies of the sport.

MODULE 7.5, PAGE 306

## Electrolyte drinks

Sports drinks are accessible nutrition and hydration tools for the general population and athletes. While water will generally provide enough fluid for hydration purposes, sports drinks have the added benefit of containing electrolytes, and many also have carbohydrates. This means that they are often easier to consume and more palatable than water, which often increases the rate at which athletes drink them and the amount they drink. When an athlete requires CHO to restore muscle glycogen after performance or to provide an alternative fuel source for the muscles to use while exercising, sports drinks are often used. The use of CHO and electrolytes in a sports drink can promote fluid retention in the body. Many have a similar osmolality to blood plasma, which decreases the rate of fluid loss by urine. Additionally, there is growing evidence to suggest that consuming cold fluid when exercising in warm environments can delay fatigue by decreasing body temperature. Milk also has the benefit of temperature regulation and fluid retention, but is challenging for athletes to tolerate mid-race or immediately after an event.

### 🚩 SIGNPOST

To explore the process and reasons behind sweat testing in a commercial sweat testing lab, watch the video on the homepage of the Sweat Lab Australia website.



**Weblink**  
The Sweat Lab Australia

ABOVE  
AND  
BEYOND  
THE STUDY  
DESIGN



# CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 7

## 7.1 Introduction to fatigue

- Fatigue is the inability to maintain a desired force production or power output.
- Fatigue is multifactorial however there are three main mechanisms:
  - fuel depletion
  - accumulation of metabolic by-products
  - thermoregulatory fatigue.
- Some of the ways fatigue can be observed are:
  - an increase in time taken to complete a distance
  - decreasing the distance covered in a particular time
  - using a rating of perceived exertion scale.

## 7.2 Fuel depletion

- Fuels that can deplete in the body are:
  - ATP
  - CP
  - glycogen.
- When CP depletes, the body increases its reliance on glycogen (CHO), which produces energy at a slower rate.
- Similarly, when glycogen depletes, the body increases its reliance on triglyceride (fat), which produces energy at a slower rate.

## 7.3 Accumulation of metabolic by-products

- An accumulation of metabolic by-products occurs when they are produced faster than they can be removed.
- By-products that can accumulate in the body and impact fatigue are:
  - ADP
  - inorganic phosphate
  - $H^+$  ions.
- The accumulation of  $H^+$  ions impairs the capacity of the body to break down glycogen, which slows down muscle contraction.
- LIP is the final point at which lactate production is matched by lactate removal.
- When  $H^+$  ions accumulate, there has been an increased reliance on the anaerobic glycolysis system and the aerobic system is unable to remove the associated metabolic by-products as fast as they are being produced.

## 7.4 Thermoregulation

- Thermoregulatory fatigue is the fatigue that results from an inability to maintain a stable body temperature.
- Blood being directed away from the working muscle results in a decrease in oxygen delivery and, therefore, aerobic ATP production.
- Additionally, sweating reduces blood volume, which means the body works harder to pump blood around the body.

## 7.5 Nutritional and hydration strategies

- Nutritional and hydration strategies are used to enhance performance, delay fatigue and improve recovery.
- Carbohydrate loading increases stores of muscle glycogen, which can delay glycogen depletion and be of benefit in endurance events lasting 90 minutes or longer.
- When carbohydrate is consumed during an event, the muscle is provided with additional fuel to use and the muscle maintains oxidation of carbohydrate, which can delay fatigue.
- Ensuring athletes are well hydrated before an event and consume fluid during an event may delay thermoregulatory fatigue.
- Water post-event works to restore blood plasma, which optimises blood flow and, therefore, recovery.
- There is a 'window of opportunity' of about an hour post-exercise to consume carbohydrate, maximise muscle glycogen restoration and allow the athlete to return to pre-exercise conditions fastest.
- Consuming protein may help athletes wishing to recover from a heavy load or to generate appropriate adaptations to training by rebuilding and repairing muscle tissue.
- There is some evidence to suggest that co-ingestion of water and carbohydrate, or carbohydrate and protein, will enhance the rate of recovery.

# CHAPTER REVIEW



**Assessment**  
Chapter 7 Review

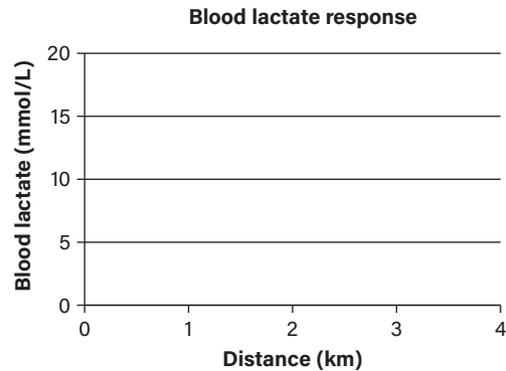
## Command term

### list

Provide a series of related words, names, numbers or items that are arranged consecutively

- Other than depletion of muscle glycogen stores, what are the main causes of fatigue in endurance athletes?
  - CP depletion and hydrogen ion ( $H^+$ ) accumulation
  - elevated body temperature and thermoregulatory fatigue
  - increased levels of ADP and hydrogen ion accumulation
  - triglyceride depletion
- Identify** the primary purpose of consuming carbohydrate after an event or training session.
- Identify** the type and duration of event in which athletes may benefit from carbohydrate loading.
- Identify** three factors that impact the loss of fluid for an athlete.
- List** three factors that may impact an athlete's consumption of food after training or an event.
- Which of the following would most likely be the cause of fatigue in a 400-metre swim race?
  - depletion of muscle glycogen stores
  - depletion of intramuscular CP stores
  - accumulation of lactate ions in the blood
  - accumulation of hydrogen ions in the muscle
- Consuming carbohydrate gels during an event is going to be most beneficial for:
  - events less than 10 seconds in duration.
  - events 30–60 seconds in duration.
  - events more than 60 minutes in duration.
  - team sports.
- The recent World Athletics Cross Country Championships were held in summer, when daily temperatures surpassed  $36^{\circ}\text{C}$ . **Explain** why, when athletes were well hydrated, many of them suffered fatigue towards the end of their 10-kilometre race and were unable to finish.

- 9 An athlete runs 4 kilometres. They run at steady state for the first 3 kilometres, then surge for the final 1 kilometre. Draw the expected blood lactate response on the graph below.



- 10 The table below shows the splits, distance and speed for the individual pursuit, which is a track cycling event over 4,000 metres.

Split	Distance (m)	Speed (km/h)
1	0–1,000	65.21
2	1,000–2,000	64.21
3	2,000–3,000	63.98
4	3,000–4,000	67.45

**Explain** why there was a decline in speed from the first to the second split with reference to energy systems and fatigue mechanisms.

**UNIT 3  
REVIEW****INTEGRATED EXTENDED-RESPONSE  
QUESTIONS**

These questions have been developed to allow you to draw on the knowledge and skills that you have developed across both areas of study in Unit 3. The responses require you to incorporate the concepts found in each area of study, draw on practical examples and integrate theoretical and practical concepts.

1 **©VCAA** Exam 2023, Section B, Q11 (8 marks)

The canoe slalom involves athletes paddling their canoes through downstream and upstream gates on river rapids. While the aim is to try to paddle as fast as possible, athletes do need to slow down as they paddle their canoe through the gate to avoid making contact and incurring a time penalty. Jessica Fox won the gold medal at the 2020 Tokyo Olympic Games in a time of 105.04 seconds.

Explain how the interrelationship between the following factors would contribute to Jessica Fox's successful performance in the canoe slalom:

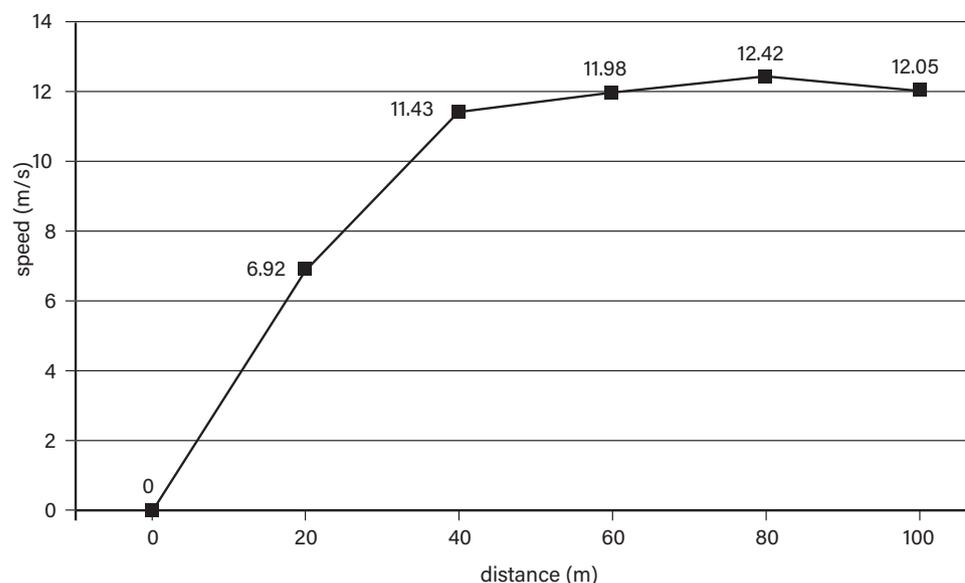
- Newton's laws of motion
- fuel.



Adam Pretty/Getty Images Sport/Getty Images

2 **©VCAA** Exam 2018, SAMPLE Q12 (8 marks)

The graph below shows the 20-metre split times for Usain Bolt's world record in the men's 100-metre sprint at the 2009 IAAF World Championships in Athletics in Berlin.



Data: H. Hommel et al., 'Scientific research project: Biomechanical analyses at the Berlin 2009 IAAF World Championships in Athletics, Final Report, Sprint Men', Deutscher Leichtathletik-Verband (German Athletics Foundation), Berlin, 2009, p. 5; IAAF, [www.iaaf.org/development/research](http://www.iaaf.org/development/research)

**Discuss** the relationship between fuel use, fatigue and force production with reference to acceleration and maximum speed during Usain Bolt's 100-metre race performance. Ensure you reference data within your response.

- 3 The following javelin results were obtained from two experienced javelin throwers from a VCE PE class during the practical activity in Chapter 6. Ahlia was given 2 minutes rest between attempts, whereas Mirra's throws were consecutive, with little rest. Both students performed a run-up before their throw and their results are displayed in the table below.

Throw	Ahlia	Mirra
1	30 m	31 m
2	33 m	29 m
3	31 m	27 m
4	29 m	24 m

Use your own participation experiences and understanding of skill classification (type), summation of momentum and speed of release to **discuss** the energy system requirements of the skills and explain the difference between the results.

- 4 Oliver and Imran are two VCE students who participated in a soccer session as part of their VCE PE class. They each tried to kick the ball as far as possible from a two-step run-up. Imran is an experienced soccer player who has played in a junior academy for 5 years. Oliver has little experience with soccer and has never played competitively.

The table below shows the results of their three attempts. The distance displayed was a measurement of the distance between when their foot struck the ball and the first bounce of the ball as it landed. The performance conditions were identical.

Kick	Oliver	Imran
1	12 m	27 m
2	13 m	24 m
3	14 m	25 m

Use your understanding of the interrelationship between biomechanics, skill acquisition and acute responses to explain the difference between the results. Ensure you refer to:

- stages of learning
- force summation
- acute responses.

# UNIT 4

## TRAINING TO IMPROVE PERFORMANCE



snaptitude/Adobe Stock

- » encourages student participation and involvement in physical activity to better understand how to improve performance from a physiological perspective
- » analyses movement skills and fitness requirements of multiple activities and apply relevant training principles and methods to improve performance at various levels
- » facilitates the evaluation and application of knowledge and understanding to training methods, principles and programs
- » demonstrates how data can be used to justify the selection of fitness tests based on the physiological requirements of an activity
- » considers important physiological data, training principles and methods used to design a training program
- » demonstrates how training program effectiveness needs to be considered based on the needs of the individual and chronic adaptations to training.

<b>CHAPTER 8</b> Fitness components used in physical activity, sport or exercise	320
<b>CHAPTER 9</b> Conducting an activity analysis	364
<b>CHAPTER 10</b> Assessment of fitness	402
<b>CHAPTER 11</b> Monitoring and recording training variables	448
<b>CHAPTER 12</b> Training program principles	474
<b>CHAPTER 13</b> Training methods	500
<b>CHAPTER 14</b> Components of a training session	552
<b>CHAPTER 15</b> Chronic training adaptations	582

## CHAPTER

# 8

## FITNESS COMPONENTS USED IN PHYSICAL ACTIVITY, SPORT OR EXERCISE

UNIT 4 - AREA OF STUDY 1



DragonImages/Adobe Stock

**FIGURE 8.01** Fitness is not just being strong or fast. It has multiple components.

### Quizzes

Chapter 8 Pulse check

**8.1** Check-in questions

**8.2** Check-in questions

**8.3** Check-in questions

Chapter 8 Review

### Videos

Masterclass: Chapter 8

**8.1** In focus: Muscle fibre type

### Resources

Chapter 8 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



- » factors affecting fitness components required in physical activity, sport or exercise (aerobic power, anaerobic capacity, muscular strength, power and endurance, flexibility, balance, coordination, speed and agility)

## KEY KNOWLEDGE

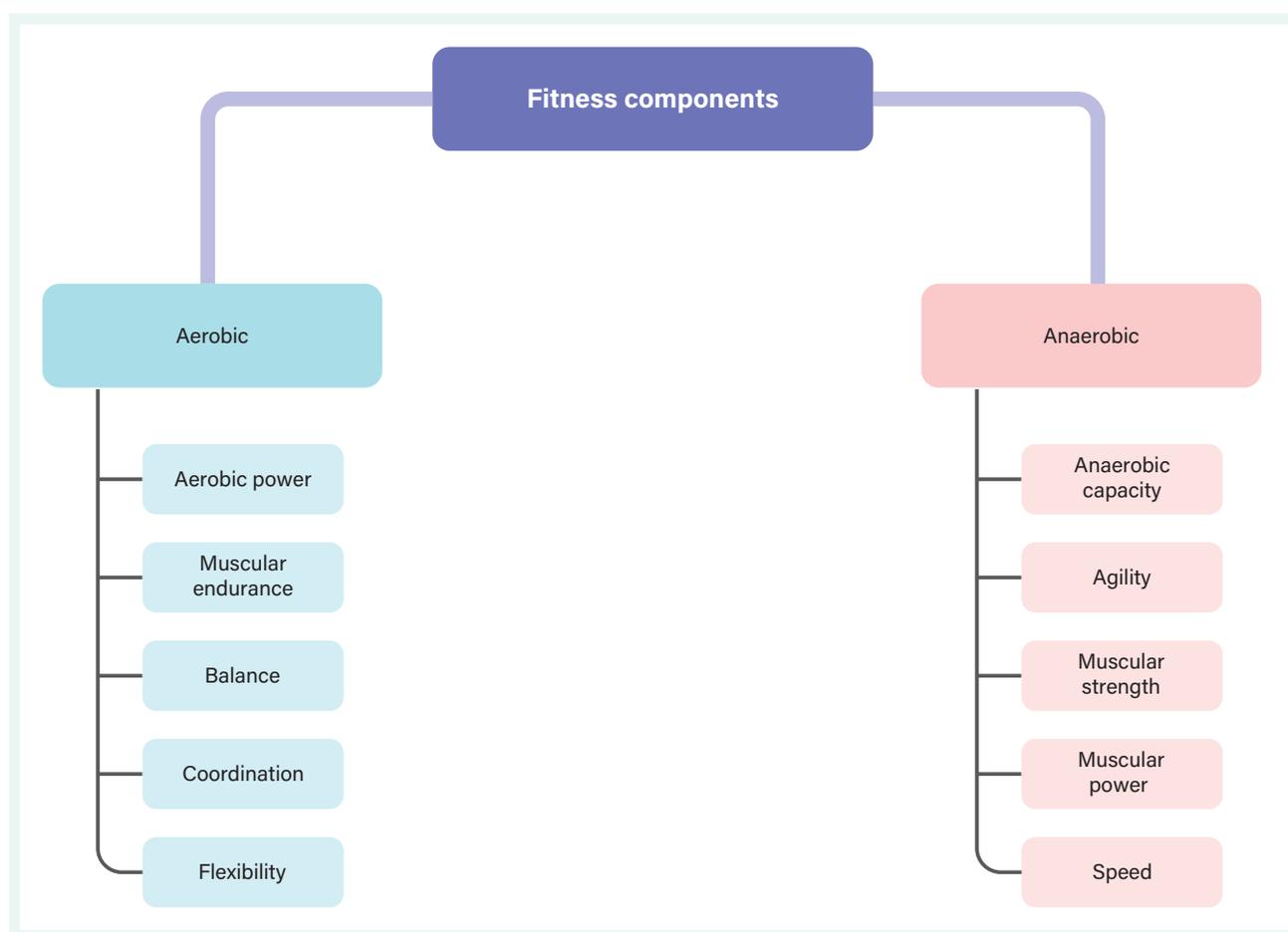
- » justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: *Victorian Certificate of Education Physical Education Study Design (2025–2029)*

Suggested key skill:

- » analyse data to determine the major fitness components and factors that affect them used in a variety of sporting events and physical activities

## KEY SKILLS





Video

Masterclass: Chapter 8

Assessment

Pulse check

In this chapter we will look at the components of fitness and the factors that affect them. The components of fitness are the individual characteristics of the different requirements for physical activity, sport and exercise. Training status affects all fitness components; however, other factors are specific to the individual component.

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 What do you think it means to 'get fit'? Why is this more complex than most people think?
- 2 **Define** the following fitness components and provide an example of a sport or activity that requires each one:
  - aerobic power
  - muscular power
  - speed.
- 3 **Identify** three factors that affect muscular endurance.
- 4 **Explain** how a lack of flexibility would impact the performance of a tennis player.
- 5 Males and females have similar relative strength but, in general, men are stronger than women. **Discuss** the accuracy of this statement.

## 8.1 PHYSICAL FITNESS

In this module you will learn about:

- the concept of physical fitness and the component model of fitness and learn to:
  - identify the fitness requirements for different sports, physical activities and exercise.

Physical fitness is one aspect of a person's overall health and wellbeing, and previously it has simply been defined as the capacity to perform daily activities without undue fatigue.

A more contemporary understanding of fitness recognises that physical fitness is the ability of the body systems to work effectively so that you can perform work and leisure activities

efficiently. Being fit allows you to be healthy – to do all your daily activities (going to school, chores around the house etc.) with minimal effort (energy expenditure) so that you have enough energy left to do the things you like to do (sport, exercise and other leisure activities). Being fit also means that you are able to respond when there is an emergency or an unforeseen situation (e.g. you miss the bus and have to walk/run home from school).

Being physically fit will mean different things to different people, depending on their stage of life, the requirements of their occupation and their choice of leisure activities. This leads to the concept that physical fitness is multidimensional.

PeopleImages.com – Yuri A/Shutterstock.com



**FIGURE 8.02** The physical requirements of an activity are specific to that activity.

Consider the work and leisure activities of an office worker, who walks to the train station each day to get to work and plays recreational netball, compared with those of a tradesperson who does manual labour as part of their work and plays golf on weekends. The idea that fitness is related to what you need to do in your daily routine means that, for athletes, fitness will be specific to their sport or activity.



Nobuo Yano/Getty Images Sport/Getty Images

**FIGURE 8.03** How do the fitness requirements of these three athletes differ?

What Alex de Minaur (tennis) is required to do in a match compared to Mary Fowler (soccer) or Lauren Parker (para-cycling/para-triathlon) is very different (see Figure 8.03). The fitness requirements can also vary based on different playing positions in team sports. As a forward, Mary Fowler has very different fitness requirements from those of goalkeeper Mackenzie Arnold (see page 68 to read more about Mackenzie Arnold).

The component model of fitness recognises the different aspects of fitness that contribute to the overall fitness of the athlete. Each component is a specific aspect of physical fitness, and this model allows us to analyse each of these aspects – the factors that affect each of these components and the contribution they make to successful performance in different physical activities, sports and exercises.

### 🚩 SIGNPOST

Lauren Parker was an elite triathlete before a bike accident left her paralysed. Watch the story about Lauren on the *60 Minutes* channel on YouTube.



#### Weblink

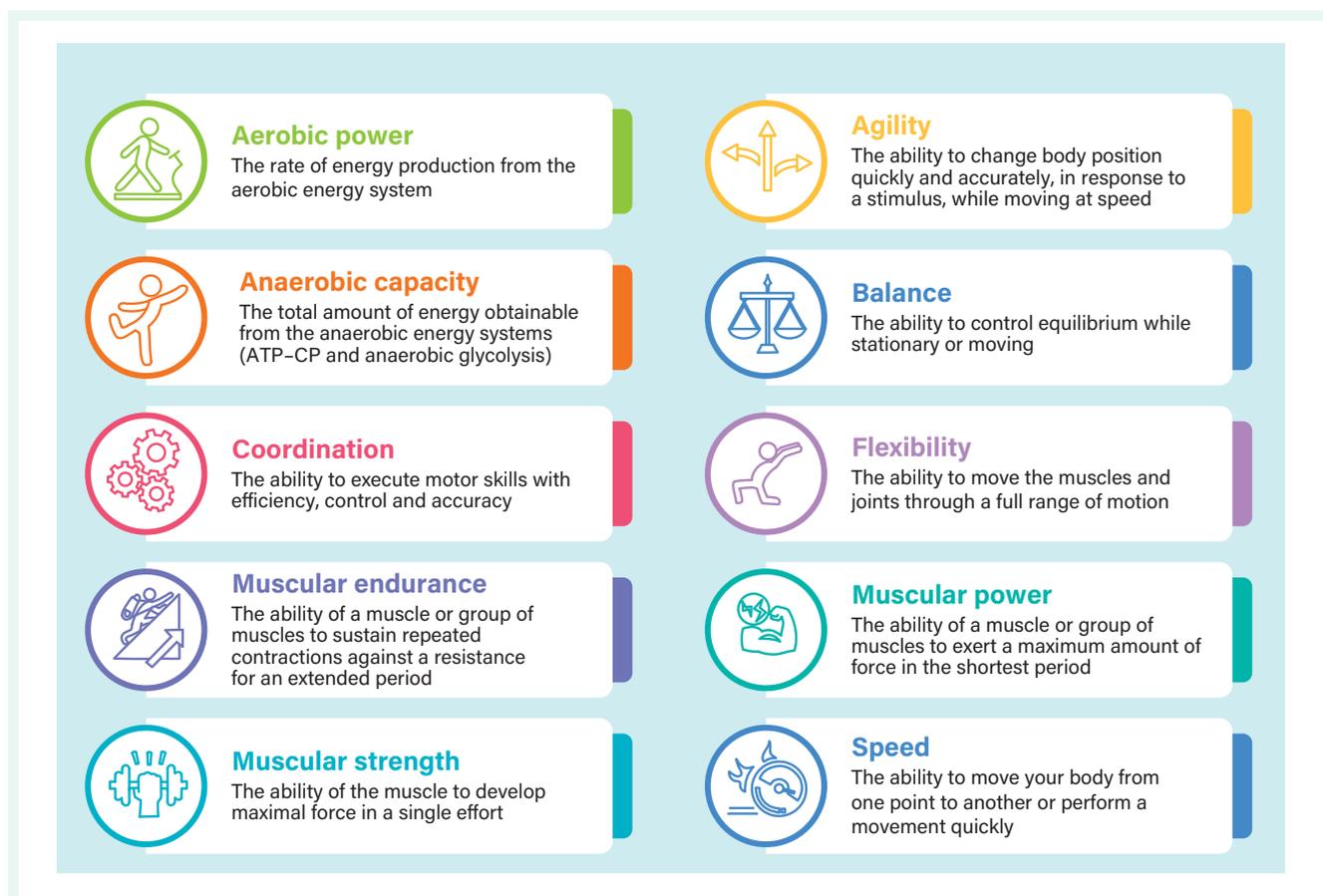
The inspirational story of Paralympian Lauren Parker

## LOOKING FORWARD

### Fitness components

#### Chapters 9, 10, 12, 13 and 15

The fitness requirements of each sport influence how an athlete trains. It is important to be able to identify the major fitness components needed for an activity (Chapter 9), assess the athlete's current level of fitness (Chapter 10) for each component and determine the aim or purpose of the training. This will then influence the selection of training methods (Chapter 13), the application of training principles (Chapter 12) and the chronic adaptations (Chapter 15) they are trying to achieve.



**FIGURE 8.04** Components of fitness



**Assessment**  
8.1 Check-in questions

## 8.1 CHECK-IN QUESTIONS

- 1 **Define** 'fitness' in your own words.
- 2 **Explain** why a component model of fitness is more suitable than a single definition of fitness.
- 3 Using suitable examples, **compare** two athletes you consider to be physically fit.

## 8.2 AEROBIC-BASED FITNESS COMPONENTS

In this module you will learn about:

- factors affecting fitness components required in physical activity, sport or exercise (aerobic power, muscular endurance, balance, coordination and flexibility) and learn to:
- analyse data to determine the major fitness components and factors that affect them used in a variety of sporting events and physical activities.

# Aerobic power

Aerobic power is the rate of energy production from the aerobic energy system.

Aerobic power depends on the capacity of the cardiovascular and respiratory systems to supply nutrients and oxygen to the muscles, and the ability of the muscles to use the oxygen for sustained exercise. Aerobic power is also known as aerobic fitness, aerobic capacity and cardiovascular or cardiorespiratory fitness, endurance or capacity.

The involvement of large muscle groups is a key characteristic of activities that require aerobic power. Activities such as swimming, running, cycling and cross-country skiing all involve aerobic power.



Long Visual Press/Universal Images Group/Getty Images

Tim de Waele/Velo/Getty Images

**FIGURE 8.05** Completing a half marathon or an event like the Tour Down Under requires a high level of aerobic power.

High levels of aerobic power, which have been linked to a larger fast excess post-exercise oxygen consumption (EPOC), lead to enhanced recovery after a bout of high-intensity intermittent exercise through faster replenishment of creatine phosphate (CP); and, through an active recovery, can increase the rate of removal of metabolic by-products.

## LOOKING BACK

### Active and passive recoveries

#### Chapters 5, 6, 7

You will recall that the type of recovery can influence the restoration of the energy system (Chapter 6) and that excess post-exercise oxygen consumption (EPOC) can assist in the restoration of CP (Chapters 5 and 7).

The best measure of aerobic power is maximal oxygen consumption ( $VO_2$  max).  $VO_2$  max is the maximum amount of oxygen that the body can take up, transport and utilise per minute. High aerobic power indicates increased capacity of the cardiovascular and cardiorespiratory systems, which allows individuals to transport and use more oxygen than those with a lower level of aerobic power.

It was initially thought that oxygen supply limited aerobic power, and others thought that the limiting factor was oxygen use. Further research has now shown that it is supply – oxygen delivery to the working muscle – that limits  $VO_2$  max (maximal aerobic power), not use – the available mitochondria and oxidative enzymes.

## DID YOU KNOW?

The highest recorded  $VO_2$  max was that of Oskar Svendsen, an 18-year-old Norwegian cyclist, who in 2012 recorded a  $VO_2$  max of 97.5 mL/kg/min.

## Factors affecting aerobic power

Aerobic power is affected by characteristics of the cardiovascular and respiratory systems, including:

- blood volume
- lung volumes
- alveoli surface area
- blood flow to working muscles
- size and number of mitochondria
- concentration of oxidative enzymes
- cardiac output (stroke volume × heart rate).

Increased levels of aerobic power are associated with:

- healthy lungs and respiratory muscles
- a stronger, more efficient heart muscle
- muscle tissue capable of using the oxygen delivered to it
- higher levels of **haemoglobin** in the blood (to carry the oxygen)
- proportion of Type I (slow-twitch) muscle fibres within the muscle
- healthy blood vessels (arteries, veins and capillaries) that are elastic and free from obstructions.

Training the aerobic energy system leads to improvement in aerobic power as a result of chronic adaptations of the cardiovascular and respiratory systems. We will look at chronic adaptations in Chapter 15.

### haemoglobin

An oxygen-binding structure found in red blood cells, used to carry oxygen from the lungs to the rest of the body

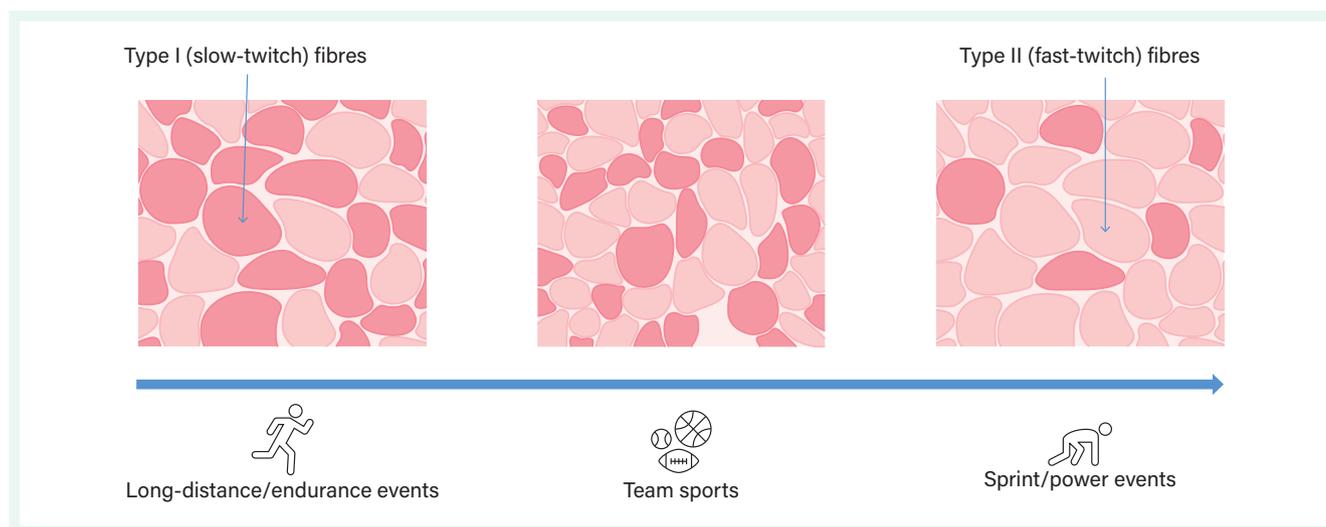


Video

In focus: Muscle fibre type

### Muscle fibre type

Type I (slow-twitch) muscle fibres generate energy through the aerobic energy system due to their high density of mitochondria, capillaries and myoglobin, which makes them very efficient at producing ATP aerobically. Therefore, the greater the percentage of Type I fibres within the muscle, the better the aerobic power of the athlete. Athletes such as long-distance runners and cyclists usually have a much higher proportion of Type I muscle fibres, resulting in high levels of aerobic power and muscular endurance. Type I fibres are preferentially recruited for endurance activities but, if the intensity, duration or fatigue increases, Type II (fast-twitch) fibres will be recruited to meet the demands of the activity.



**FIGURE 8.06** As the duration of the activity decreases, the proportion of Type I (slow-twitch) fibres decreases and that of Type II (fast-twitch) fibres increases.

## DID YOU KNOW?

An individual's fibre type composition is a good predictor of athletic performance. Got more Type I (slow-twitch) fibres? The chances are you will have greater success in endurance events. If you have a higher percentage of Type II (fast-twitch) fibres, then you are more likely to be suited to high-intensity, power events. Sports such as basketball, hockey and soccer, which are played over an extended time period, require sustained muscular contractions, with short bursts of high-intensity efforts. These activities utilise a more equal contribution from both Type I and Type II muscle fibres.



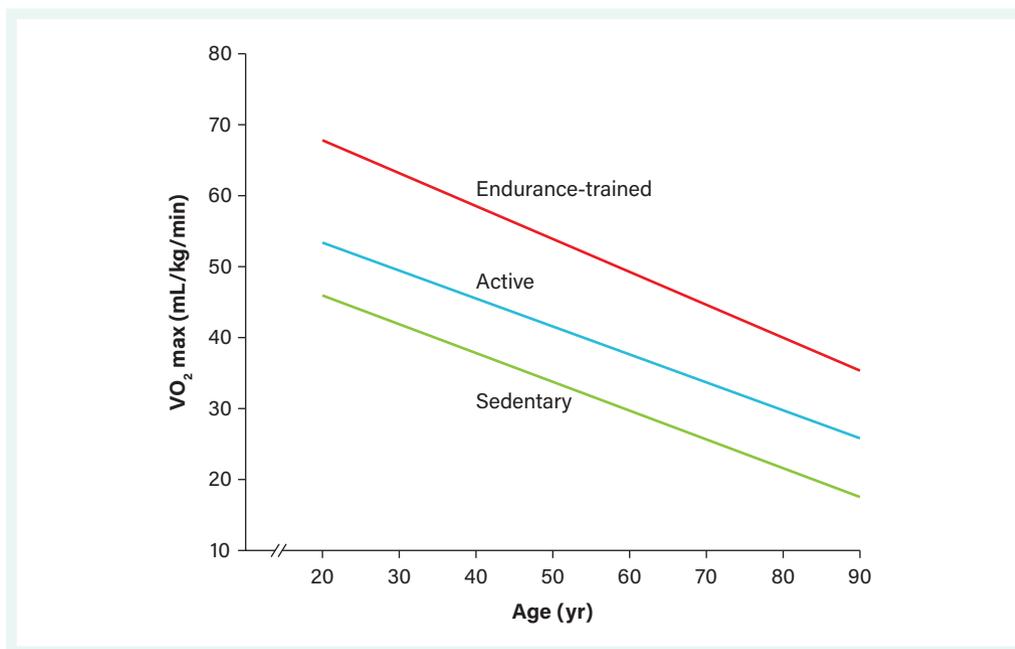
## ABOVE AND BEYOND THE STUDY DESIGN

Fatigability of Type I, Type IIa and Type IIb muscle fibres, page 359

### Age

Generally, aerobic power will decline with age, at a rate of approximately 10 per cent per decade, due to a decrease in how effectively the body utilises oxygen. A decrease in maximum heart rate reduces cardiac output and oxygen delivery to the muscles, resulting in a lower  $\text{VO}_2$  max.

$$\text{max HR} \cong 220 - \text{age}$$



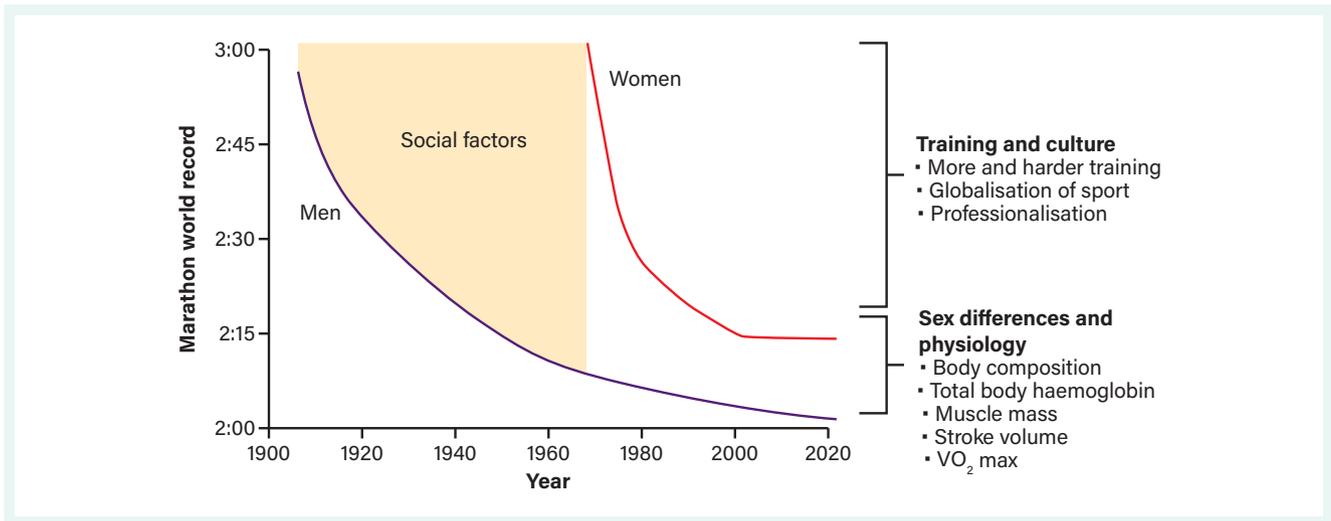
**FIGURE 8.07** The relationship between maximal oxygen consumption ( $\text{VO}_2$  max) and increasing age in three subject groups. Rates of decline in  $\text{VO}_2$  max with age were not different among the three populations.

Adapted from: Wilson, T.M. & Tanaka, H. (2000), 'Meta-analysis of the age-associated decline in maximal aerobic capacity in men: Relation to training status', in *American Journal of Physiology: Heart and Circulation Physiology*

## Sex

The differences that are seen in aerobic power between males and females can be attributed to physiological factors. Higher haemoglobin concentration and lean body mass in males, and smaller heart size and lower blood volume, which result in lower stroke volume and cardiac output, in females, mean that males will generally have higher levels of aerobic power than females.

It wasn't until 1984 that women were allowed to compete in the marathon at the Olympic Games. The graph below shows the steep improvement in race times until 2000, with the significant improvements attributed to sociocultural factors. The gap between men's and women's times has remained constant since 2000, and it is likely due to the physiological differences between the sexes.



**FIGURE 8.08** Marathon times for both men and women have decreased over time.

Source: Santisteban, K.J. et al. (2022), 'Sex differences in  $VO_2$  max and the impact on endurance-exercise performance', in *International Journal of Environmental Research and Public Health* 19(9): 4946. CC BY 4.0

In 2023, Tigist Assefa smashed the previous world record for women of 2 hours 14 minutes and 4 seconds, completing the Berlin marathon in 2 hours 11 minutes and 53 seconds (see Figure 8.09).



Reuters/Lisi Niesner

**FIGURE 8.09** Female marathon times continue to improve. What factors may be contributing to the faster times?

## WORKED EXAMPLE

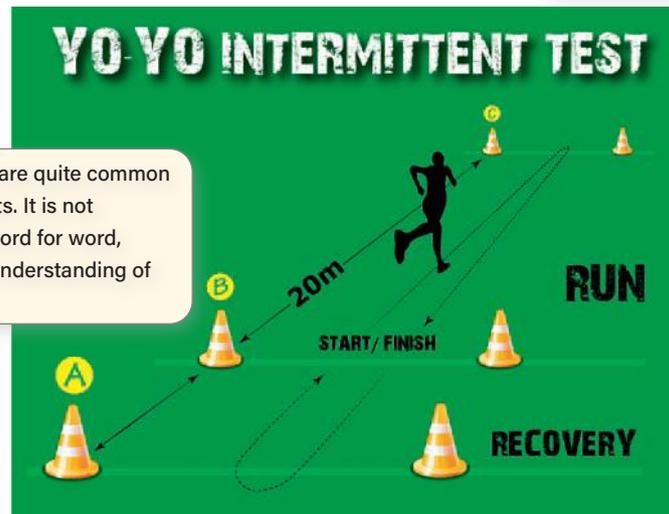
©VCAA Exam 2022, Section B, Q6 a

The handball players were also required to complete the Yo-Yo intermittent recovery test shown in the diagram below. This is a fitness test that involves **running** at increasing speeds between markers placed 20 metres apart and recovering in between runs. The test **continues** until the runner is exhausted.

The question stem provides evidence to help you determine the correct fitness component.

Aerobic power is associated with activities that involve large muscle groups ('running') for sustained exercise ('continues').

Questions that require a definition are quite common when looking at fitness components. It is not necessary to recall the definition word for word, but your answer needs to convey understanding of the term.



Source: R Wood, 'The Complete Guide to the Yo-Yo Test', 2018, <[www.theyoyotest.com](http://www.theyoyotest.com)>

Name and **define** the fitness component that is assessed in the Yo-Yo intermittent recovery test.

### Sample response

*Aerobic power – the rate of energy release from the aerobic system.*

## Muscular endurance

**Muscular endurance** is the ability of a muscle or group of muscles to perform repeated contractions against a resistance for an extended period of time or to hold an **isometric muscle action** for an extended period of time.

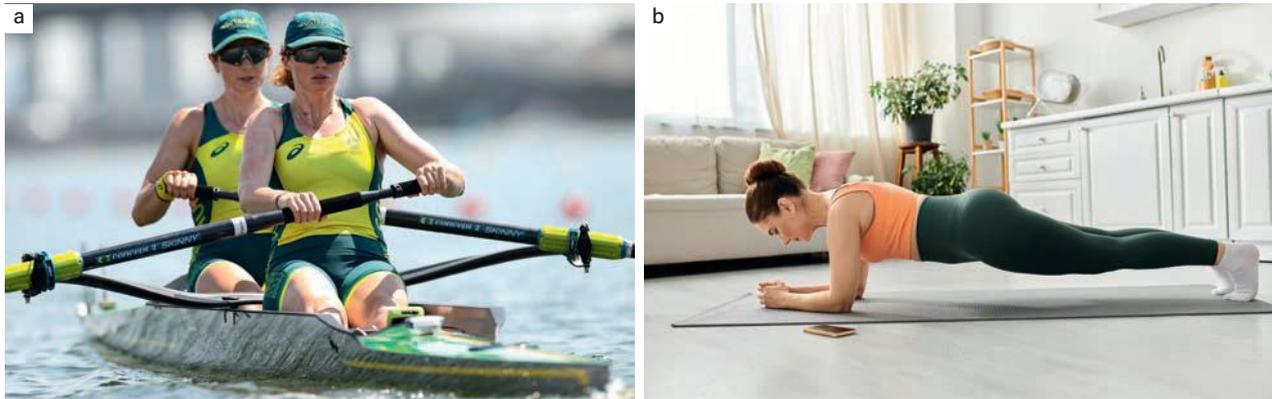
Physical activities such as running, swimming, rowing and cycling are typically associated with muscular endurance as they use the same muscle groups in a continuous and repetitive movement pattern for extended periods of time. Muscular endurance is important for performance in these types of activities so the athlete can sustain higher workloads before fatigue starts to impact performance.

### muscular endurance

The ability of a muscle, or a group of muscles, to sustain repeated contractions against a resistance for an extended period

### isometric muscle action

Muscle action where there is no change in muscle length as force is developed



**FIGURE 8.10** **a** Rowing requires muscular endurance in both the upper and lower body; **b** planking requires muscular endurance to hold the position for an extended period.



## COLLABORATIVE TASK

### Prac activity

#### 'Local' muscular endurance

Muscular endurance is often referred to as local muscular endurance, or LME. The term 'local' refers to the use of a particular muscle group.

Perform the following exercises and discuss with a partner which muscle group/s are being used. (Hint: where did you feel the 'burn'?)

Hold each position for 60–90 seconds.

#### METHOD

##### 1 Plank

Start in a push-up position.

Lower your body to rest on your elbows, maintaining a straight line from head to heels.

##### 2 Wall sit

Stand about 50 centimetres from a wall, leaning your back against it.

Bend your knees to form a 90-degree angle, as if you were sitting in a chair.

##### 3 Glute bridge

Lie on your back with your knees bent, arms by your sides.

Lift your pelvis upwards, keeping your tail bone tucked and your feet flat on the floor.

##### 4 Calf raise hold

Stand with your hands on your hips.

Rise up onto the balls of your feet, keeping your heels off the ground.



#### Weblink

'Bring Sally Up' challenge

## 🚩 SIGNPOST

For a fun and motivating activity to 'test' your muscular endurance, complete the 'Bring Sally Up' challenge. You can do push-ups, sit-ups, lunges or squats!

## Factors affecting muscular endurance

Factors that affect muscular endurance are:

- muscle fibre type
- fatigue
- age
- sex.

### Muscle fibre type

Muscular endurance is affected by the proportion of Type I (slow-twitch) fibres within the muscle. Muscle fibre type distribution is determined by both genetics and environmental factors (training, diet, coaching). Genetics is thought to account for 40–50 per cent of the variability in the proportion of Type I (slow-twitch) and Type II (fast-twitch) fibres. The proportions of Type I and Type II fibres within the muscle affect the muscle's function: the higher the percentage of Type I fibres, the greater the endurance capacity of the muscle. As is the case with aerobic power, the greater the proportion of Type I fibres within a muscle, the greater the capacity of the muscle to sustain repeated muscular contractions involved in activities that require muscular endurance.

- Type I (slow-twitch) fibres are used in submaximal, aerobic activities.
- Type IIa (fast-twitch) fibres are intermediate muscle fibres as they rely mainly on aerobic energy production while still contracting relatively fast.
- Type IIb (fast-twitch) fibres are used in high-intensity, anaerobic activities.

**TABLE 8.01** Characteristics of Type I (slow-twitch) and Type II (fast-twitch) muscle fibres

	Type I	Type II	
	Slow-twitch – slow oxidative	Type IIa (fast-twitch) – fast oxidative glycolytic	Type IIb (fast-twitch) – fast glycolytic
<b>Structural aspects</b>			
Fibre diameter	Small	Intermediate	Large
Mitochondrial density	High	Intermediate	Low
Capillary density	High	Intermediate	Low
Myoglobin content	High	Intermediate	Low
<b>Functional aspects</b>			
Twitch or contraction time	Slow	Fast	Fast
Relaxation time	Slow	Fast	Fast
Force production	Low	Intermediate	High
Fatigability	Low	Intermediate	High
<b>Metabolic aspects</b>			
PC stores	Low	High	High
Glycogen stores	Low	High	High
Triglyceride stores	High	Intermediate	Low
Myosin-ATPase activity	Low	High	High
Glycolytic enzyme activity	Low	High	High
Oxidative enzyme activity	High	Intermediate	Low

### Fatigue

Muscular endurance and muscular fatigue are opposite sides of the same coin:

- A muscle that has high endurance capacity takes longer to fatigue.
- A muscle that has low endurance capacity will fatigue quickly.

Muscle fibre type distribution is the main factor that contributes to local muscle fatigue. The aerobic nature of Type I fibres means that they produce enough energy to sustain continuous activities and resist fatigue. Therefore, the greater the distribution of Type I (slow-twitch) fibres in the muscle, the lower the levels of muscular fatigue and the higher the levels of endurance. Athletes with a greater proportion of slow-twitch fibres are likely to have a higher lactate inflection point (LIP) and are able to continue to work at higher intensities aerobically, delaying the fatigue associated with an accumulation of metabolic by-products. Muscular fatigue mechanisms including fuel depletion, accumulation of metabolic by-products and thermoregulation were covered in detail in Chapter 7.

## Age

Muscular endurance will generally increase in young adulthood, peaking between 18 and 24 years, and then, depending on physical activity levels and training, will remain stable before starting to decrease with advancing age. It is likely that the age-related decline in the cross-sectional area of the muscle fibres, reduced number of mitochondria in Type I (slow-twitch) fibres and the subsequent reduction in oxidative enzymes contribute to the overall decline in muscular endurance.

## Sex

Sex-related differences in muscular endurance between males and females have received very little attention, but the research that has been done shows that muscles in females are generally more fatigue-resistant, display less mechanical damage after exercise and recover faster than those in males. We still don't fully understand the mechanisms that account for the differences, but it is thought that they relate to differences in hormonal status. Performance in muscular endurance tests is often related to the ability of the body systems to provide the working muscle with the required oxygen. As males are able to supply larger amounts of oxygen and fuels to the muscles, this is likely to improve their performance in activities that require a high level of muscular endurance.

## Balance

**Balance** is the ability to control **equilibrium** while stationary or moving, and is important in almost all types of physical activity, sport or exercise. To maintain equilibrium, external forces must be counteracted with internal forces (muscular contractions). Balance is reflected in the ability to remain upright throughout the movement.

Balance is specific to the task being performed and is needed when the body is held stationary (static equilibrium) and when the body is moving (dynamic equilibrium).

### balance

The ability to control equilibrium while stationary or moving

### equilibrium

The state the body is in when all forces and torques are balanced

iStock.com/ebstock



Lukas Gojda/Shutterstock.com

**FIGURE 8.11** Balance is important to maintain correct body position: **a** while stationary; and **b** while moving.

Activities such as cycling, gymnastics and surfing require more effort to maintain body balance than walking or standing. It is a complex process for the body to continually adjust its position to maintain balance in all situations. Multiple body systems (the central nervous system, sensory system and peripheral nervous system as well as the musculoskeletal system) work together to respond to changes in the physical environment that may disrupt balance and adapt or adjust the movement pattern in order to maintain balance.



LUCA BETTINI/AFP/Getty Images

**FIGURE 8.12** Crashes in cycling events are often due to spectators getting too close to the riders, causing them to lose balance.

## LOOKING BACK

### Equilibrium, stability and balance

#### Chapter 3

In Chapter 3 we looked at external forces acting on the body, including gravity, friction and forces applied by moving objects. We also looked at the relationship between equilibrium, stability and balance and the factors that an athlete can manipulate to maintain balance.

Those factors are:

- size of the base of support
- position of the centre of gravity
- position of the line of gravity
- mass of the body
- friction between the body and the surface or surfaces contacted.

## DID YOU KNOW?

Goalkeepers in soccer have been found to have greater static and dynamic balance than other players, and midfielders were found to have better dynamic balance than both defenders and forwards (Mahmoudi et al, 2023).

## Factors affecting balance

Balance can be affected by a change in:

- location
- the environment that supports the body
- the position of one or more body parts.

Athletes may need to adjust to change in just one of these factors – for example, a cricketer walking in from the outfield as the bowler starts their run-up only changes location, and to maintain balance while walking is relatively easy.

When an activity involves two or more such changes, the athlete takes in information through the senses, formulates a response and adjusts their movement so that balance is maintained. This process continues throughout the activity, involving constant evaluation of the surroundings and the body's position in space to make adjustments and maintain balance.

For example, to maintain dynamic balance while riding a skateboard, the rider must adapt to changes in location (as they skate from one place to another), changes in environment (if the surface they are skating on changes) and changes in the position of body parts (as they use their foot to propel the board).



Tuned in by Westend61/Shutterstock.com

**FIGURE 8.13** Skateboarding requires a high level of dynamic balance.

### Age

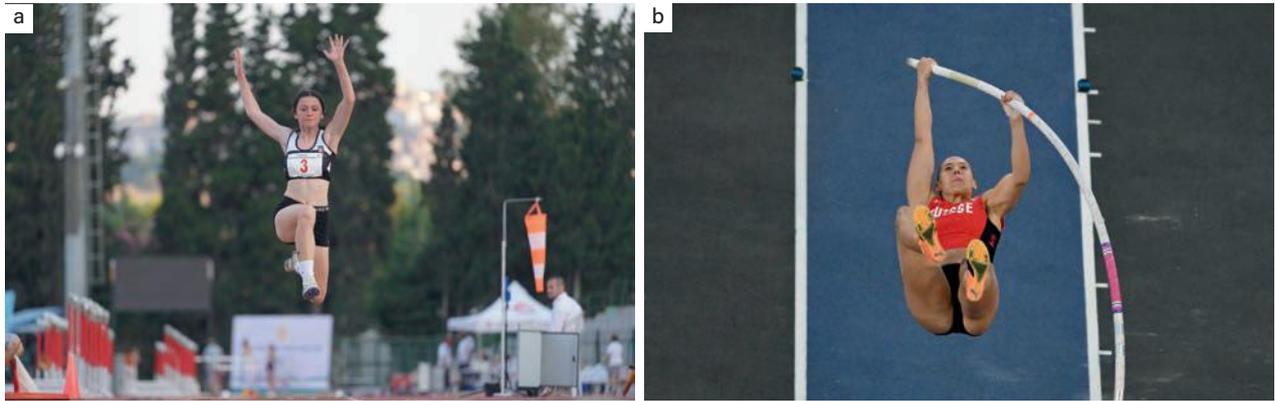
Balance typically decreases with age (from about 50 years of age) due to cognitive decline and decreased muscle mass, which leads to a decrease in strength, power and endurance. However, with training, balance can be maintained or improved. A focus on flexibility, strength and mobility (walking, stair climbing, cycling) can lead to improved balance.

## Coordination

### coordination

The ability to use the body's senses to execute motor skills smoothly and accurately

**Coordination** is the ability to use the body's senses to manipulate body parts so as to execute motor skills smoothly and accurately. A movement pattern may require the coordination of body parts to perform complex movement sequences (e.g. triple jump) or it may involve coordination of an external implement and various body parts (e.g. pole vault) – see Figure 8.14.



**FIGURE 8.14** Triple jump and pole vault require a high level of coordination.

Coordination is often referred to as hand–eye, head–eye or foot–eye coordination. This simply refers to the body parts involved in the motor skill. In each situation, information is collected through the senses (visual) and then the information is sent to the relevant body part to execute the skill. A header in soccer requires a high level of head–eye coordination; hitting a tennis ball requires hand–eye coordination; and kicking a football requires foot–eye coordination.

A key characteristic of highly skilled athletes is smooth, well-timed movements. Elite athletes often have excellent coordination and can execute a skill with less effort, requiring less energy to complete a skill, and more efficient transfer of energy between joints (so that, for example, they can throw, hit or kick a ball further).

## Factors affecting coordination

The complexity of the task and the level of experience of the person performing it may affect coordination. Coordination improves when a new skill is practised. The first time you do something new, it can feel awkward. For example, imagine that a golfer who has been using the same grip for years decides to get some coaching and the coach suggests changing their grip. The first time the golfer swings with the new grip, it feels different and awkward. The golfer may feel as if it takes more effort to swing with this grip, and the movement may be jerky and feel unnatural. With practice, however, learning occurs, and over time the movement will become smooth and coordinated.

### COLLABORATIVE TASK

#### Prac activity

#### Hand–eye coordination circuit

##### AIM

To practise hand–eye coordination

##### EQUIPMENT

- a variety of lightweight and small balls
- balloons
- skipping ropes





### METHOD

1 Set up a circuit with a selection of the following drills:

- balloon tossing
- juggling
- small ball tossing
- jump rope drills
- target practice
- ball toss from different positions
- balloon hockey
- dribbling (small ball)
- wall ball bounce.

2 Rotate through each activity (3–5 minutes per station).

To see demonstrations of each of these drills, watch the video *Hand/Eye Coordination Drills* on the GMB Fitness channel on YouTube.

### OBSERVATIONS

How difficult were the tasks? Why were some tasks more difficult than others?

### DISCUSSION

What are the benefits of improving hand–eye coordination for physical activity, sport and exercise?



**Weblink**

Hand/Eye Coordination Drills

### flexibility

The ability to move the muscles and joints through a full range of motion

### static flexibility

The ability to reach and hold a point in a joint's range of motion

### dynamic flexibility

The ability to move a joint quickly through its range of motion with little resistance

## Flexibility

**Flexibility** is the capacity of a joint to move through its full range of motion. Flexibility reflects the ability of the muscles and connective tissues to stretch. It is specific to the joint, and joint flexibility refers to the range of motion in the movements in which the joint should move. For example, flexibility of a hinge joint (elbow or knee) is specifically related to flexion and extension, and how easily these movements can be performed. This means that having good flexibility in one joint does not mean there will be good flexibility in all joints of the body.

There are two types of flexibility:

- static
- dynamic.

**Static flexibility** refers to a joint's range of motion under stationary conditions – the ability to reach and hold a point in a joint's range of motion. Static flexibility is important for good dynamic flexibility, but having high levels of static flexibility does not automatically mean you will have high levels of dynamic flexibility.

**Dynamic flexibility** is the ability to move a joint quickly through its range of motion with little resistance. A person with good dynamic flexibility can move the joint through its full range of motion quickly and easily.

Athletes need to train for both types of flexibility, depending on the requirements of their sport. Hurdlers, for example, need good dynamic flexibility to be able to clear the hurdles while moving quickly; and sepak takraw players require high levels of dynamic flexibility just to serve the ball (see Figure 8.15).



YE AUNG THU/AFP/Getty Images

**FIGURE 8.15** How does dynamic flexibility improve performance in sports like sepak takraw?

## Factors affecting flexibility

Flexibility and the range of motion of a joint is affected by:

- joint type and structure
- soft-tissue (muscle, connective tissue, skin) structures
- body and muscle temperature
- age
- sex.

## Joint type and structure

Joint flexibility is determined in part by the type of joint and the range of motion in the planes of movement in which the joint is designed to move. Different joints allow different movements, and the flexibility of the joint is specific to the body part moving through the full range of motion of that movement.

**TABLE 8.02** Movement allowed at different types of joint

Joint type	Example of joint	Movement allowed at the joint
Ball and socket	Shoulder Hip	<b>Flexion, extension, adduction, abduction</b> , internal and external <b>rotation</b>
Ellipsoidal (condyloid)	Wrist	Flexion, extension, adduction, abduction, <b>circumduction</b>
Gliding	Ankle	Sliding
Hinge	Knee Elbow	Flexion, extension
Pivot	Neck	Rotation
Saddle	Thumb	Flexion, extension, adduction, abduction, circumduction

While flexibility can be increased through training (see Chapter 13), the structure of the joint cannot be changed. To increase flexibility, the changes must come from an increase in muscle and connective tissue lengths.

---

### flexion

Movement that decreases the angle of the joint

---

### extension

Movement that increases the angle of the joint

---

### adduction

Bringing a body part towards the midline of the body

---

### abduction

Moving a body part away from the midline of the body

---

### rotation

Moving a body part inward or outward around its longitudinal axis

---

### circumduction

A combination of flexion, extension, adduction and abduction, in which the end of the limb being circumducted draws a circle



## COLLABORATIVE TASK

### Prac activity

#### Effect of muscle length on flexibility

##### AIM

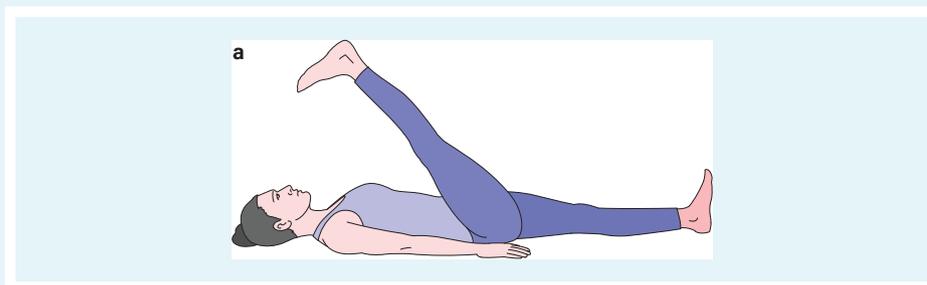
To investigate the range of motion of the hip joint

##### EQUIPMENT

None

##### METHOD

- 1 Lie on your back on the floor.
- 2 Flex your right hip while keeping the leg straight, as shown in illustration **a**.



- 3 Flex (bend) your right knee.
- 4 Flex your right hip, as shown in illustration **b**.



##### OBSERVATIONS

Which position allowed greater range of motion of the hip?

Are there other examples where bending or flexing the knee increases the range of motion of a different joint? (Hint: think of stretches that can be performed with single or double leg.)

##### DISCUSSION

- 1 How is the length of the hamstring muscle a limiting factor in hip flexion in the first position?
- 2 How did flexing your knee affect the range of motion of the hip joint?

Adapted from: McGinnin, P.M. (2013), *Biomechanics of Sport and Exercise*

## Soft-tissue structures

The same factors that provide stability within a joint also limit the range of motion of the joint. Specifically, soft-tissue structures – including muscle, connective tissue within the muscle, **tendons**, **ligaments** and skin – provide some resistance to movement. It is necessary to restrict excessive movement of the joint to benefit and protect the function of the joint. Injuries are often caused by hyperextension, which occurs when a joint is moved outside its normal range of motion.

Muscle is elastic in nature – that is, it will return to its original length after being stretched. Stretching lengthens connective tissues and increases flexibility. Increasing the length of the muscles and tendons associated with a joint increases the range of motion, and therefore the flexibility, of the joint. Skin has little effect on the flexibility of a joint under normal conditions.

### tendons

Connective tissues that attach muscle to bone

### ligaments

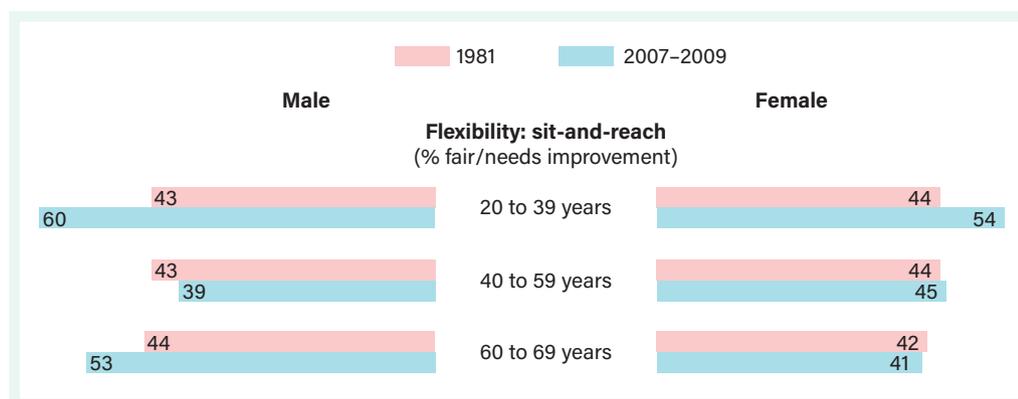
Connective tissues that connect bone to bone

## Body and muscle temperature

Increasing body and muscle temperature increases the elasticity, and decreases the stiffness, of the muscle and the joint. Increasing muscle temperature improves both the ability to stretch the muscles and the flexibility of the joint.

## Age

Flexibility is initially high in children. Hormonal changes that occur during puberty, however, often lead to rapid growth, causing the bones to grow at a much faster rate than the muscles and connective tissue. The components of the musculoskeletal system catch up to each other in early adulthood, and flexibility peaks in a person's mid- to late 20s. In a study that tracked Canadian adults from 1981 to 2009, flexibility was shown to decrease significantly for both males and females in the 20–39 years age group.

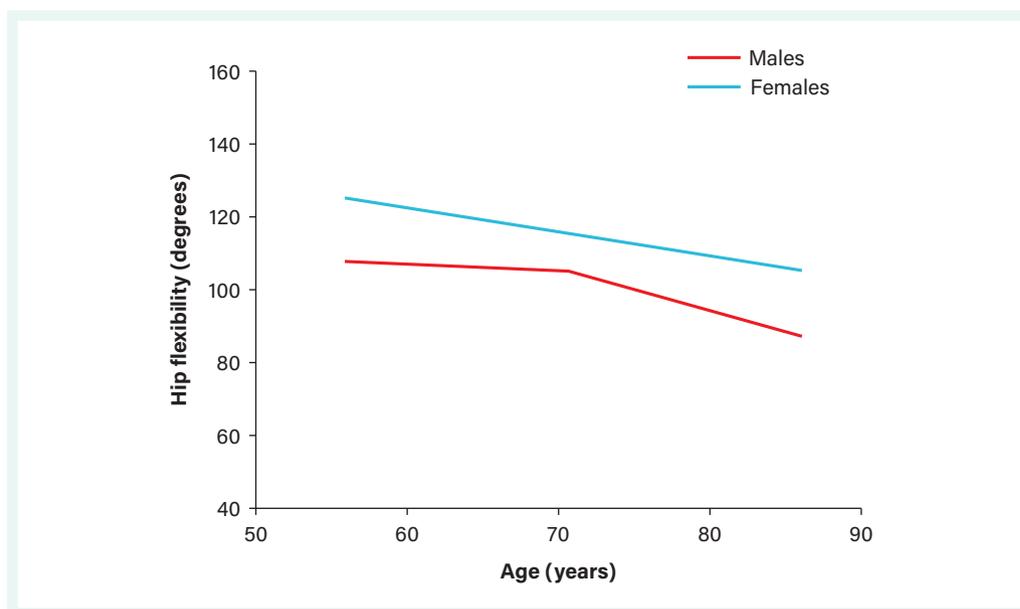


**FIGURE 8.16** What factors may have contributed to a decrease in flexibility for 20- to 39-year-olds from 1981 to 2009?

Source: 'Fitness of Canadian adults: Results from the 2007–2009 Canadian Health Measures Survey (2010)'

Flexibility begins to decline in this age group and will continue to decrease at a rate of approximately 0.5–1 per cent per year, depending on the joint that is measured and the training status of the individual.

This loss of flexibility with age is thought to be due to the loss of elasticity in the connective tissue, but this decline may be a result of decreasing activity levels, and not purely the result of aging.



**FIGURE 8.17** Flexibility in both males and females declines with age.

Adapted from: Stathokostas, L. et al. (2013), 'Flexibility of older adults aged 55–86 years and the influence of physical activity', in *Journal of Aging Research*

## Sex

Females have consistently been shown to outperform males in the sit-and-reach test for flexibility, which has led to the misconception that females are more flexible than males. As flexibility is joint-specific, a high level of lower back and hamstring flexibility – as measured by the sit-and-reach test – does not represent overall flexibility. Studies investigating flexibility of other joints show little or no significant difference between the sexes. Any differences in flexibility that are found between males and females are likely to be linked to skeletal differences (such as women's wider hips) and hormonal influences.

## LOOKING FORWARD

### Assessment of fitness

#### Chapter 10

In Chapter 10 we will look at assessment of fitness and the test protocols for a range of fitness tests for each of the fitness components covered in this chapter, including the sit-and-reach test for flexibility.



#### Assessment

8.2 Check-in questions

#### Command term

##### define

Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity

## 8.2 CHECK-IN QUESTIONS

- The ability of a muscle to repeatedly contract is a characteristic of which fitness component?
  - muscular power
  - muscular strength
  - anaerobic capacity
  - muscular endurance
- Define** 'balance' and provide three examples of sports that require a high degree of balance.

## 3 ©VCAA Exam 2010, Section B, Q11

From the photograph below, **identify** two [aerobic-based] fitness components required to perform this action. **Explain** why they are important in this manoeuvre.



- 4 Muscle biopsies were taken from the quadriceps muscle of four athletes. The results are shown in the table below.

Athlete	Type II muscle fibre concentration	Mitochondria density	Oxidative enzyme activity
A	Low	High	High
B	Low	Moderate	High
C	Moderate	High	Moderate
D	High	Low	Low

From the data presented in the table, which athlete would be most suited to long-distance running? Using the data, **justify** your answer.

- 5 With reference to a sport-specific skill of your choice, and referring also to coordination, **discuss** the difference between a skilled and unskilled performer.
- 6 Evidence shows that females are more flexible than males. To what extent do you think this is physiological rather than societal?

**Command terms**
**identify**

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

**discuss**

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

## 8.3 ANAEROBIC-BASED FITNESS COMPONENTS

In this module you will learn about:

- factors affecting fitness components required in physical activity, sport or exercise (anaerobic capacity, agility, muscular strength and power and speed) and learn to:
- analyse data to determine the major fitness components and factors that affect them used in a variety of sporting events and physical activities.

## Anaerobic capacity

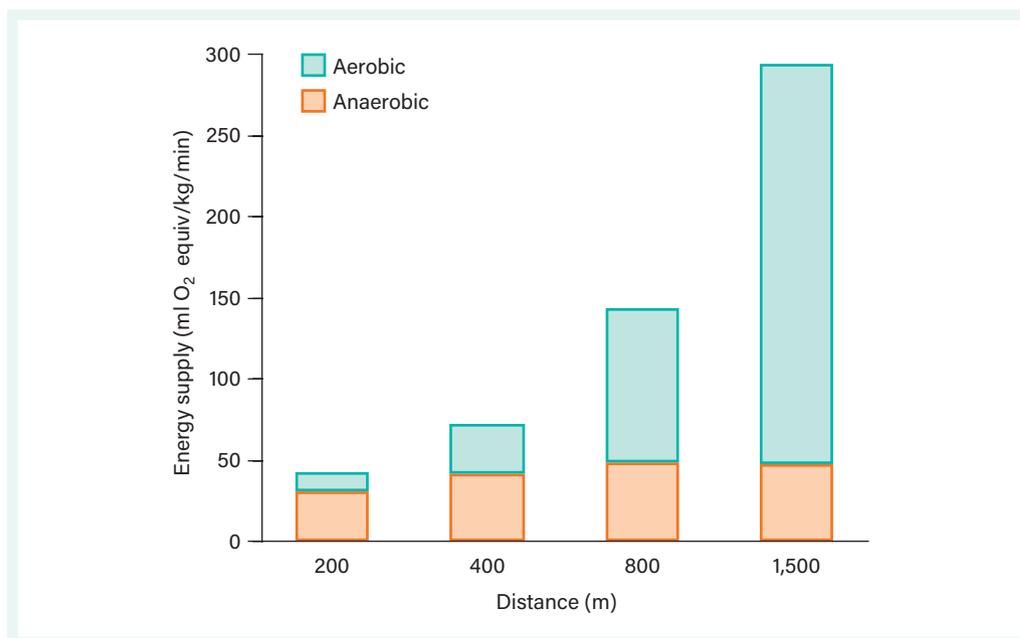
Anaerobic capacity is the maximum amount of energy (ATP) obtainable from the anaerobic energy systems (ATP–CP and anaerobic glycolysis) and refers to the total amount of work that can be done by the anaerobic systems. The ‘work’ the systems are doing is producing ATP, and the rate at which the system can do this is referred to as power.

**TABLE 8.03** Power and capacity of the three energy systems

Energy system		Maximal power (kcal/min)	Maximal capacity (total kcal available)
Anaerobic systems	ATP–CP	36	11.1
	Anaerobic glycolysis	16	15
Aerobic system (glycolytic)		10	2,000

Source: Brooks, G. et al. (2005), *Exercise Physiology: Human bioenergetics and its application*, McGraw-Hill

The capacity of the anaerobic systems is finite, which means that they can only supply a limited amount of energy. Figure 8.18 shows that, because of the finite capacity of the anaerobic systems, the anaerobic contribution to the overall energy supply is the same for each of the events shown (the 200, 400, 800 and 1,500 metres). As the distance of the race increases, the contribution from the aerobic system increases to meet the energy demands of the activity.



**FIGURE 8.18** The contribution to the total energy supply from the anaerobic systems remains relatively constant across all four events because the capacity of the anaerobic systems is finite.

Source: Gastin, P. (2001), ‘Energy system interaction and relative contribution during maximal exercise’, in *Sports Medicine*

### anaerobic capacity

The total amount of energy available via the ATP–CP and anaerobic glycolysis systems

In summary, the ATP–CP and anaerobic glycolysis systems have limited capacity but high power output. This means that the systems can supply energy very quickly for short periods. A high **anaerobic capacity** benefits performance in activities that are high in intensity and short in duration.

## Factors affecting anaerobic capacity

Factors that affect anaerobic capacity are

- muscle fibre type
- muscle mass
- age
- sex.

### Muscle fibre type

As discussed earlier (page 333), the distribution of Type I and Type II muscle fibres is, in part, genetically determined. Type II (fast-twitch) muscle fibres are more suited to high-intensity, anaerobic activities due to their faster contraction time, higher force production, greater CP and glycogen stores and higher glycolytic enzyme activity (see Table 8.01 on page 333).

Recruitment of Type II (fast-twitch) fibres is associated with increased lactate formation. As blood lactate levels increase, athletes who have a greater capacity to effectively buffer and neutralise the acidity associated with high levels of lactate are able to continue working at a higher rate for longer periods.

### DID YOU KNOW?

Lactate tolerance is related to the athlete's ability to continue working while withstanding high levels of lactate in the blood. Increased levels of lactate cause the blood to become more acidic, which can cause discomfort and have a negative impact on performance. Lactate tolerance is important in sports that involve high-intensity efforts and, while training can improve the body's ability to clear lactate at higher intensities (increased LIP), those athletes who can push through the physical discomfort caused by lactate build-up improve their lactate tolerance.

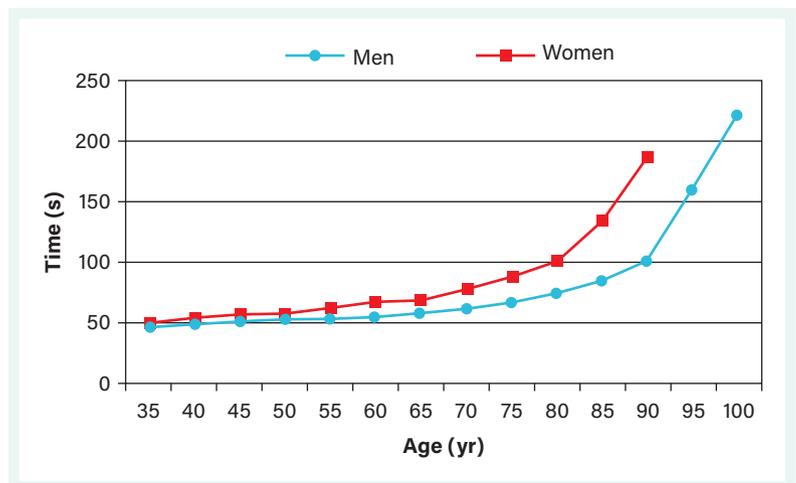
### atrophy

A reduction in the cross-sectional area of muscle or muscle fibres; in particular, a reduction in the cross-sectional area of muscle or muscle fibres

### Age

Anaerobic capacity decreases with age by approximately 7–14 per cent per decade after the age of 30, with a rapid rate of decline after 70 years of age. The reasons for the decline are mostly due to the physiological changes that occur with getting older. The decrease in anaerobic work capacity impacts on performance, and this can be seen in the increased race times for the 400 metres track running event for masters athletes aged 35–100 (see Figure 8.19).

Decreased muscle mass – specifically, Type II muscle fibre **atrophy** – a decreased rate of force development and changes in enzyme activity have all been linked to the decrease in anaerobic capacity with age.



**FIGURE 8.19** World record times for the 400 metres track running event increase with age for both men and women.

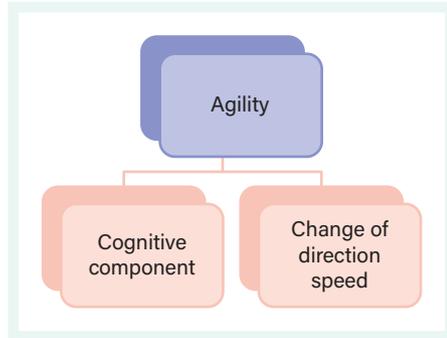
Reaburn, P. & Dascombe, B. (2009), 'Anaerobic performance in masters athletes', in *Eur Rev Aging Phys Act* 6, pp. 39–53. CC BY 2.0.

## Sex

Anaerobic capacity is approximately 20 per cent higher in males than in females. This is thought to be due to greater total muscle mass (more storage sites from CP), increased strength, a greater proportion of Type II (fast-twitch) muscle fibres and an increased capacity of the glycolytic enzymes in male muscle.

### agility

The ability to perform a rapid, whole-body movement with change in velocity or direction in response to a stimulus



**FIGURE 8.20** Agility is the combination of a response to a stimulus (cognitive component) and a rapid change in velocity or direction.

## Agility

**Agility** is the ability to change body position quickly and accurately, in response to a stimulus, while moving at speed. This contemporary understanding – that agility must involve a cognitive aspect and a change of direction speed – has predicated the rise of testing for change of direction speed (CODS). Agility is important in many team sports where players must respond to a stimulus (movement of the ball or an opponent), make a decision (cognitive component) and adjust their movement direction and accelerate or decelerate quickly (change of direction speed) to evade an opponent, or to intercept a ball or player.

In summary, agility involves:

- whole-body movement
- considerable uncertainty, in either space or time
- open skills only
- a physical component and a cognitive component, such as recognition of a stimulus, a reaction or a physical response.



**FIGURE 8.21** Agility is important in evading opponents in invasion games such as Australian Rules football.

## Factors affecting agility

There is limited understanding of the factors that affect agility, but it appears that cognitive and perceptual factors (visual processing, timing, reaction time, perception and anticipation) have the greatest impact on performance (Paul et al., 2016). Physical factors that have been shown to affect agility include strength and power, although the importance of strength may be reduced when a cognitive component is included.

# Muscular strength

**Muscular strength** is the ability of a muscle or muscle group to develop peak force in a single effort. Because muscular strength is specific to the muscle group, type of muscle action, speed of contraction and joint angle, it is not practical or useful to describe an individual's overall muscular strength. However, greater muscular strength has been shown to contribute positively to overall performance as it will enhance the athlete's ability to perform general skills such as jumping, sprinting and change of direction tasks (Suchomel et al., 2018). Muscular strength also contributes to superior performances in sport-specific tasks – for example:

- a gymnast gripping the rings when performing a routine
- a basketball player holding position to defend space
- a dancer or figure-skater performing a lift.

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## muscular strength

The ability of a muscle to develop peak force in a single effort

---

## isoinertial

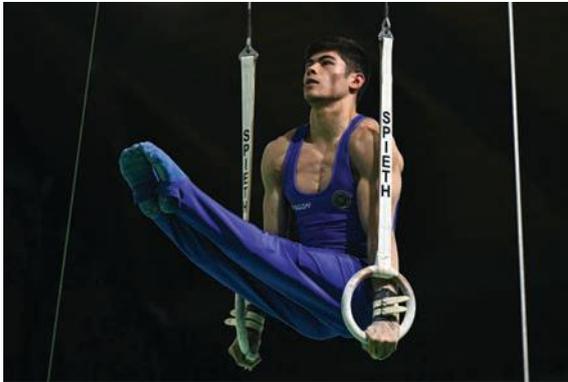
A muscle action in which muscle length changes throughout the movement

---

## eccentric

A muscle action in which a muscle lengthens as force is developed

GABRIEL BOUYS/AFP/Getty Images



iStock.com/simonkr



StockphotoVideo/Shutterstock.com

**FIGURE 8.22** All three of the tasks pictured require muscular strength.

## Muscle actions

The type of action the muscle performs impacts on the amount of force that can be developed. When a muscle contracts, tension is developed as the muscle shortens, lengthens or stays the same length. **Isoinertial eccentric** muscle actions produce the greatest force, followed by **isometric** (static) muscle actions and then **concentric** muscle actions.

---

## isometric

A muscle action in which muscle length remains constant as force is developed; a static contraction, typically used to stabilise a joint

---

## concentric

A muscle action in which a muscle shortens as force is developed

**isokinetic**

A muscle action in which a muscle lengthens or shortens at maximal tension and constant velocity over the full range of motion; the speed of the contraction is controlled

**TABLE 8.04** Summary of the characteristics of the three types of muscle actions

Muscle action	Characteristics	Example
Isometric	<ul style="list-style-type: none"> <li>No change in muscle length throughout the movement</li> </ul>	Gripping sports equipment (bats, clubs, racquets etc.)
<b>Isokinetic</b>	<ul style="list-style-type: none"> <li>Muscle lengthens or shortens at maximal tension and constant velocity over the full range of motion</li> </ul>	Hydraulic resistance machines (see Figure 8.23)
Isoinertial <ul style="list-style-type: none"> <li>concentric</li> <li>eccentric</li> </ul>	Most common muscle actions <ul style="list-style-type: none"> <li>Tension developed as muscle shortens</li> <li>Tension developed as muscle lengthens</li> </ul>	Biceps curls, squats, kicking a ball, tennis serve



antoniodiaz/Shutterstock.com

**FIGURE 8.23** Hydraulic machines allow the muscles to develop strength throughout the full range of movement.

**LEARNING HACK**

The origins of words can help us to remember the types of muscle actions. From the Latin or Ancient Greek:

- iso = equal or the same
- metric = length
- inertial = resistance
- kinetic = motion.

Therefore, muscle actions that are:

- isometric (same length) = muscle length does not change throughout the movement
- isoinertial (same resistance) = resistance is constant throughout the movement
- isokinetic (same motion) = speed of the movement is the same throughout the action.

**LOOKING FORWARD**

**Muscle actions**

**Chapter 13**

The force generated in a muscle is dependent on the load placed on the muscle and the type of action being performed. In Chapter 13 we will look at different types of muscle action that are used to ensure the movement is specific to requirements of the sport when training to improve strength, power and endurance.

## Factors affecting muscular strength

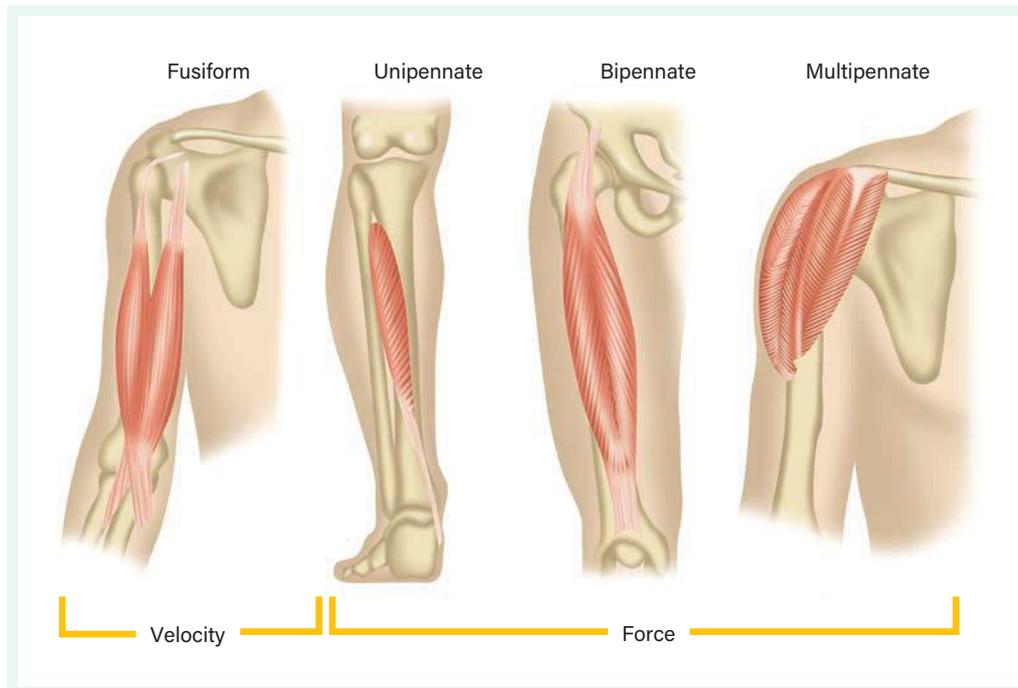
The amount of strength that can be generated in an individual muscle or muscle group is dependent on:

- muscle size, fibre type and arrangement
- joint angle and velocity of movement
- age
- sex.

### Muscle size, fibre type and arrangement

The maximal force that can be generated in a muscle is directly related to the cross-sectional area of the muscle: the greater the cross-sectional area of the muscle, the greater the strength.

The arrangement of the muscle fibres also affects the force that can be generated. Muscles designed for strength have fibre arrangements that maximise the cross-sectional area of the muscle. As illustrated in Figure 8.24, unipennate, bipennate and multipennate fibre arrangements are all designed for strong, forceful contractions. The fibres in pennate arrangements lie at an angle to the long axis of the muscle. Muscles designed for speed of contraction have fibres arranged in a fusiform pattern, where the fibres run parallel to the long axis of the muscle.



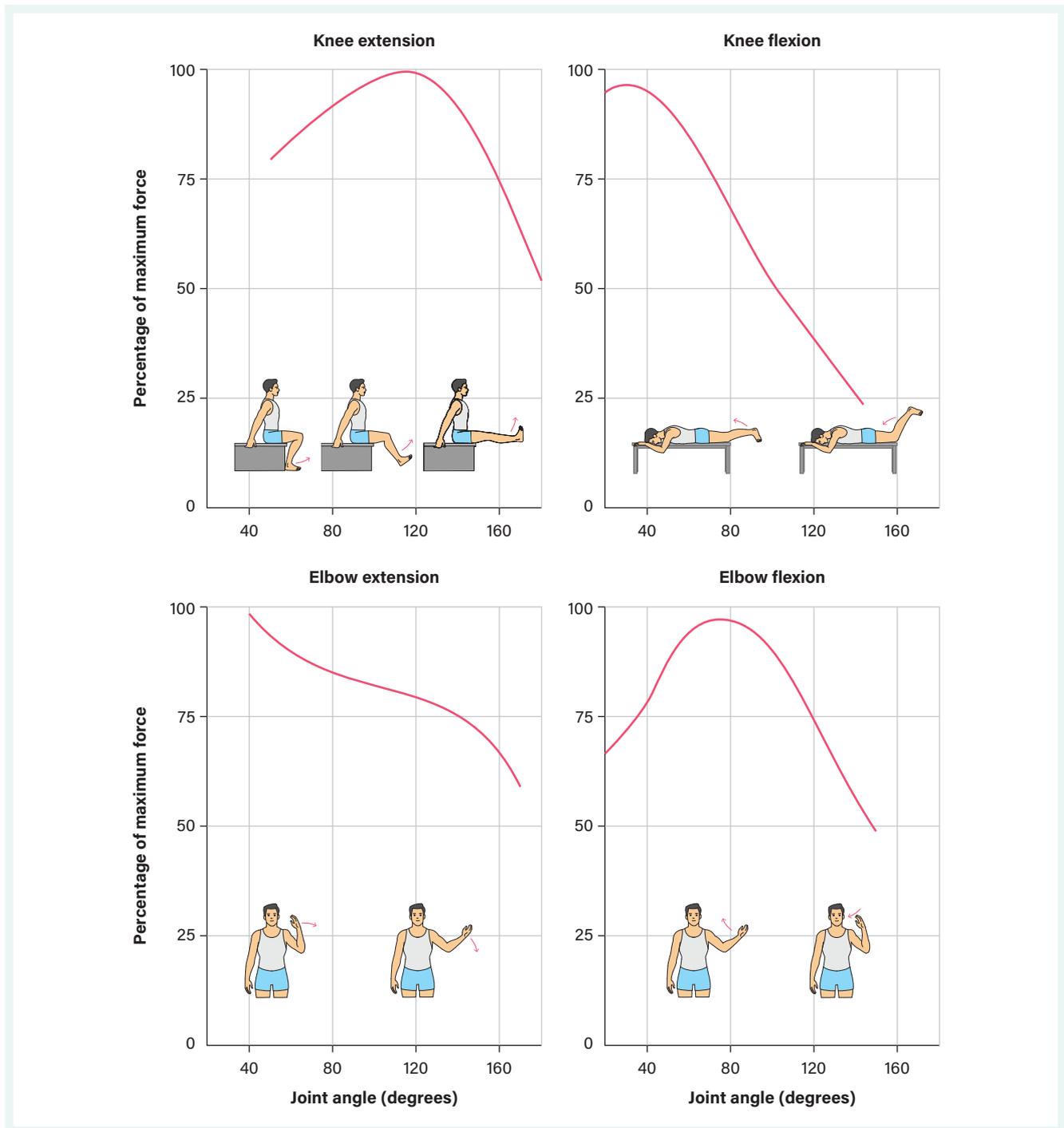
**FIGURE 8.24** Fibre arrangements that maximise the cross-sectional area of the muscle are more suitable for generating force.

Type II (fast-twitch) muscle fibres have characteristics that enable them to generate stronger and faster contractions than Type I (slow-twitch) fibres. Type II fibres have a greater cross-sectional area, faster twitch (contraction) time and higher force production capabilities than slow-twitch fibres (see Table 8.01 on page 333), making them more suited to activities that are high in intensity and require more force. As a determinant of muscular strength, the percentage of Type II fibres in the muscle has been shown to predict one repetition maximum (1RM). Current research, however, suggests that the proportion of Type II fibres is more important for determining strength in elite athletes than in the general population (Kuschel et al., 2022).

### Joint angle and velocity of movement

The capacity of a muscle to generate force is related to the joint angle. When the body part is moved through the full range of motion, the amount of force that can be developed will vary as the joint angle changes and the muscles lengths and shortens. As the joint moves through its full range of motion, different amounts of force are generated at different angles, as shown in Figure 8.25.

Maximal force is developed in the muscle at the optimal length (the length that allows maximum overlap of the thick myosin filaments and thin actin filaments within the muscle).



**FIGURE 8.25** The force generated in the muscle varies with the joint angle.

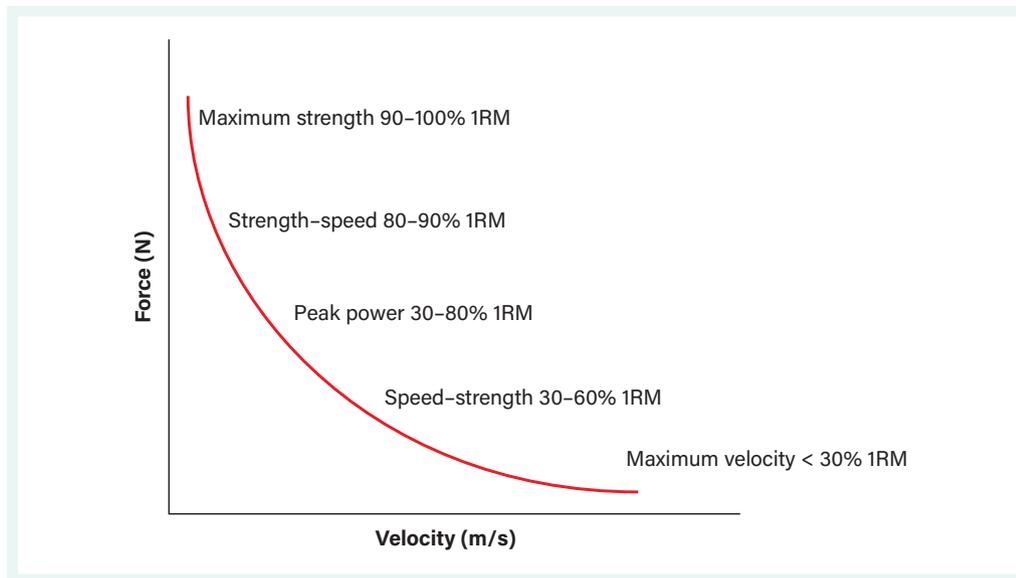
Source: McArdle, W.D. et al. (2015), *Exercise Physiology: Nutrition energy and human performance*

There is an inverse relationship between force and the velocity of the movement. What that means is that the force generated in the muscle:

- decreases as the velocity of the movement increases
- increases as the velocity of movement decreases.

Consider the strength needed to lift a heavy barbell compared to lifting a light dumbbell. The movement to lift the barbell would be much slower than the movement to lift the dumbbell. There is a trade-off between the strength required and how quickly the movement can be executed.

The force vs velocity curve in Figure 8.26 clearly shows this relationship.



**FIGURE 8.26** For movements that require strength, the movement velocity is relatively slow.

## Age

Muscular strength peaks in adults at about 25–30 years. It then decreases in both males and females at a rate of approximately 3–8 per cent per decade until the age of 60, and then more rapidly thereafter.

The decline in strength is due to:

- decreased muscle mass
- loss of contractile properties of the muscle
- reduced activation of motor units.

Muscle is trainable at any age, and the loss of muscle mass is largely due to adults becoming less active as they age. When a muscle is not used regularly, it will atrophy, and the decrease in muscle mass results in a decrease in strength.



Elena Stroud/Shutterstock.com

**FIGURE 8.27** Muscle can be trained at any age.

## CASE STUDY

## REVERSING THE DECLINE

## IT'S NEVER TOO LATE TO LIFT: OLDER PEOPLE CAN STILL BUILD MUSCLE MASS

BY GRETCHEN REYNOLDS

Contrary to popular wisdom among many gym-goers and even some scientists, healthy people in their 60s, 70s and beyond can safely start lifting weights and rapidly build substantial muscle mass, strength and mobility.



Experts say a loss of physical function is what defines frailty.

A new study of resistance exercise and the elderly found that even people in their 80s and 90s – who hadn't weight trained before – showed significant gains after starting a supervised program of lifting weights three times a week.

'It shows that healthy older people can certainly respond to resistance training, that their muscles are still plastic,' says Tommy Lundberg, an exercise researcher at the Karolinska Institute in Sweden, who was not involved in the study.

Lundberg ... says the research shows it's never too late for older people to start lifting weights. 'They can increase both their muscle size and their strength,' he says.

### Aging muscles can grow

'It is often assumed that the oldest old, or, say, people past the age of 80, are less likely to be able to gain muscle mass and strength,' says Luc van Loon, a professor of human biology at Maastricht University, and senior author of the new study.

But van Loon and his colleagues were unconvinced. 'Muscle tissue is constantly turning over as long as we live,' he says, so why shouldn't an octogenarian's muscles strengthen and grow as well as a youngster's of 65?

To investigate that idea, he and his co-authors recruited 29 healthy, older men and women. The study consisted of two groups. The 'younger old' included 17 people between the ages of 65 and 75. Participants in the 'older old' group were at least 85. All lived independently and had no debilitating illnesses.

The volunteers lifted three times a week for 12 weeks, in supervised sessions, using weights set to as much as 80 per cent of their full strength.

This program is more intense than some people might expect older people to tolerate. But the volunteers 'loved participating in this intervention'. Attendance was high, injuries rare. And both the 'younger old' and 'older old' groups responded powerfully to the exercise, surprising the researchers somewhat.

After three months, the people aged 85 and up had packed on more strength and mass, in relative terms, than the younger group, adding an average of 11 per cent to muscle mass and 46 per cent to strength, versus 10 per cent more muscle and 38 per cent more strength among the younger volunteers.

### Never too late to lift

The results persuasively show that 'it's never too late to start training,' says Michael Roberts, a professor of kinesiology at Auburn University

in Alabama, who has extensively studied resistance exercise.

The results have caveats. The study was small and lasted only for three months. Plus, the training was supervised, with people's lifting form and loads monitored and adjusted as needed, a level of attention that could be difficult to replicate for ordinary people.

The study also is not meant to give any of us carte blanche to skip weight training now, in anticipation of starting in retirement. 'It's better

to start at an earlier age,' Marzucca-Nassr says, 'and continue throughout life.'

The study's key takeaway, though, is that there seems to be no age limit or hard stop on our bodies' ability to adapt and improve, says study co-author van Loon. 'You are never too old to start exercising.'

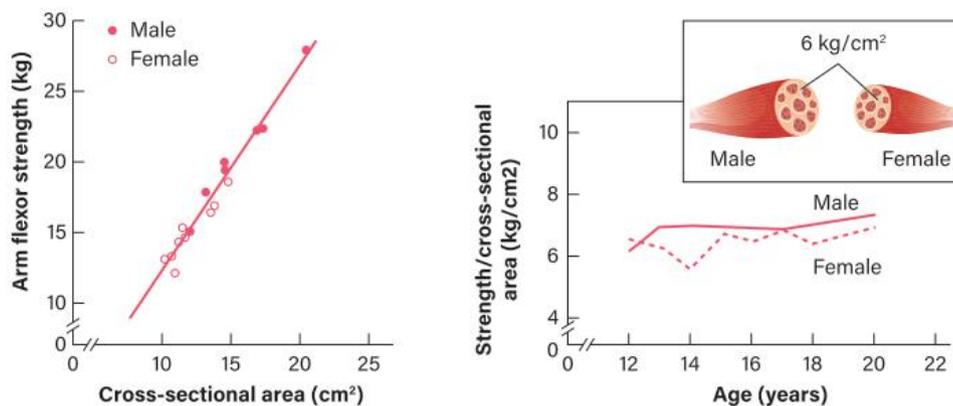
Source: Gretchen Reynolds, 'It's never too late to lift: Older bodies can still build muscle', in *The Washington Post* (29 November 2023)

## QUESTIONS

- 1 Who did Luc van Loon and his colleagues recruit to take part in the study? List one variable common to participants from either group.
- 2 What is the relationship between muscle mass and strength that the researchers were looking to capitalise on?
- 3 Both the 'younger old' and 'older old' groups 'responded powerfully' to the exercise. List and explain one of the key findings the researchers found as a result of the intervention.
- 4 'The study's key takeaway ... is that there seems to be no age limit or hard stop on our bodies' ability to adapt and improve, says study co-author van Loon. "You are never too old to start exercising." Using evidence from the article, explain two limitations associated with this study.

## Sex

Strength gain in males and females is similar from early childhood, through adolescence and into adulthood. After puberty, absolute strength is higher in boys than in girls, most likely due to an increase in testosterone levels in boys. Testosterone promotes muscle growth, which results in greater muscle mass and cross-sectional area, and this is reflected in greater overall strength. Males continue to be stronger than females across adulthood. If strength is compared with cross-sectional area of muscle, however, no difference is found between relative strength of males and females.



**FIGURE 8.28** For a muscle of the same size, the amount of force that can be exerted is the same for both males and females.

Source: Fox, E.L. et al. (1993), *The Physiological Basis for Exercise and Sport*

**DID YOU KNOW?**

Testosterone levels increase in both boys and girls up to about age 17. At this point, the level increases dramatically in males, but remains relatively constant in females. Testosterone levels then decrease with age in both sexes, typically from age 20.

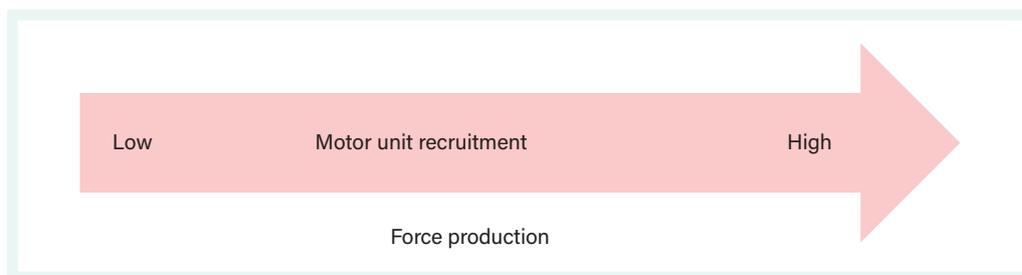
## Muscular power

Muscular power is the ability of a muscle or muscle group to exert a maximum amount of force in the shortest time period. Power is the product of the strength (force) and the speed (velocity) of the movement:

$$\text{power} = \text{force} \times \text{velocity}$$

Due to this relationship, power can't be developed without first developing strength, and the largest improvements in power come from improvements in strength as a result of resistance training.

Physiologically, the development of force within the muscle is determined by the number and size of motor units recruited and the frequency of motor unit stimulation.



**FIGURE 8.29** Greater force is developed when more motor units are involved.

Short-duration, high-intensity efforts are characteristic of movements that require power, and the ATP–CP energy system is the only system capable of providing the energy needed at a fast enough rate to meet the demands of the action.

Muscular power is important in athletics for events such as long jump, high jump or triple jump, and in throwing events such as javelin, hammer throw, shot-put and discus. Many team sports also require power to leap, jump and rebound to intercept a ball from the opposition.

**LOOKING FORWARD****Plyometric training****Chapter 13**

Concentric muscle actions are not capable of producing as much force as eccentric actions. When concentric and eccentric actions are used together, however, power can be increased. Plyometric exercises maximise the use of both eccentric and concentric actions through the stretch–shortening cycle to develop power. Plyometric training is covered in detail in Chapter 13.



AAP Image/SNPA, Adam Binns

**FIGURE 8.30** Muscular power is important in explosive movements such as leaping.

## Factors affecting muscular power

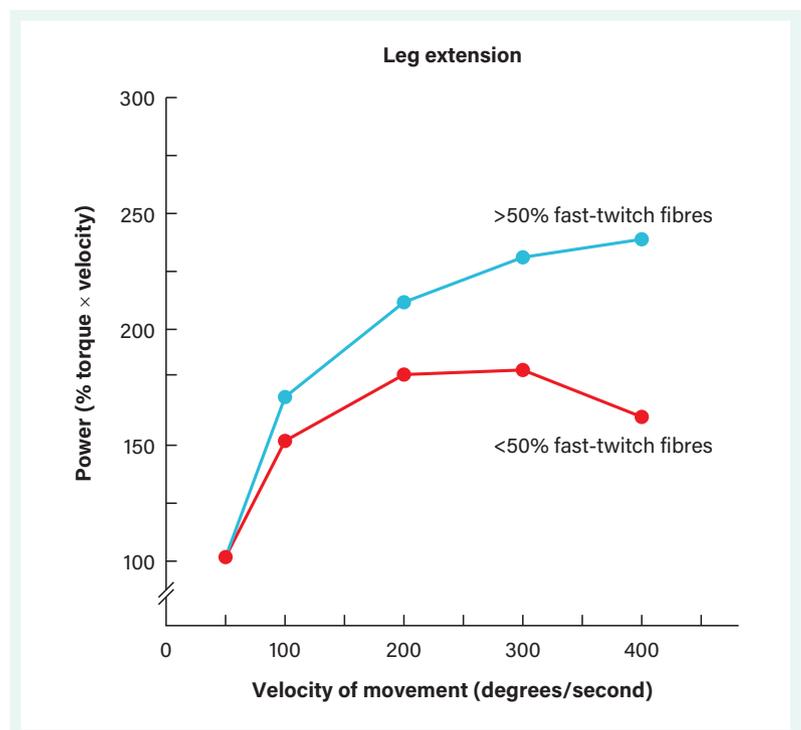
The power generated by a muscle or muscle group is dependent on:

- muscle fibre type
- velocity of movement.

### Muscle fibre type

The characteristics of Type II (fast-twitch) muscle fibres (see Table 8.01 on page 333) make them more suitable for generating power than Type I (slow-twitch) fibres. The greater ATP and PC stores in Type II muscle fibres mean there is an energy source immediately available, and force production is higher in Type II fibres. The greater the percentage of Type II fibres in the muscle, the greater the capacity of that muscle to generate power.

Figure 8.31 shows that at any velocity of movement, the peak power output of a muscle with greater than 50 per cent of Type II fibres is greater than the peak power output for those with less than 50 per cent of Type II fibres.



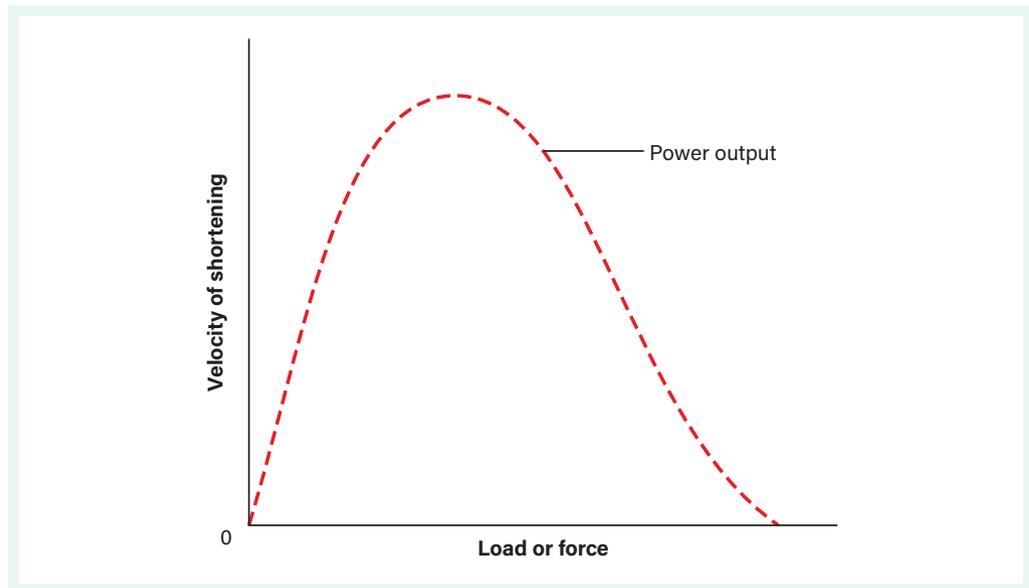
**FIGURE 8.31** The relationship between power, velocity of movement and fibre type

Adapted from: Fox, Bowers & Foss, 1993

## Velocity of movement

The power that a muscle can generate will depend on the force produced and the velocity at which the muscle lengthens or shortens. Velocity is affected by the arrangement of the muscle fibres, with a fusiform arrangement (see Figure 8.24) being more suited for fast movement compared with a pennate arrangement. The higher levels of myosin ATPase activity within Type II fibres contribute to the fast rate of ATP breakdown (and energy release), which leads to faster contraction velocities and therefore increased power output.

As the velocity of the movement increases, so does the power generated – to a point. At high speeds, power will decrease because there isn't enough time to develop maximum force.



**FIGURE 8.32** Peak power is generated with moderate force at an intermediate velocity.

Source: Kraemer, W.J. & Looney, D.P. (2012), 'Underlying mechanisms and physiology of muscular power', in *Strength and Conditioning Journal*

## Age and sex

The effect of age and sex on muscular power is a consequence of the changes that occur with aging that are covered in relation to strength on page 351 and the differences between males and females described on page 353.

### DID YOU KNOW?

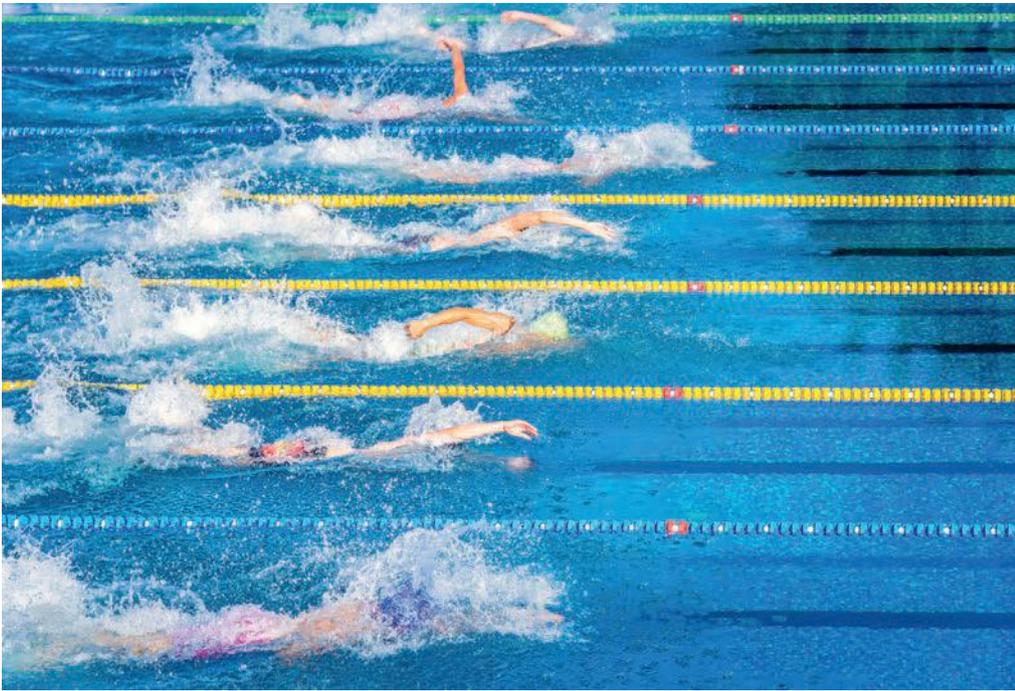
The American College of Sports Medicine groups the terms 'muscular strength', 'endurance' and 'power' into a category it names 'muscular fitness' and has identified muscular fitness as a key aspect of developing and maintaining overall fitness.

# Speed

Speed is the ability to move your body, or body parts, from one point to another or perform a movement quickly. In the area of physical activity, sport and exercise, speed is obviously important in activities such as the 50 metres freestyle or a time trial in cycling. Being able to move quickly and get from the start to the finish in the shortest amount of time possible is the aim of such events, and the movement relies on the athlete's ability to move their arms and legs as quickly as possible. An athlete's ability to accelerate to their maximal speed and then maintain that speed is a key indicator of success.

## speed

The distance travelled divided by the change in time; the rate of change in position



**FIGURE 8.33** Activities that involve racing rely heavily on speed.



## ABOVE AND BEYOND THE STUDY DESIGN

Reaction time, page 359

## Factors affecting speed

There are a number of biomechanical factors that affect speed, and these can be improved on through technical training. Physiologically, factors that affect speed include:

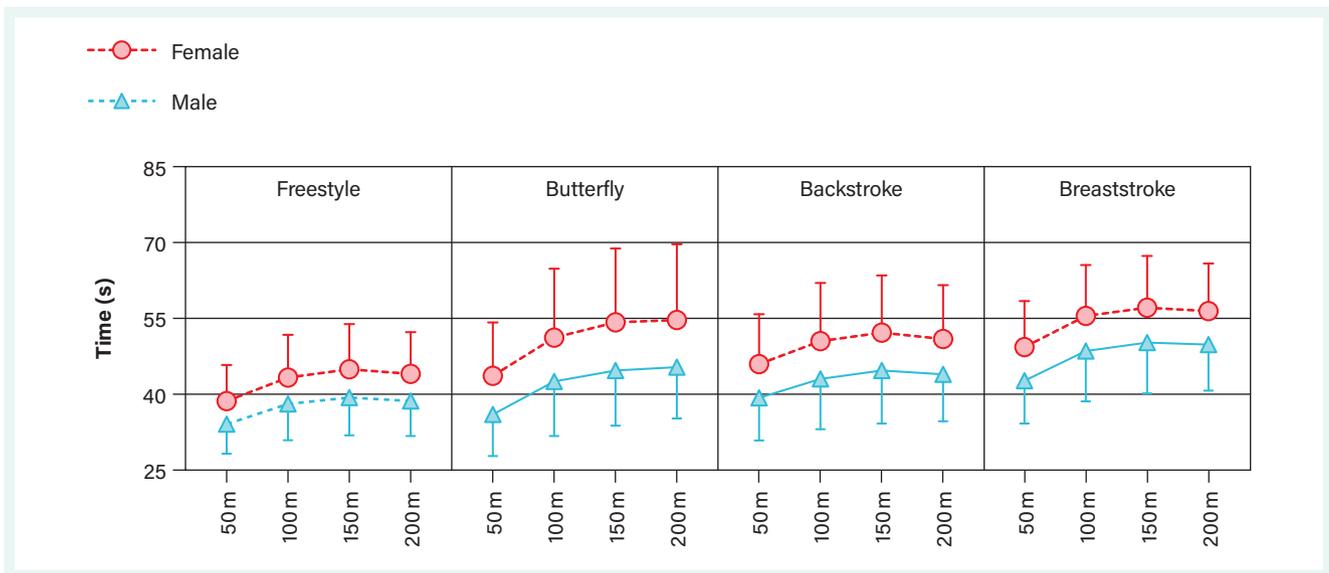
- the ability of the energy systems to provide ATP quickly
- muscle fibre type
- age
- sex.

## Energy system efficiency

Speed relies on ATP being rapidly available to provide energy for movement. The ability of the anaerobic pathways (anaerobic glycolysis and ATP-CP systems) to provide energy is linked to the duration of the activity and to fatigue. As distance increases, speed decreases due to a decline in the rate of ATP production that is associated with the increased contribution, firstly, from the anaerobic glycolysis system and then the aerobic system, and/or an

increase in the accumulation of metabolic by-products, which impact on the muscles' ability to contract quickly.

Figure 8.34 shows 50-metre split times for the different swimming styles. For both men and women, the time taken to complete each 50 metres increases from the start of the race.



**FIGURE 8.34** 50-metre split times in the 200 metres freestyle, butterfly, backstroke and breaststroke events

Source: Moser, C. et al. (2020), 'Pacing in world-class age group swimmers in 100 and 200 m freestyle, backstroke, breaststroke, and butterfly,' in *International Journal of Environmental Research and Public Health*, CC BY 4.0

### Muscle fibre type

Type II (fast-twitch) muscle fibres are preferentially recruited for activities that require speed. The same characteristics that make Type II fibres more suited to power activities also make them more suited to speed. Fast contraction time, high CP and glycogen stores, increased ATPase activity and glycolytic enzyme activity all result in Type II fibres being more suited to a faster rate of force production, which translates to increased speed of movement. Speed is also associated with increased activation of motor units (through increased speed of impulses and greater frequency of impulses), which leads to faster contraction time and improvements in speed.

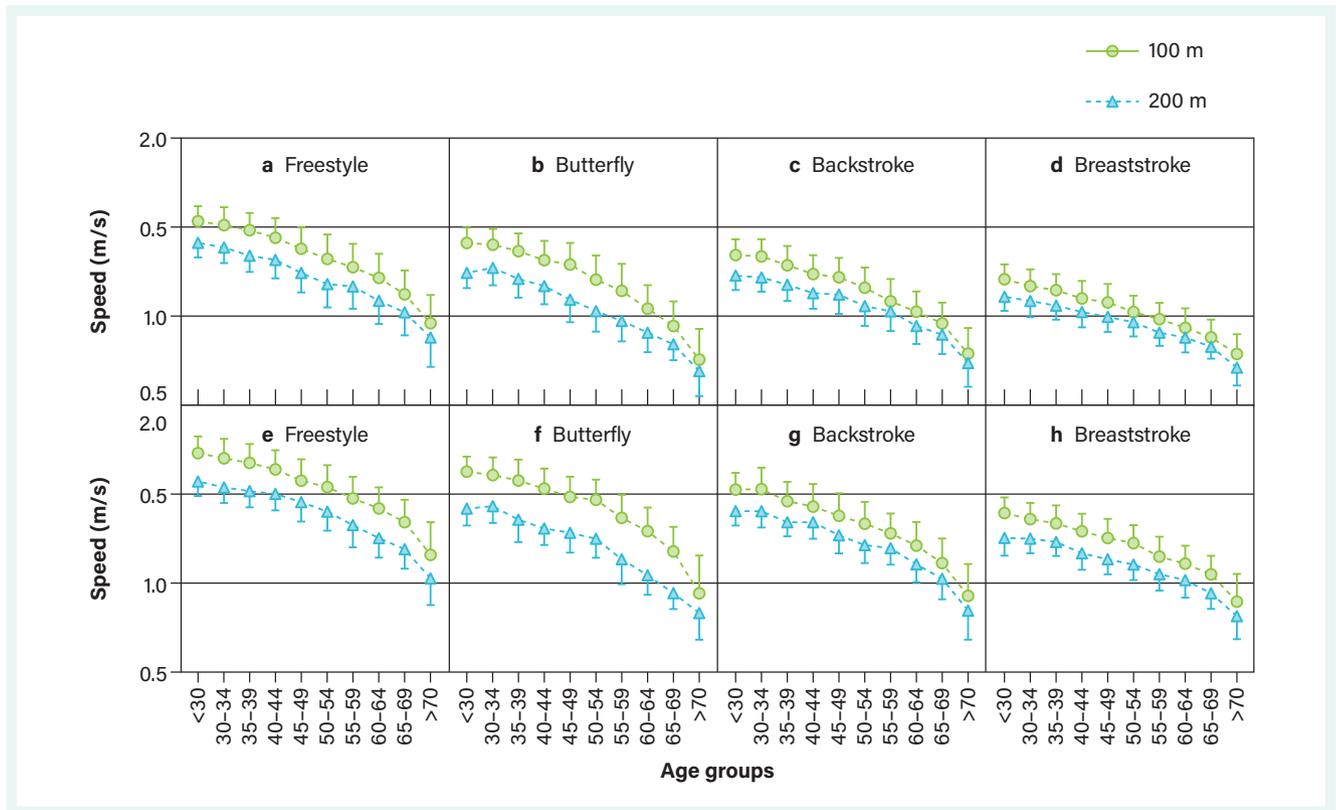
### Age

Speed typically declines with increasing age, due to the physiological changes in the body that accompany aging.

Figure 8.35 shows that, for both males and females, the time to swim 100 metres and 200 metres increases with age. Within running disciplines, age-related declines are more rapid in sprints than in longer-duration events. This is likely due to the more pronounced decline in strength compared to aerobic power.

### Sex

It is estimated that there is a 10–12 per cent difference between males and females across all distances when comparing times in running events, but this difference is thought to be smaller for sprint events that rely predominantly on speed. The differences between male and female speeds in swimming events can be seen in Figure 8.35.



**FIGURE 8.35** Swimming speed decreases with age across all events for both women (a-d) and men (e-h).

Source: Moser, C. et al. (2020), 'Pacing in world-class age group swimmers in 100 and 200 m freestyle, backstroke, breaststroke, and butterfly', in *International Journal of Environmental Research and Public Health*, CC BY 4.0

## Effects of age on fitness

The decline in many fitness components is affected by the physiological changes that typically accompany aging. Table 8.05 summarises the changes in these variables.

**TABLE 8.05** Effects of aging on selected physiological and health-related variables

Variable	Change
Resting heart rate	Unchanged
Maximum heart rate	Lower
Maximum cardiac output	Lower
Resting and exercise blood pressure	Higher
Absolute and relative maximum oxygen uptake reserve (VO <sub>2</sub> R max; L/min and mL/kg/min)	Lower
Residual volume	Higher
Vital capacity	Lower
Reaction time	Slower
Muscular strength	Lower
Flexibility	Lower
Bone mass	Lower
Fat-free body mass	Lower
Percentage of body fat	Higher
Glucose tolerance	Lower
Recovery time	Longer

Adapted from: American College of Sports Medicine (2014), *ACSM's Guidelines for Exercise Testing and Prescription*



## COLLABORATIVE TASK

### Prac activity

#### Soft-lacrosse (or team game decided by the class)

##### AIM

To identify fitness components used in a team sport

##### EQUIPMENT

As required for the game chosen

##### METHOD

Participate in a team sport/game for 20–30 minutes.

##### DISCUSSION

- 1 Justify the importance of the following three fitness components, using a specific example from the game:
  - aerobic power
  - coordination
  - agility.
- 2 Identify other fitness components, if any, that are important when playing this sport.
- 3 Discuss any differences in the way different classmates use fitness components according to their playing position and previous sport or training experiences.



##### Assessment

##### 8.3 Check-in questions

## 8.3 CHECK-IN QUESTIONS

- 1 The most important fitness component in the 400 metres running event is:
  - A anaerobic capacity.
  - B muscular endurance.
  - C muscular strength.
  - D muscular power.
- 2 Cathy Freeman was one of Australia's greatest and most successful 400 metres runners. It is likely that she had:
  - A a high proportion of Type I muscle fibres in her leg muscles.
  - B increased levels of oxidative enzymes.
  - C increased tolerance to lactate.
  - D low muscle fuel (ATP, PC, glycogen) stores.
- 3 Strength declines with age. **Outline** three reasons for the decrease in strength with age in both males and females.
- 4 **Identify** three characteristics of Type II muscle fibres that make them more suited to activities that involve the anaerobic-based fitness components.
- 5 How is agility related to balance?
- 6 Team sports involve many different fitness components. Select a sport and **outline** the three main fitness components required. Provide specific examples to support your answer.

### Command term

#### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

MODULE 8.2, PAGE 327

## Fatigability of Type I, Type IIa and Type IIb muscle fibres

The fatigability of muscle fibres is relative to the oxidative capacity of the fibre type:

- Type I fibres have high oxidative and low glycolytic capacity, have low ATPase activity and are relatively resistant to fatigue.
- Type IIa fibres have high oxidative and glycolytic capacity, have high myosin ATPase activity and are relatively resistant to fatigue.
- Type IIb fibres have low oxidative and high glycolytic capacity, have high myosin ATPase activity and fatigue rapidly.

MODULE 8.3, PAGE 355

## Reaction time

In race events that require speed, the ability of the athlete to start moving at the sound of the starting gun is imperative for a successful performance. The time it takes for the body to react to an external stimulus is called the **reaction time**. Reaction time is also important in events where the environment is constantly changing and athletes need to quickly make adjustments to movement, so it is also relevant for activities that require agility. This is especially so when a decision needs to be made before the movement is instigated. If there is only one possible action (e.g. the starting gun sounds and athletes start running), then reaction time is quickest. When a decision needs to be made, reaction time increases. Distractions (e.g. noise in the stadium and fans moving in the crowd) can also impact on reaction times. If both the number of response alternatives and the number of distractions increase, then reaction time will increase.

### reaction time

The time from the presentation of a stimulus to the onset of a response



Jacob Lund/Shutterstock.com

**FIGURE 8.36** Reaction time is important in sprint events.

ABOVE  
AND  
BEYOND  
THE STUDY  
DESIGN



# CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 8

## 8.1 Physical fitness

- Physical fitness is the ability of the body systems to work effectively so that you can perform work and leisure activities efficiently.
- The component model of fitness recognises the different aspects of fitness that contribute to the overall fitness of the athlete; and that physical fitness is specific to the type of activity or sport that a person undertakes.
- The components of fitness required in physical activity, sport or exercise are aerobic power, anaerobic capacity, muscular strength, power and endurance, flexibility, balance, coordination, speed and agility.

## 8.2 Aerobic-based fitness components

- Aerobic power is the rate of energy production from the aerobic energy system.
- Factors that affect aerobic power include (and are not limited to) concentration of oxidative enzymes, size and number of mitochondria, blood volume, lung volumes, cardiac output (stroke volume  $\times$  heart rate), age and sex.
- Balance is the ability to control equilibrium while stationary or moving.
- Balance can be maintained through the manipulation of the size of the base of support, the position of the centre of gravity, the position of the line of gravity and the friction between the two contact surfaces.
- Coordination (hand–eye, foot–eye, head–eye) is the ability to use the body’s senses to manipulate body parts to execute motor skills smoothly and accurately.
- Coordination is seen in smooth, well-timed movements that are executed with less effort, requiring less energy and a more efficient transfer of energy between joints.
- Flexibility is the ability to move a joint through its full range of motion, either while stationary (static flexibility) or while moving (dynamic flexibility).
- Flexibility is affected by joint type and structure, soft-tissue (muscle, connective tissue, skin) structures, body and muscle temperature, age and sex.
- Muscular endurance is the ability of a muscle or group of muscles to perform repeated contractions against a resistance or to hold an isometric muscle action for an extended period.
- Factors that affect muscular endurance are muscle fibre type, fatigue, age and sex.
- Type I (slow-twitch) muscle fibres are more suited to submaximal-intensity, long-duration (aerobic) activities due to their higher mitochondrial density, capillary density and myoglobin content.
- Type IIa muscle fibres are referred to as intermediate fast-twitch fibres and have overlapping characteristics of both slow-twitch and fast-twitch.
- Type IIb (fast-twitch) muscle fibres are more suited to high-intensity, short-duration (anaerobic) activities due to their larger size, fast contraction time, higher force production, increased CP and glycogen stores and increased myosin ATPase activity.

### 8.3 Anaerobic-based fitness components

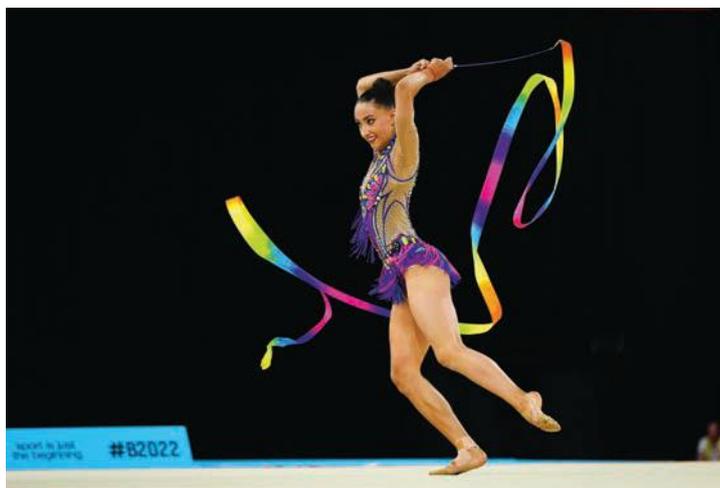
- Anaerobic capacity is the maximum amount of energy (ATP) obtainable from the anaerobic energy systems (ATP-CP and anaerobic glycolysis) and refers to the total amount of work that can be done by the anaerobic systems.
- Factors that affect anaerobic capacity are muscle fibre type, muscle mass, age and sex.
- Agility is the ability to change body position quickly and accurately, in response to a stimulus, while moving at speed. Agility must include a cognitive component and a change of direction speed.
- Muscular strength is the ability of the muscle or muscle group to develop maximal force in a single effort. Muscular strength is specific to the muscle group, type of muscle action, speed of contraction and joint angle.
- Factors affecting strength include muscle size, fibre type and arrangement, joint angle and velocity of movement, age and sex.
- Muscular power is the ability of a muscle or muscle group to exert a maximum amount of force in the shortest period of time.  $\text{Power} = \text{force} \times \text{velocity}$ .
- Muscular power is affected by muscle fibre type and the velocity of the movement.
- Speed is the ability to move the body or body part from one point to another or perform a movement quickly.
- Factors that affect speed include the ability of the energy systems to provide ATP quickly, muscle fibre type, age and sex.

# CHAPTER REVIEW



## Assessment Chapter 8 Review

- 1 Agility is the ability to:
  - A control equilibrium.
  - B exert a single maximal force.
  - C move the body from one point to another quickly.
  - D change direction quickly in response to a stimulus.
- 2 Which of the following fitness components would be the most important in rhythmic gymnastics?



Craig Mercer/MB Media/Getty Images Sport/Getty Images

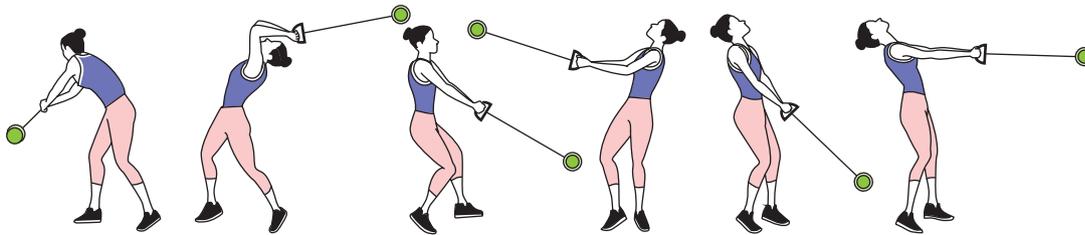
- A speed
  - B coordination
  - C aerobic power
  - D muscular endurance
- 3 **Identify** the major fitness component required for each of the following sports:
  - a 1,500 metres freestyle
  - b shot-put
  - c 110 metres hurdles.
- 4 **Name** the three fitness components that make up muscular fitness, and provide a practical example from a physical activity, sport or exercise where each component is required.

### Command term

#### name

Provide a word or term (something that is known and distinguished from other people or things) used to identify an object, person, thing, place etc.

5 ©VCAA Exam 2020, Section B, Q2



The diagram above shows the sequence for a hammer throw. Flexibility is an important fitness component in hammer throwing.

**Define** 'flexibility' and explain the importance of flexibility in hammer throwing.

6 ©VCAA Exam 2020, Section B, Q1

Below is an example of a high-intensity interval training (HIIT) program.

Frequency	Intensity	Work period	Recovery period	Type	Repetitions
3 x per week	89–90% VO <sub>2</sub> max	4 min	1–3 min	Running	4–6

**State** the fitness component being targeted by the training program above.

- Other than age, sex and cross-sectional area of the muscle, **state** two other factors that affect muscular strength.
- What is the relationship between muscular strength, endurance and power? Provide an example of how each is needed in the sport of cycling.
- Compare** and **contrast** the suitability of Type I and Type II muscle fibres for generating power.
- Patrick played a 90-minute soccer game. During the game he made a number of runs to present an option up forward (repeated sprints), he dribbled the ball down the pitch, turned to evade an opponent, then moved quickly to his right as he was able to see that the space had opened up (decision-making). Using specific examples from the scenario, **identify** three fitness components that are important in soccer.

#### Command terms

##### compare

Recognise similarities and differences and the significance of these similarities and differences

##### contrast

Show how things are different or opposite

## CHAPTER

# 9

## CONDUCTING AN ACTIVITY ANALYSIS

### UNIT 4 - AREA OF STUDY 1



Sergey Nivens/Adobe Stock

**FIGURE 9.01** Data collected during an activity analysis provides information about relevant fitness components, muscle actions and energy system interplay.

### Quizzes

Chapter 9 Pulse check

- 9.1** Check-in questions
- 9.2** Check-in questions
- 9.3** Check-in questions
- 9.4** Check-in questions
- 9.5** Check-in questions

Chapter 9 Review

### Videos

Masterclass: Chapter 9

- 9.5** In focus: Unpacking an activity analysis on hockey

### Resources

- 9.2** Template: Data collection
- 9.3** Template: Locomotor recording sheet
- 9.5** Template: Playing intensity recording sheet

Chapter 9 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](http://cengage.com.au/nelsonmindtap)



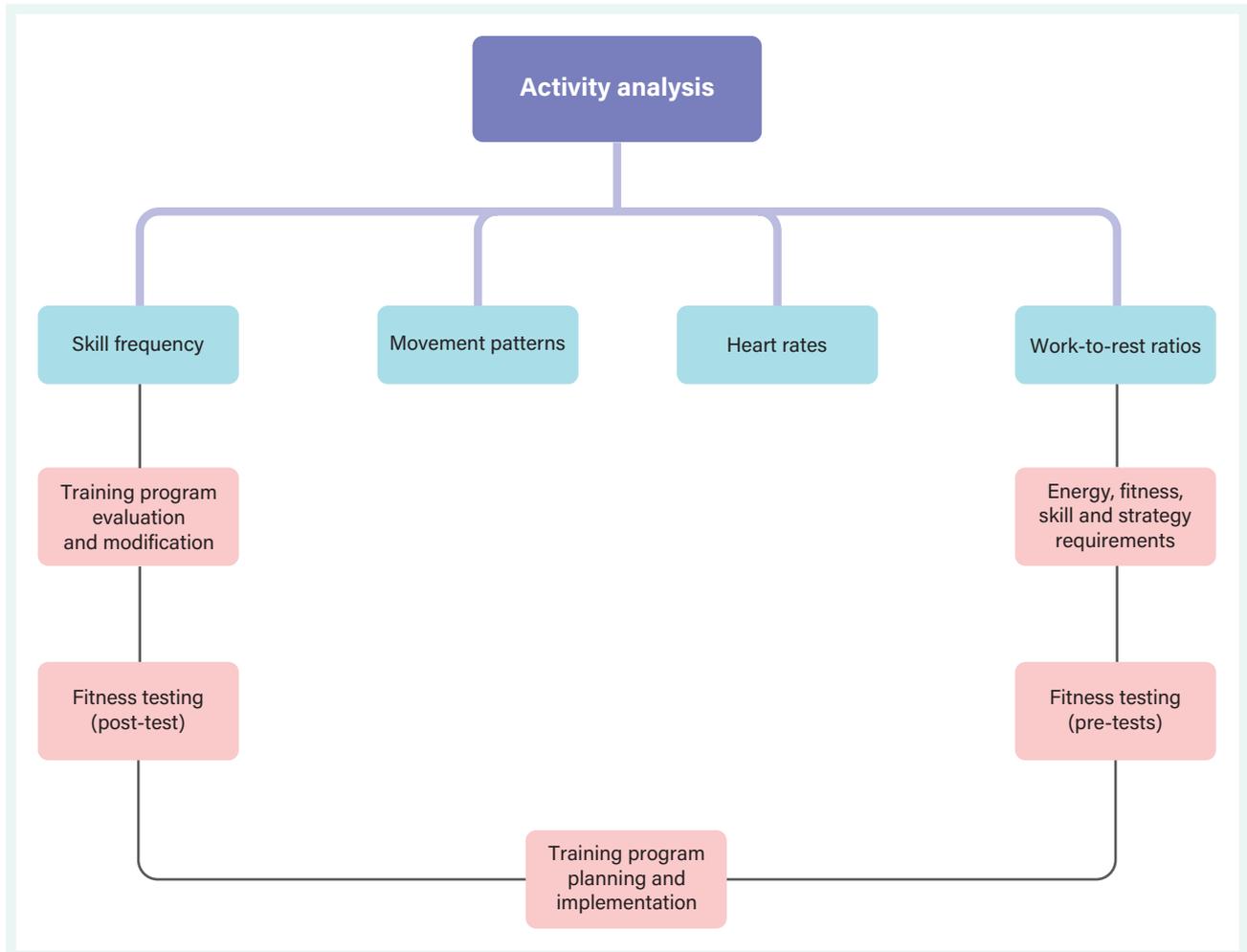
» activity analysis, including skill frequencies, movement patterns, heart rates and work-to-rest ratios

## KEY KNOWLEDGE

» analyse data to determine the major fitness components, the factors that affect them, and energy systems used in a variety of sporting events and physical activities

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)





Video

Masterclass: Chapter 9

Assessment  
Pulse check

An activity analysis can be used determine how the performance might be improved by a coach's immediate intervention using direct observation and feedback. Alternatively, data is collected and then analysed after the performance to provide information about the:

- physiological requirements (relevant fitness components, energy systems, muscle groups and actions)
- technical/tactical requirements (specific movement sequences and skill execution).

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 **Describe** the difference between qualitative and quantitative data.
- 2 Direct observation allows coaches to make immediate decisions about any changes that may be needed to bring about improvements. What are some of the limitations associated with simply 'watching a performance' to analyse it?
- 3 If a player such as a midfielder needs to cover more than 8,000 metres during a match, what fitness components would they need to meet this requirement?
- 4 What does 'specificity' mean when considering a games analysis and subsequent selection of fitness tests and training activities?
- 5 **List** two advantages of digitally recording a sports performance as part of the games analysis. Suggest any disadvantages associated with digital recording of games/performances.
- 6 Why do some coaches analyse the performances of opposition teams from a tactical, rather than a physiological, perspective?

## 9.1 PURPOSE OF AN ACTIVITY ANALYSIS

In this module you will learn about:

- the rationale behind conducting an activity analysis
- types of data/information an activity analysis can provide
- the difference between primary and secondary data and learn to:
- link the principle of specificity to the collection of data.

The main purpose of viewing a performance (direct observation) is to determine how the performance might be improved by a coach's immediate intervention. This is the most significant use of **primary data** collection. Alternatively, data is collected and then analysed after the performance to provide information about the:

- physiological requirements (relevant fitness components and energy systems)
- technical requirements (biomechanical efficiency and execution of skills)
- tactical requirements (specific movement sequences and skill execution).

### primary data

Information and data that is collected firsthand – either individually or as a team

## Physiological requirements (relevant fitness components and energy systems)

Analysing how players use aerobic power, anaerobic capacity, strength, power, muscular endurance, speed, agility, stability and mobility during matches and competition is vital to determining how to best improve these during training. Additionally, the intensity of efforts that players produce during matches and training sessions allows coaches to better understand the varying contribution of energy systems and to ensure there are high levels of replication during both competition and training. You may have heard the expression, 'You get what you train for' – this is a great example of **specificity**.

### LOOKING BACK

#### Fitness components

##### Chapter 8

Recall how the fitness components contribute to successful performance in a variety of sporting settings.

#### specificity

The kind of precision achieved by fitness testing and training that mimics the skills, movements and actions observed during competition and performances, and that enhances the physiological requirements (major muscle groups, fitness components and energy systems) of the sport or physical activity

## Technical requirements (biomechanical efficiency and execution of skills)

The biomechanical detail of skills performed by sportspeople allow the detection of technique flaws, monitoring of improvements and identification of changes during preparation, and assist in the rehabilitation from injury. The effectiveness with which an athlete performs specific skills or a broader passage of play is measured, compared and classified, either positively or negatively, against a predetermined expected outcome. These are then used to create player performance profiles that are used as a **baseline** for comparisons throughout a season, against teammates or even opposition/other players.

### LOOKING BACK

#### Qualitative movement analysis

##### Chapter 4

A qualitative movement analysis takes into consideration how skills are performed and how improvements are sought from a technical and tactical perspective.

#### baseline

A performance result/ outcome against which future performances are compared; or a standard of performance excellence against which current performances are measured or that they aim to achieve

## Tactical requirements (specific movement sequences and skill execution)

An activity analysis allows coaches to better understand the impact of their tactical decisions. It can also identify specific tendencies and preferred tactical set-ups by opposing teams. Analysts evaluate patterns of play in conjunction with skills performed, field placings, timings and players involved to draw an accurate representation of tactical variances given particular match scenarios.

## Primary data

### secondary data

Information or data that has been collected by others and that is used to increase understanding and application of existing knowledge

Primary data is often used alongside **secondary data** (data that has been collected by others on similar activities or sports performances) when consolidating understanding of specific fitness components, energy systems and movement sequences, as well as the tactical and technical components associated with the activity. It is important to consider performers at the highest level possible when seeking to develop benchmarks on optimal performance requirements. This data is often used when selecting fitness tests as well as planning, implementing and evaluating a training program to try to bring about improved performances.

### LOOKING BACK

#### Assessment of fitness

#### Chapter 10

The analysis will provide information about how the components are used and how their application needs to be replicated when performing fitness tests.

Coaches and performance analysts use the data collected in an activity analysis to inform them about:

- major muscle groups involved in the execution of movements
- intensity and duration (time and distance) of efforts
- movement types, patterns and field-of-play coverage
- skill frequencies and efficiency
- energy system interplay and contribution throughout performances
- efficiency of movement and biomechanical applications to technique/skill execution
- team and opposition playing strategies and tactics.

It is worth noting that an activity analysis can be equally well applied to team and individual sports in an effort to determine the requirements for optimal performances and to provide feedback to allow improvements to be made via training interventions.

DIRK WAEM/AFP/Getty Images



Alex Davidson/Getty Images Sport/Getty Images

**FIGURE 9.02** The type of data collected to enable coaches and analysts to best determine the performance requirements for a hockey player is very different from that collected for a rower.

**DID YOU KNOW?**

We need to consider all elements of performance and train them in order to bring about improvements. Simply focusing on the physiological aspects of performance will not bring about improvements in skill execution!

**🚩 SIGNPOST**

To see the major muscles used in performing various volleyball skills, visit the 'Muscles used in volleyball' page on the Volleyball Advice website.



**Weblink**

Muscles used in volleyball

**Assessment**

9.1 Check-in questions

**9.1 CHECK-IN QUESTIONS**

- 1 **Outline** the difference between data collection and data/activity analysis.
- 2 **Describe** why an activity analysis forms the first step in designing a training program.
- 3 **Discuss** why it is easier to perform an activity analysis on an individual performer such as a road cyclist than a team player such as a netball centre.
- 4 How might a coach benefit from using qualitative movement analysis data instead of quantitative serve accuracy data when applied to the sport of volleyball?

**Command terms****outline**

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

**describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

**9.2 DATA COLLECTION METHODS**

In this module you will learn about:

- the advantages and disadvantages associated with direct observation vs digital recording
  - data collection considerations
- and learn to:
- make decisions about the most appropriate data collection tools/options depending on task requirements and levels of experience.

Before data can be analysed, it needs to be collected, and there are basically only two ways this can occur – using:

- direct viewing or observation
- digital recording.

**Direct viewing or observation**

Direct viewing or observation is the most common form of activity analysis used by students, but it is also used by sports professionals and coaches. Coaches are positioned at vantage points such as coaching boxes or beside the playing area to directly communicate with players. The information obtained by viewing is **subjective**, which allows immediate changes to be made if required. Typical information gathered includes:

- key skills/actions and associated muscles and fitness components
- movement patterns (the type of movements being made)
- use of the playing area and location of the 'hot spots' or most-utilised parts of the field
- playing intensities and ability to sustain high-intensity efforts
- repeated actions and set team plays – for the team and the opposition.

**subjective**

Based on, or influenced by, personal feelings or opinions



**Template**  
Data collection

### quantitative data

Any set of numerical data – typically, statistics – that can be analysed and measured objectively

While direct viewing or observation is subjective, observations and associated decisions at a professional level are based on years of experience. At lower levels, they may be compromised by lack of experience or game knowledge, observer bias towards certain players or playing styles, an inability to keep up with the pace of the game or with multiple players, and a loss of concentration. Some of these problems can be alleviated by creating a team of observers. This is typically what students do when asked to conduct an activity analysis of their classmates during a practical activity. A team of three or four students is assigned to each key player, with each student responsible for noting specific aspects of play, such as the skills they use, their movement patterns and playing intensities, and the major muscles and fitness components they call upon during the observation period.

Direct viewing or observation and statistical recording can alleviate the problems associated with recall and loss of concentration. This greatly increases the ability to store and compare data, and can result in more specific and effective augmented feedback. Statistical recording can be accomplished by manually completing paper-based data collection sheets while viewing the play, so **quantitative data** can be analysed post-performance. One problem with this data collection method is that it can be difficult to both watch and manually record information at the same time.

Observed actions and movements can be recorded with the help of apps and computer programs, which both improve the accuracy and increase the amount of data that can be collected. As analysts and recorders have become more highly trained, they have learnt to collect data via a keypad without taking their eyes off the players – a bit like touch-typing and using a keyboard without looking at the keys your fingers are striking. Multiple mobile phone and tablet apps have been developed to assist with collection of games data. The advantages of mobile apps include convenience and portability, as well as accessibility and affordability. For students, apps such as Time Motion, Dartfish and CoachNow represent a contemporary means of conducting an activity analysis.

Stephen McCarthy/Sportsfile/Getty Images



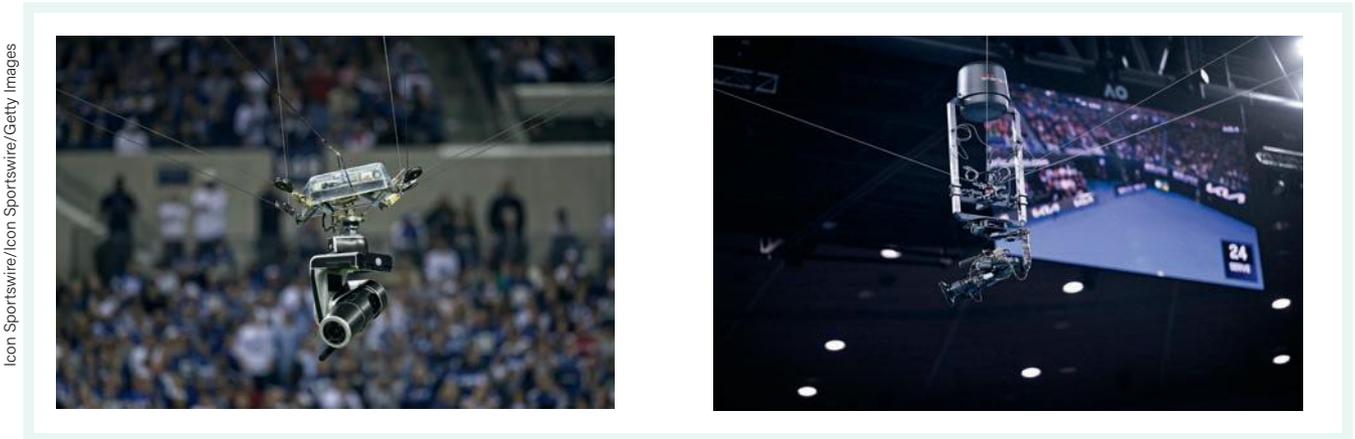
Emily Barker/Getty Images Sport/Getty Images

**FIGURE 9.03** Direct observation can be used to make immediate changes and can also be supplemented by the collection of statistics/notes to refer to at a later stage.

## Digital recording

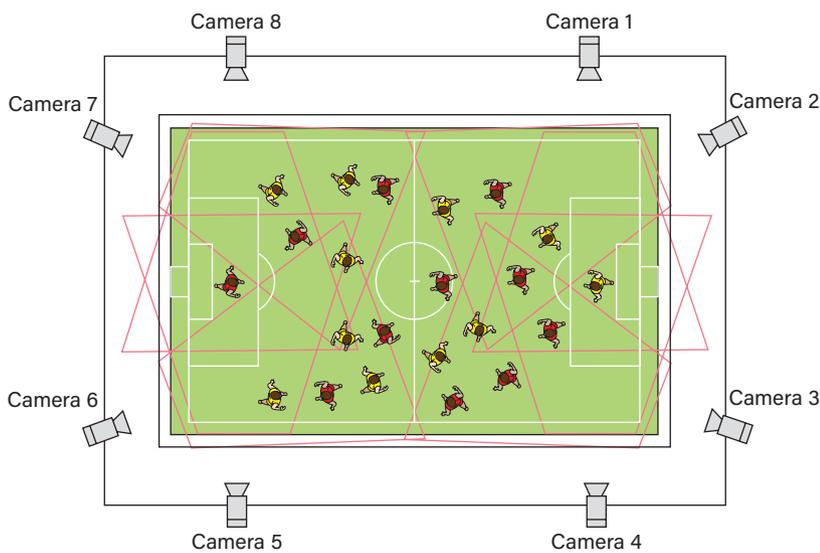
Digital recording includes the use of digital video cameras, mobile phones, tablets, heart rate monitors, global positioning systems (GPS) and/or aerial sports-analysis technology. In schools, a game can easily be recorded using a fixed digital video camera, smartphone or tablet. These are all practical and accessible means by which performance data can be recorded, viewed, archived and replayed. The recording device must remain focused on the performer at all times to accurately capture their performance. This permits a truly accurate analysis, which leads to specific fitness testing, followed by accurate program design that is tailored to the needs of the individual.

At the elite level, multiple video/digital recorders are often set up at high viewpoints on the sidelines of playing fields to collect footage from various angles. These might include a closer angle, capturing just a few players, and wider angles of sections of the playing area, capturing every player. In some instances, drones and other aerial digital recording devices such as 'cable cams' are also used. These can capture an even wider angle from above the players and can be used to clearly identify gaps during plays or structural set-ups and formations.

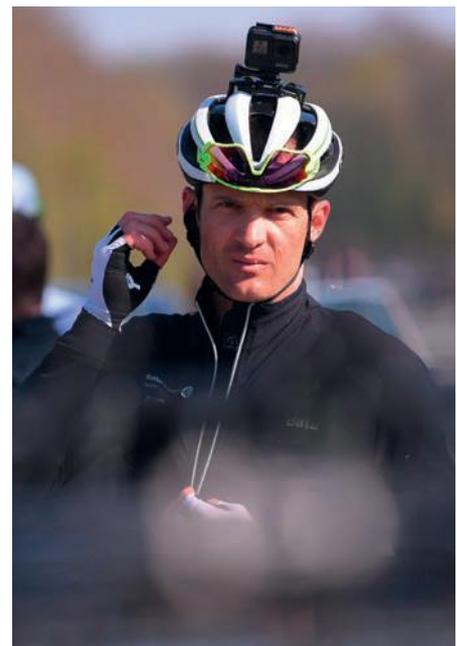


**FIGURE 9.04** Various cable-suspended camera systems are used in sports, including Spidercam, Skycam and Cablecam. They enable cameras to move both vertically and horizontally over a playing area such as a cricket pitch, football field or tennis/volleyball court.

Certain actions during training sessions may require analysts to get closer to the performers and use a fixed or handheld camera, such as a GoPro, to capture additional angles that show closer movements and player technique. For example a GoPro can be used to closely record swim starts, tumble turns, relay changeovers etc. that might not be as clearly seen by cameras positioned further away from the pool.



**FIGURE 9.05** Fixed cameras can capture multiple angles of a soccer pitch.



**FIGURE 9.06** A GoPro may be used in road cycling to capture information for later analysis.

**TABLE 9.01** The advantages and disadvantages associated with direct observation and digital recording

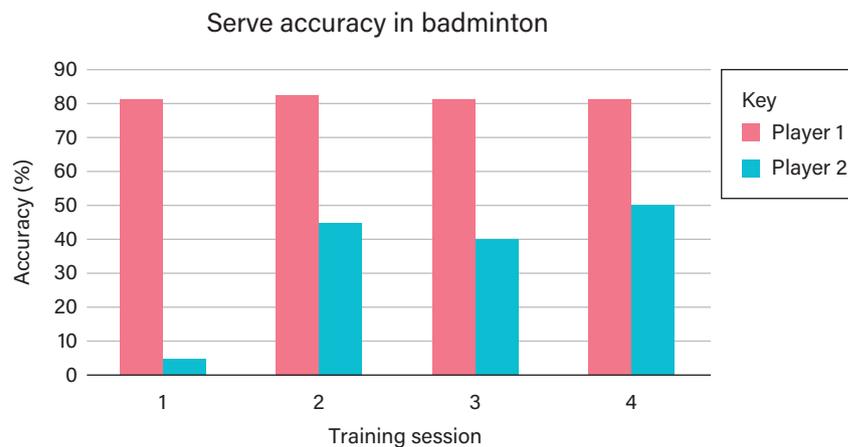
Activity analysis method	Advantages	Disadvantages
Direct observation	<ul style="list-style-type: none"> <li>Immediate feedback and performance improvement strategies can be shared with players</li> <li>Able to make immediate player/positional changes based on what opposition players are doing</li> </ul>	<ul style="list-style-type: none"> <li>Subjective decision-making (can be reduced via training and experience)</li> <li>Cannot 'show' players how they are performing (limited visual feedback)</li> <li>Multiple players cannot be effectively observed simultaneously</li> <li>Restricted/limited view of players depending on size of playing field and style of play</li> <li>Difficult to consider multiple performance outcomes at the same time (fast-paced play makes it difficult to take everything in)</li> <li>Cannot 'store' information for future reference and relies on memory, which has fixed capacity</li> </ul>
Direct observation with additional statistics and note-taking	<ul style="list-style-type: none"> <li>Observers/coaches can discuss performances with players with direct reference to stats/notes (reduces subjectivity)</li> <li>Data can be stored for future reference and comparison</li> <li>Player profiles and performance efficiencies can be easier to create</li> </ul>	<ul style="list-style-type: none"> <li>Difficult to observe and record data at the same time (improved via training).</li> <li>Restricted/limited view of players depending on size of playing field and style of play</li> <li>Game summaries take a large amount of time to collate</li> </ul>
Digital recording	<ul style="list-style-type: none"> <li>Data can easily be downloaded and linked to performance-analysis programs seeking to make improvements</li> <li>Performances can be stored, replayed and shown to players to improve understanding of game play</li> <li>Data can easily be shared, transmitted and analysed over multiple platforms</li> </ul>	<ul style="list-style-type: none"> <li>Systems/equipment used by elite performers and professionals can be expensive</li> <li>High degree of technical expertise required to operate the equipment</li> </ul>
Heart rate monitoring	<ul style="list-style-type: none"> <li>Monitors are unobtrusive and don't interfere with performances</li> <li>Relatively cheap compared to other digital recording options</li> <li>Can be transmitted to a central hub for immediate access</li> <li>Records playing intensities for a direct link to energy system interplay</li> </ul>	<ul style="list-style-type: none"> <li>Lag time between performance effort/workload changes and monitor detecting this change – delayed 'real-time signal'</li> <li>Recorded data may need to be downloaded before it can be used</li> </ul>
Global positioning system (GPS)	<ul style="list-style-type: none"> <li>Monitors are unobtrusive and don't interfere with performances</li> <li>Provides accurate and clear links to field/movement patterns</li> <li>Identifies playing intensities and associated changes/drops that suggest fatigue and a need to rest/rotate players</li> </ul>	<ul style="list-style-type: none"> <li>Some models don't transmit data and thus it must be downloaded post-performance</li> </ul>
Aerial sports analysis	<ul style="list-style-type: none"> <li>Every player visible at all times and in context with other players on the field</li> <li>Close-ups and specific performance angles can be captured to allow superior biomechanical and tactical analysis to be performed</li> </ul>	<ul style="list-style-type: none"> <li>Systems/equipment is expensive</li> <li>Many operators and high degree of technical expertise required to use the equipment</li> </ul>

To gain a thorough understanding of game requirements, data should be collected that will enable analysis of movement patterns, fitness components, energy systems, skill frequencies, playing intensities (including work-to-rest periods and heart rates) and the use of muscle groups in performing skills. With direct observation or the viewing of digital recordings, it is vital that the performer is in view at all times. It is impossible to conduct an activity analysis by simply viewing TV footage of a game of football, netball, basketball or beach volleyball because the data is incomplete.

## 9.2 CHECK-IN QUESTIONS

- Clearly **discuss** why an activity analysis cannot be performed on an AFL player by simply watching a replay of the game provided by the official television broadcaster.
- A netball goal shooter is having their shooting technique assessed by the coach. The coach has prepared a benchmark/checklist before observing the goal shooter take shots from multiple distances and angles at goal.
  - Explain** why using digital recording as part of goal shooting analysis is the optimal method to improve the netballer's goal shooting technique.
  - Outline** two limitations of using direct observation to **analyse** the goal shooter's technique.
- Explain** why a coach might refer to slow-motion replay of a player performing a skill by providing a sporting example of your choice.
- ©VCAA Exam 2019, Section B, Q7

The graph below shows the serve accuracy data of two badminton players over four training sessions.



**Identify** one method of data collection that a coach could have used to obtain the data above, and provide one benefit of using this method.



**Assessment**  
9.2 Check-in questions

### Command terms

#### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

#### analyse

Identify components/elements and the significance of the relationship between them; draw out and relate implications; determine logic and reasonableness of information

#### identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

## 9.3 COLLECTING AND ANALYSING DIFFERENT TYPES OF DATA

In this module you will learn about:

- make connections between collected data and energy systems, fitness components and major muscles used during sports
- data/evidence-based decision-making with objectivity and learn to:
- use specificity when linking data to fitness tests and training actions.

### Skill frequency analysis

Skill frequency data is mainly used to inform coaches and analysts about the involvement of fitness components and major muscle groups in performances. The effectiveness of skills can also be considered in an effort to improve technical and tactical aspects of the performance.

### Tennis

For example, Table 9.02 shows frequencies for skills that a tennis player used during the first set of a match. The data shows that the player was 92 per cent effective for forehand ground strokes, but only 65 per cent effective for backhand. This information helps the coach identify a skill that can be improved.

The effectiveness of skills provides crucial information for elite coaches and performers conducting a qualitative movement analysis and seeking to improve tactical and technical aspects of performance. Senior physical education students wanting to design a training program to make physiological improvements need to focus on the physiological performance demands and how to best replicate these via training.

The analysis also provides important information about physiological parameters. For example, knowing that the player executed five smashes in the first set would indicate that arm power is important.

**TABLE 9.02** Skill frequencies for a tennis player

Skill	Forehand	Backhand	Serve	Smash	Volley	Lob	Directional change
Frequency	68	52	64	5	29	4	198
Effectiveness (%)	92	65	81	80	90	50	n/a

n/a = not applicable

The number of serves also indicates that arm power is an important component, and data about the number of forehand and backhand winners might also support this. The large number of directional changes is a clear indication that agility is very important, and, because players can't be agile unless they are fast and flexible, speed and flexibility would also be important related fitness components.



Juergen Hasenkopf/Alamy Stock Photo

**FIGURE 9.07** Skill effectiveness is an additional consideration to skill frequency that a coach may use.

## Australian Rules football

Table 9.03 shows frequencies for skills that an Australian Rules footballer used during one quarter of a match. Knowing that the player had 15 kicks measuring longer than 45 metres would indicate the reliance on leg power and flexibility, but a right-foot disposal efficiency of 85 per cent compared with 55 per cent for the left foot would indicate that left-foot skills need attention.



Michael Willson/AFL Photos/Getty Images Sport/Getty Images

**FIGURE 9.08** Overhead marks require a high degree of muscular power.

**TABLE 9.03** Sample skill frequencies for an Australian Rules footballer

Skill	Tackle	Overhead (aerial) mark	Kick <45 m	Kick >45 m	Handball	Directional change
Frequency	8	7	L: 2, R: 3	L: 4, R: 11	L: 1, R: 13	255
Effectiveness (%)	100	100	L: 60, R: 95	L: 50, R: 80	L: 100, R: 95	n/a

L = left, R = right, n/a = not applicable

Table 9.03 also reveals many directional changes, indicating a reliance on high levels of agility and muscular power. The use of muscular power is also evident from the number of kicks over 45 metres in length. Strength is quite often observed in team sports where contact is a feature of the game, such as Australian Rules football, Rugby League and soccer. The eight tackles recorded most likely involve maximal contraction force being applied over a longer time than for muscular power, and would therefore call upon muscular strength.

## Basketball

Table 9.04 shows typical skill frequencies in a game of basketball. The skills must be broken down into the major associated muscles, and specific fitness tests must be chosen to match (as closely as possible) the way muscles are used during the game. This is taken a step further when the muscles are trained specifically, using similar actions, as part of a training program (see Table 9.05 for examples).

**TABLE 9.04** Skill frequencies for basketball

Skill	Frequency	Skill	Frequency
Chest pass	38	Defend	35
Overhead pass: 2 hands	8	Leap forwards	16
Overhead pass: 1 hand (shoulder pass)	15	Leap sideways	12
Rebound	7	Directional change	95
Jump	52	Posting or screening	9
Guard	12		

## LOOKING FORWARD

### Assessment of fitness and training principles

#### Chapters 10, 12

Specificity must be taken into account when considering the most appropriate fitness test and training activities that mimic actions from the activity analysis.

### Specific examples from the basketball analysis

Posting or screening requires high levels of core strength to hold off (or hold out against) opponents. A fitness test focusing on core strength such as the seven-stage sit-up test would be ideal as it targets these muscle groups. Similarly, training activities that focus on these lower back and abdominal muscle groups while developing strength should be considered. The skill data collected during the basketball analysis was further considered in terms of the major associated muscles and actions used during the performance, and Table 9.05 provides a summary of the most relevant information.

**TABLE 9.05** Basketball skills and associated muscle groups with specific fitness tests and training activities

Skill	Major muscles	Specific fitness test	Specific training activity
Chest pass (38)	Pectorals, deltoid, trapezius	Seated basketball throw	1 Clap push-ups 2 Pec deck resistance machine (weights) 3 Power presses – fast and low % RM
Shoulder pass (15)	Biceps, triceps, pectorals, trapezius	Baseball throw	1 Overhead elastic pulls 2 Dips 3 Lat pull-downs (weights)
Leap – including rebounds/jumps (87)	Quadriceps, hamstrings, gastrocnemius, tibialis anterior	Vertical jump	1 Wall slaps 2 Stair running 3 Depth jumps (plyometrics)
Directional change (95)	Quadriceps, hamstrings, abdominals, lower back	SEMO agility	1 Agility sprints over 5–10 metres 2 Short interval sprints 3 ‘Speed ladders’

## Movement pattern analysis

Movement patterns are sometimes referred to as ‘locomotor patterns’ and basically reveal where a player moves during a match. They also capture distances and intensities associated with each type of movement. It is easy to create an image of the playing area, either on a sheet of paper or digitally on a screen, but it’s nearly impossible to have your eyes on the recording sheet/screen and the player at the same time. This is made even more complex when considering the movements of players such as midfielders, who cover large distances and are involved in frequent repeat efforts.

Fortunately, **global positioning system (GPS)** devices have become more accessible in terms of technical knowledge and cost. Schools can purchase a GPS unit with associated performance-analysis software for approximately \$500. More advanced systems allow for the integration of multiple players from the same team and can transmit movements in ‘real time’, which allows coaches and fitness staff to make immediate decisions during a game. Recall also that, because the data is recorded digitally, it can be saved and analysed in multiple ways at any future time.

### global positioning system (GPS)

A satellite-based navigation system that can use body sensors to locate and track performers’ position and movements

Paul Greenwood/BPI/Shutterstock.com

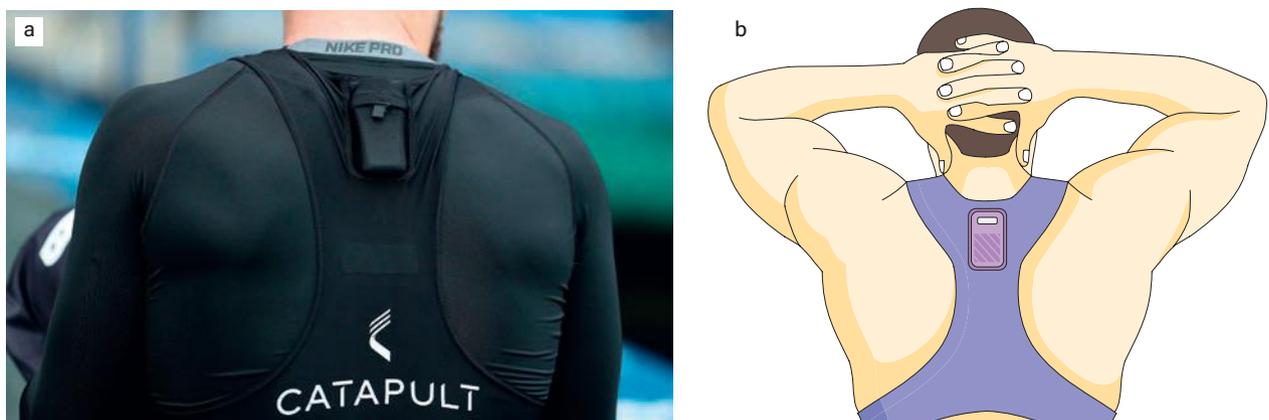

**FIGURE 9.09 a** GPS in use during soccer training, and **b** typical location and unobtrusive/non-restrictive wearing of the GPS unit

Table 9.06 shows a sample analysis of a player's movement during two quarters of an AFL game. Each zone equates to a range of movement speeds. For example, zone 1 (0–6 kilometres per hour) would include walks and low-intensity jogs while, at the other end of the scale, zone 6 (22–40 kilometres per hour) would be high-intensity sprints.

### fatigue

A decreased capacity, or an inability, to maintain a given force production or power output

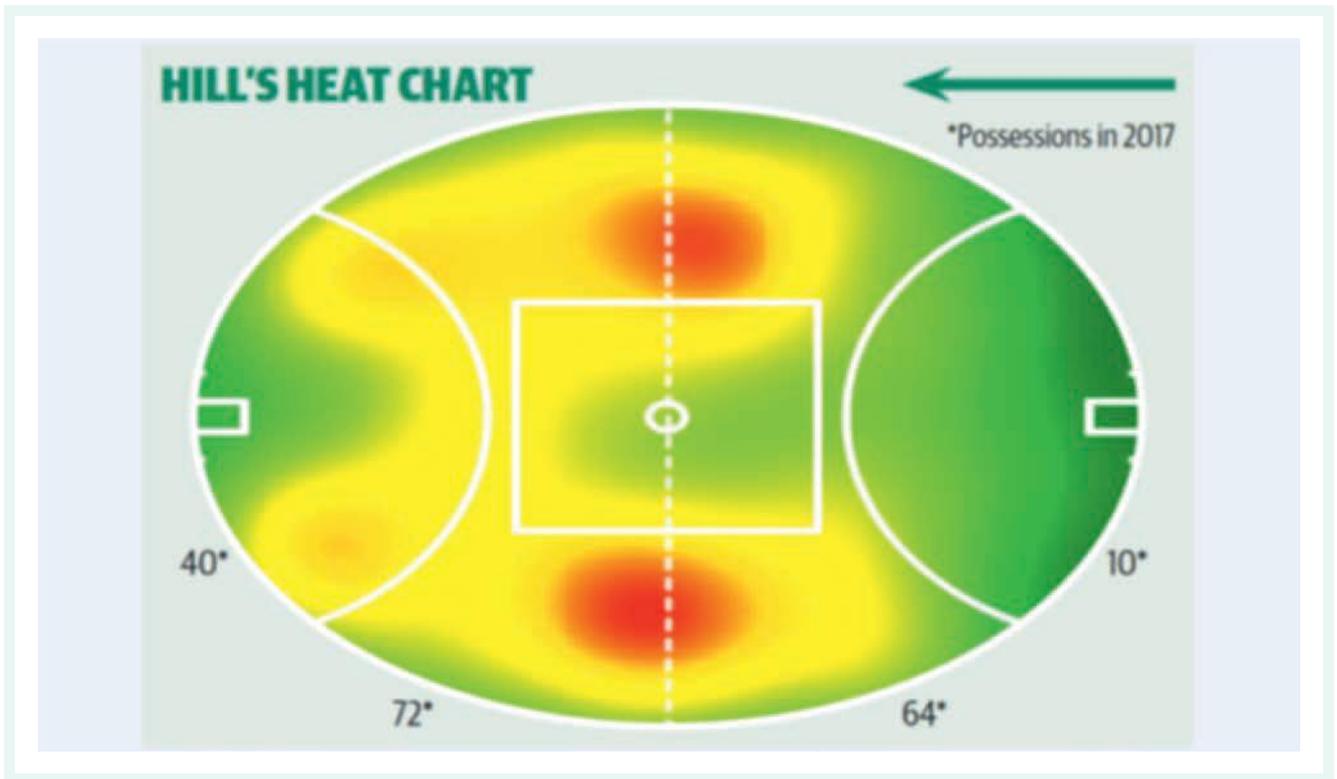
The data reveals obvious **fatigue** when comparing last-quarter efforts to those from the first quarter. For example, in the last quarter:

- there were only three zone 6 entries, compared with 14 in the first quarter
- 51.3 per cent of time was spent in zones 1 and 2, compared with 34.1 per cent in the first quarter
- the average sprint distance was 12.6 metres (37.9 metres ÷ 3 efforts). This had dropped from 24 metres (335.6 metres ÷ 14 efforts) in the first quarter.

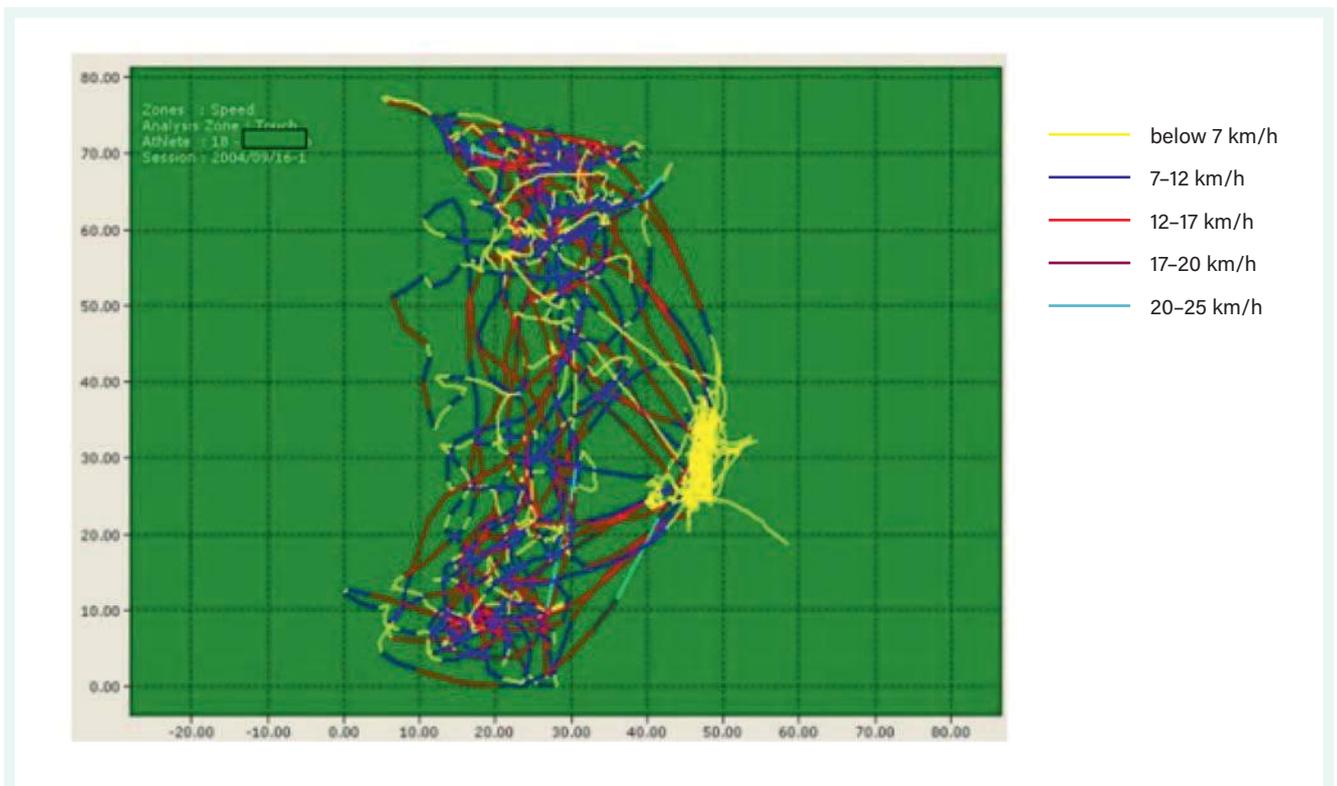
**TABLE 9.06** Movement patterns for an AFL player in the first and last quarters of a game

Zone	Speed range (km/h)	Distance (m)	% of quarter	Entries
<b>1st quarter</b>				
1	0–6	712.6	21.8	68
2	6–10	403.3	12.3	111
3	10–14	780.0	23.8	93
4	14–18	686.2	21.0	60
5	18–22	353.5	10.8	33
6	22–40	335.6	10.3	14
<b>Total</b>		3,271.2		
<b>4th quarter</b>				
1	0–6	685.5	40.7	41
2	6–10	178.8	10.6	55
3	10–14	326.3	19.4	49
4	14–18	303.2	18.0	33
5	18–22	150.8	9.0	15
6	22–40	37.9	2.3	3
<b>Total</b>		1,682.5		

GPS data can be superimposed over the image of the playing field to create a summary of where players have moved on the field. These 'heat maps' are often produced for the benefit of television viewers and do not provide the amount of useful information seen in the previous example, which allows coaches to make specific training interventions. Bradley Hill's heat map in Figure 9.10 reveals Hill spent most of his time in his back half to support the defence. He also used his explosive speed (red zones) to help drive the team into their offensive half of the field. The data also shows Hill covered most of the ground during the match and he would rely heavily on the aerobic energy system and aerobic power as a fitness component – both of which would no doubt feature heavily in specific aerobic-based training activities.

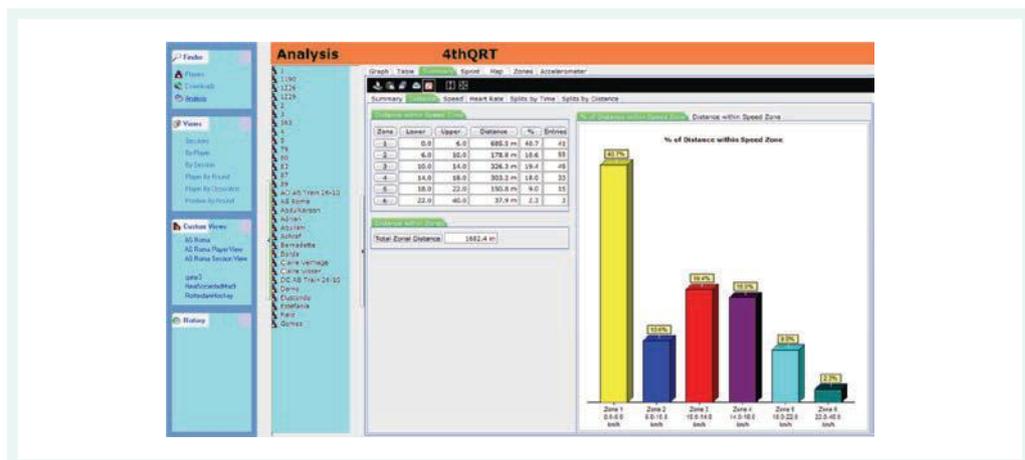


**FIGURE 9.10** Bradley Hill's GPS 'heat map' during an AFL game when playing for the Fremantle Dockers



**FIGURE 9.11** In this touch rugby example, the grid lines are 10 metres apart and the colour-coded lines indicate the player's actual speed and field coverage.

Fortunately, GPS software allows users to remove one or more speed zones to more accurately analyse a particular workload/intensity.



**FIGURE 9.12** GPS data showing the percentage of time spent in each different intensity zone

Analysis of the movement patterns allows a specific sprint distance to be selected for fitness testing. There is little point in assessing a player's speed over 100 metres if this rarely or never occurs during a football match. A more specific speed test could be the 30-metre sprint test or, depending on their playing position, a 20-metre sprint. A repeat effort sprint recovery test may be another relevant fitness test to consider if the analysis reveals periods of high intensity followed by short breaks. Players need to be constantly replenishing their creatine phosphate (CP) stores following repeated high-intensity efforts. The ability of the body to replenish phosphates is assessed via the phosphate recovery test (see Chapter 10).

## LOOKING FORWARD

### Assessment of fitness

#### Chapter 10

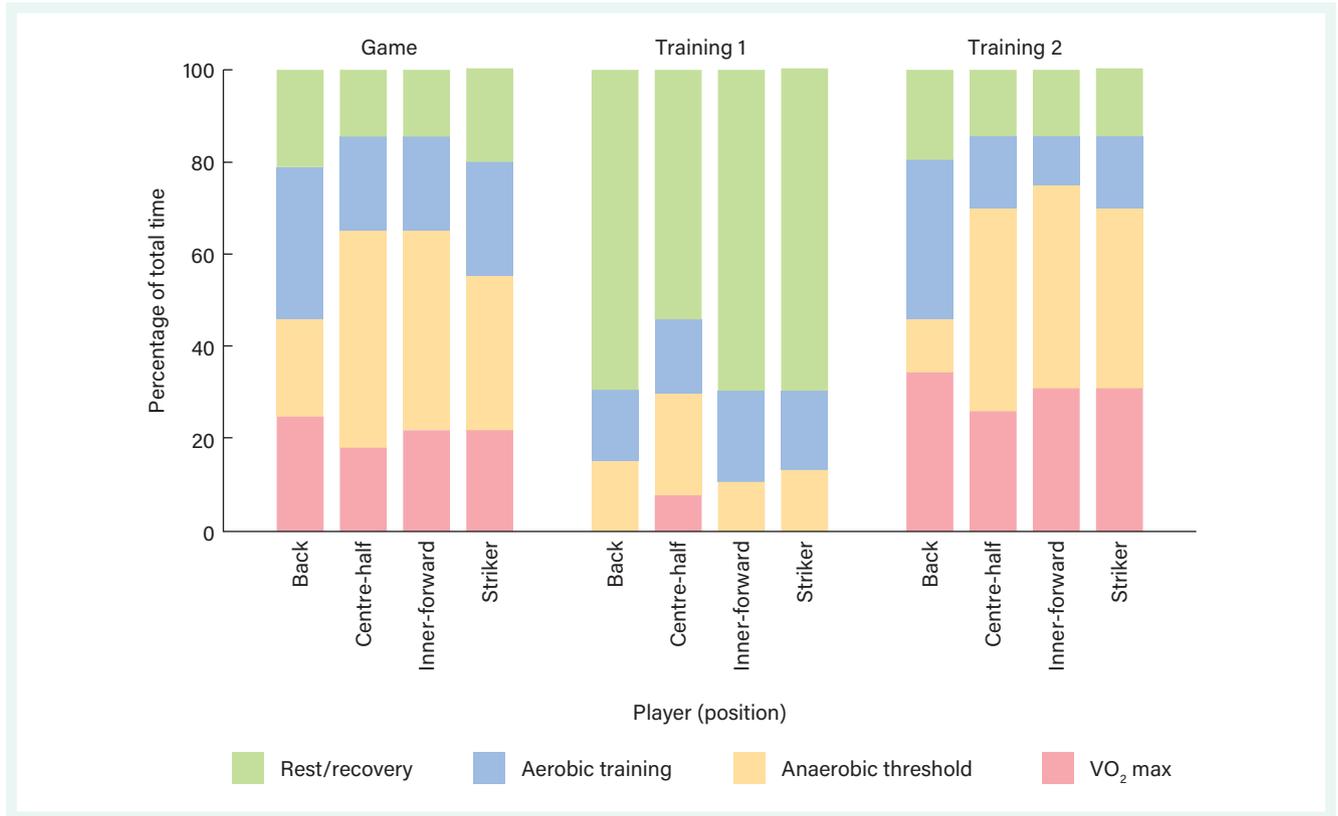
The most appropriate fitness tests mimic muscle actions, distances covered and intensities from the activity analysis.

If 24 metres is the average sprint distance observed during the game, the short course (25 metres) would be much more specific to game demands than the long course (40 metres).

As soon as players start showing a decrease in the number of high-intensity efforts, coaches consider giving them a short break. This gives the players an opportunity to refuel, recover and then rejoin the game and have a greater input. It also allows them to communicate directly with the coach, giving them an opportunity to discuss tactics they need to put in place when they return to the field. In the long term, this data can be used to make training more specific, building the player's capacity to bring about improved performance.

It is vital that the game intensities identified in the activity analysis are replicated during training sessions to specifically train and develop the associated energy systems and fitness components. You should also note that specificity carries over during training, with similar work-to-rest periods being reproduced.

In Figure 9.13, Training 1 spends too much time at low intensities, which is not replicating what occurs during the game. This reveals that Training 1 lacks specificity and real purpose. It seems that players, regardless of their playing positions and different demands, are all expected to train in the same way. Training 2 better simulates what happens during the game, making it much more specific and tailored to the individual energy system and fitness component requirements of each player.



**FIGURE 9.13** Intensities observed during a game of hockey and two different training sessions

## LOOKING FORWARD

### Training principles

#### Chapter 12

Specificity is a training principle that must be applied to training activities, ensuring actions from the activity analysis are reproduced.



## COLLABORATIVE TASK

### Prac/Lab activity

#### Collecting movement patterns

Figure 9.14 can be used as the basis for a statistical recording sheet to be used when viewing games or competitions. It might prove to be easier to use and provide more useful data than trying to draw the types of movements occurring on an image of the playing field. Use a separate sheet for each time period; this could range from 10 minutes to a quarter or a half of the game, depending on the sport or activity. It is very important to record the stage of the game, as this allows for consideration of fatigue and recovery mechanisms.



Template  
Locomotor  
recording sheet

LOCOMOTOR RECORDING SHEET									
Observation time (stage of the game): _____ (minutes)									
Locomotion (zone)	Intensity	Distance moved (m)				Number of entries	Distance in the zone (m)	% of total distance	Average distance (m)
		0-5	6-10	11-15	16+				
Walk	Low								
Jog	Low-medium								
Shuffle	High								
Sprint	Very high								
Totals							100%		

**FIGURE 9.14** An example of a locomotor recording sheet

Table 9.07 gives sample data from one row of a locomotor recording sheet, including the calculated distance in the zone.

**TABLE 9.07** Sample data from the 'Sprint' zone of a locomotor recording sheet

Distance moved (m)				Number of entries	Distance in the zone (m)	Average distance (m)
0-5	6-10	11-15	16+			
				21	193	$193 \div 21 = 9.2$

## 9.3 CHECK-IN QUESTIONS

1 **List** five of the most common skills that would be observed (live or recorded) for each of the following sports:

- a badminton
- b soccer
- c basketball.

2 The following skills are commonly observed when collecting data on volleyball:

- serve
- block/spike (legs)
- lateral/sideways lunge.

**List** the major muscles associated with each of the above skills and, if you can, based on previous knowledge, describe a training activity or exercise that closely replicates the movements involved in the skill.

3 The following table reveals the frequency of some skills performed during a game of netball by a national-level centre player.

Skill/Movement	Frequency
Sprint	87 @ 0.7 s average
Jump/leap	22
Short chest/centre pass (< 5 m)	98
Long shoulder pass (> 10 m)	35
Changing direction	117

- a **Justify** why it is vital, when conducting an activity analysis, to select the highest level that is accessible, rather than observe someone on your own team.
  - b **List** the major fitness component associated with each of the skills/movements in the table.
  - c The average duration of a sprint was expressed in seconds rather than metres. Estimate how far a netball centre would sprint in 0.7 seconds and then select a similar sprint distance for a fitness test used to assess this component.
- 4 **Discuss** how movement patterns obtained via a games analysis can be used in the next stages of planning a training program. In particular, discuss how they can be used when considering:
- fitness test selection
  - training program activities/exercises.
- 5 **Outline** why it is preferable to use GPS technology and analysis software, rather than superimposing the different movement patterns players make on images of the playing area.
- 6 Some analysts believe it is equally important to gather information on the type and duration of recovery, as well as the type and duration (time or distance) of movements performed during a game. **Suggest** ways in which coaches and fitness staff might use recovery data.



### Assessment

9.3 Check-in questions

### Command terms

#### list

Provide a series of related words, names, numbers or items that are arranged consecutively

#### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

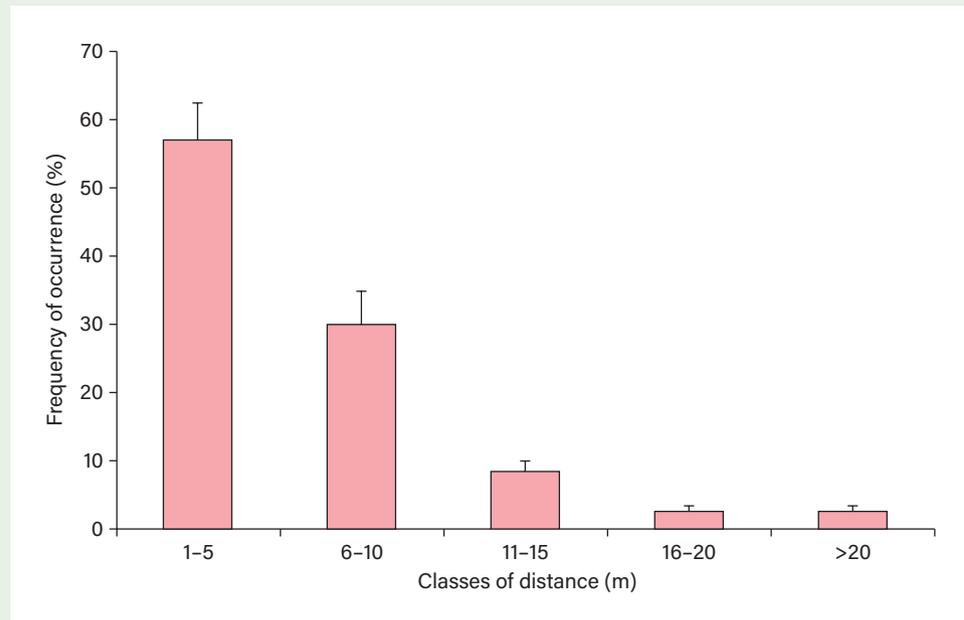
#### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer





7 The movement pattern data shown in Figure 9.15 and Tables 9.08 and 9.09 was obtained from an elite women's basketball game.



**FIGURE 9.15** Mean and standard deviation of frequency of occurrence (in percentage) of sprint activity in relation to five different distances

Source: Conte, D. et al. (2015), 'Time-motion analysis of Italian elite women's basketball games: Individual and team analyses', in *Journal of Strength and Conditioning Research* 29(1): 144–150

**TABLE 9.08** Mean and standard deviation of the most common locomotor patterns

Classes of activity	Frequency of occurrence (n)	Frequency of occurrence (%)	Live time (%)	Duration (s)
SW	205 ± 42 (121–280)	35.4 ± 2.0	50.2 ± 5.5	7.42 ± 10.58
LM	91 ± 23 (55–137)	15.5 ± 2.0	10.0 ± 2.7	1.69 ± 1.17
JOG	73 ± 20 (40–121)	12.8 ± 3.0	11.7 ± 2.9	2.66 ± 2.21
MM	56 ± 20 (20–104)	9.6 ± 2.5	6.5 ± 2.4	1.77 ± 0.95
RUN	63 ± 16 (36–105)	11.0 ± 1.8	13.1 ± 2.4	3.13 ± 1.58
HM	25 ± 10 (13–56)	4.5 ± 1.5	2.7 ± 1.4	1.62 ± 0.92
SPRINT	44 ± 15 (18–72)	7.8 ± 2.2	5.2 ± 1.8	1.77 ± 0.80
JUMP	19 ± 10 (5–44)	3.4 ± 1.5	0.6 ± 0.3	0.46 ± 0.13

SW = standing/walking; LM = low-intensity-specific movement; JOG = jogging; MM = medium-intensity-specific movement; RUN = running; HM = high-intensity-specific movement; SPRINT = sprinting; JUMP = jumping of players for each game in relation to their occurrence (n and %), proportion of live time (%) and duration (s)

**TABLE 9.09** Mean and standard deviation of frequency of occurrence (in percentage) of three different sprinting types, with or without the ball

Sprint activity	Total sprint	Sprint with the ball (%)	Sprint without the ball (%)
Linear	48.3 ± 2.9	14.5 ± 2.9	48.3 ± 2.9
Curved	31.0 ± 3.9	59.1 ± 2.0	25.2 ± 4.1
Change of direction	20.7 ± 1.5	26.4 ± 5.9	19.6 ± 1.1

**a** Figure 9.15 reveals that most sprints were less than 10 metres long. What implications would this have when selecting a fitness test and then potential activities in a training program?



&gt;

- b** Use the data in Table 9.08 to determine the percentages of aerobic-based and anaerobic-based work. What conclusions can you make in relation to their inclusion in a training program?
- c i** When considering the different types of sprints, with and without the ball, **propose** a reason why more curved sprints are performed with the ball and more linear sprints are performed without the ball.
- ii** There are more directional changes with the ball than without it. If you were coaching these players, how would you use this information when designing a specific training drill to improve the associated fitness component and skill at the same time?

**Command term****propose**

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action

## 9.4 HEART RATE ANALYSIS

In this module you will learn about:

- heart rate being used as a measure of performance intensity
- heart rate 'lag'
- heart rates being used to set 'training limits' based on major energy system being targeted
- heart rates working alongside AI to better set training loads and monitor workloads and learn to:
- distinguish between practicality and accuracy of measurement tools.

Heart rate data provides information about the intensity of effort during sporting performances and training sessions. It should also be collected during rest, warm-ups and recovery to provide a complete assessment of how a person is responding, both physiologically and psychologically.

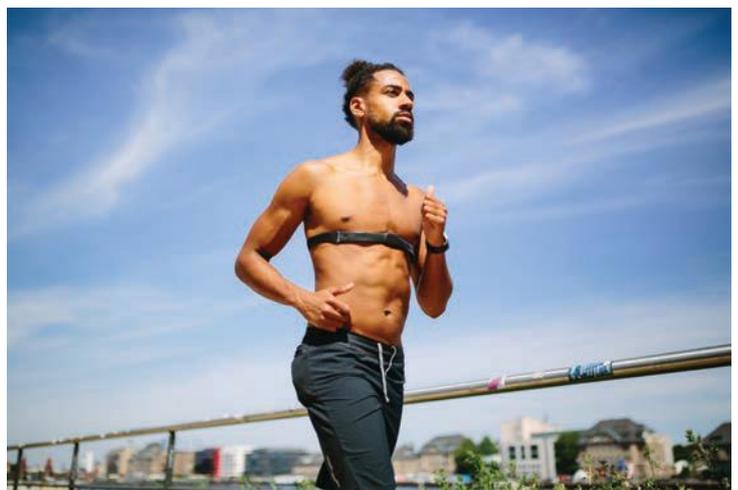
### DID YOU KNOW?

An elevated resting heart rate is an indication of overtraining, and this often flags to coaches and sports trainers the need to review training programs and recovery modalities.

## Heart rate monitoring

Heart rate monitoring was originally used only by elite and professional athletes and clubs, who had access to the expensive technology and the expertise required to assess the data. Typically, this involved the use of chest strap/band monitors, which quickly improved in comfort levels as their design became smaller, less obtrusive and non-restrictive to performances.

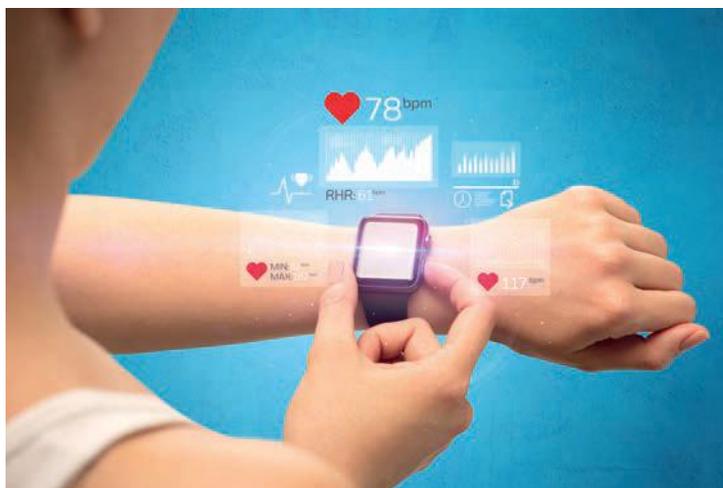
In recent years, heart rate monitoring has become much more accessible and practical, thanks to a range of 'smart watches' using heart rate sensor technology that are worn around the wrist. More recently, wearable devices embedded in smart clothing transmit heart rate information to smart watch, mobile phone or computer screens.



**FIGURE 9.16** Chest strap/band heart rate monitors accurately capture heart rates.

iStock.com/alvarez

ra2.studio/Shutterstock.com

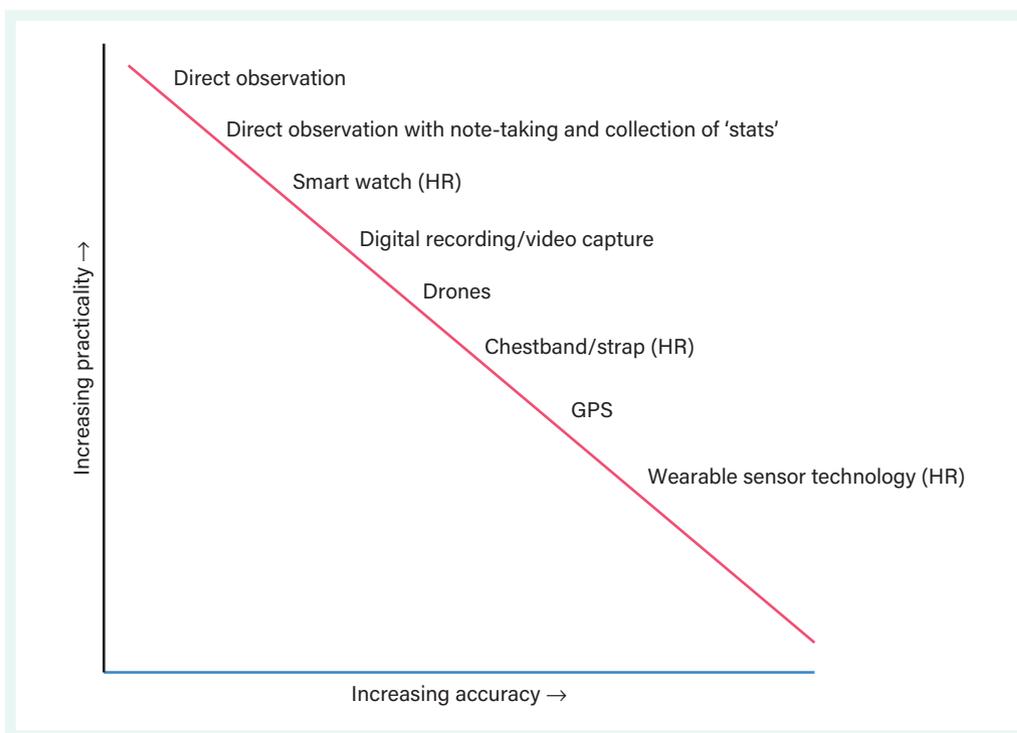


**FIGURE 9.17** Smart watches provide an easy and practical way of monitoring heart rates.

All these devices provide data in real time, but there is a trade-off between accuracy and **practicality**. Smart watches are the most practical, but also have the lowest levels of accuracy, whereas chest strap/band devices are the least practical but the most accurate. While a smart watch might be very suitable for a PE student who wants to monitor their training intensities, its data might need to be downloaded (if possible) before it can be analysed and used in determining activity requirements and associated specific training. More expensive options typically provide a greater range of functions and are often associated with increased accuracy and, therefore, more usable data.

**practicality**

A measure of how conveniently an object can be set up and used



**FIGURE 9.18** The trade-off between practicality and accuracy of various games analysis options

## DID YOU KNOW?

Artificial intelligence (AI) and heart rate analysis can combine through human and 'machine' collaboration to improve the quality of training. They do this by ensuring that training workloads are kept consistent, rather than varying within a range – especially when considering aerobic-based training. For example, an automated real-time heart rate control system used with treadmills, rowers, ellipticals and bikes can adjust the resistance, incline or operating speed when heart rates change slightly to ensure that they stay within a 1–2 beats per minute (bpm) range, rather than a much broader 5–10 bpm range. This is vital to ensuring that the workload/intensity remains 'locked' at a certain rate, rather than within a range. A midfielder, for example, may want to work at or just below their **lactate inflection point (LIP)**, which is where the greatest gains are made to aerobic power. For this example, let's assume the LIP occurs at 85% max HR.

### lactate inflection point (LIP)

The highest workload/intensity a person can sustain, which represents maximal lactate production being matched by maximal lactate removal. This is also sometimes referred to as a person's highest steady state associated with no accumulation of lactate.

## Heart rates and training zones

Simply running on a treadmill with heart rate monitoring could see a performer running at 165 bpm. In trying to then increase to 85% max HR (170 bpm), they might work harder than necessary and overshoot this key indicator. If this happened, they would start to increase activation from the anaerobic glycolysis system, rather than maintaining maximal contribution from the aerobic energy system as they would if they were working at LIP. Artificial intelligence, linked to the treadmill, would ensure the workload increased to exactly match LIP and did not go any higher. The longer the performer is able to work at LIP, the better the aerobic training responses will be.

Heart rate data can inform players and conditioning staff of the intensity training zones they should be working at during training sessions. This ensures that the relevant energy systems and fitness components are being specifically developed during training. For example, you may have completed an activity analysis of a midfielder in hockey or soccer. This player may frequently move at high intensity over short distances during their game, and heart rate data would reveal an elevation of heart rate during these efforts. In situations where efforts are exceptionally short, the time for heart rate to increase significantly may not allow this to be recorded due to a lag between the maximal workload and the lift in heart rate.

Imagine performing a 20-metre sprint from rest. Despite working at maximal intensity, the short duration of effort does not allow the heart rate to increase significantly over the 2–3 seconds for which the performer is working maximally. This is what is meant by the 'lag' between effort and heart rate.

In the above example, a GPS monitor would accurately record speed and velocity changes, which can be expressed as a percentage of maximum heart rate. To replicate these specific actions and intensities during a training session, the performer would need to reproduce the intensities recorded during the games analysis. In practical terms, this may be achieved by undertaking short-interval training.



**FIGURE 9.19** Collecting heart rate data for comparison with exercise workloads before using AI to optimise training by synchronising heart rate monitoring and treadmill resistance/flow

Gerodentkoff/Shutterstock.com

**chronic adaptations**

Long-term improvements occurring in multiple body systems in response to sustained training and correct application of training principles

**LEARNING HACK**

'max HR' is an abbreviation for maximum heart rate.

'LIP' stands for lactate inflection point. At this stage of exercise, athletes are performing aerobically at the highest workload they can without accumulating any lactate. Endurance performers try to increase their LIP and aerobic power so they can work aerobically at higher intensities.

'bpm' is recognised as the abbreviation for beats per minute, which is the unit used to measure heart rate.

Conversely, the heart rate data for a hockey or soccer goalkeeper may reflect low-intensity workloads during most of the game, such as those periods when the play is at the other end of the ground and they are not directly involved in it. This heart rate data would indicate that the goalkeeper works at a low intensity or submaximally during most the game. This suggests that the aerobic energy system is their major energy provider during the match. The goalkeeper moves explosively to make saves when opposition players take shots at goal, but this makes up a very small percentage of the game. It is critical to reproduce the playing intensities during training sessions in order to improve **chronic adaptations**.

**LOOKING FORWARD****Chronic training adaptations****Chapter 15**

The body will adapt, and hopefully improve, its ability to meet performance demands as a result of training.

**DID YOU KNOW?**

The International Olympic Committee added 3x3 (or 3v3) basketball to the Youth Olympic Games held in Singapore in 2010. It was first added to the Olympic basketball program at the Olympic Games held in Tokyo in 2021. At the Paris 2024 Olympics, Germany won the women's gold medal, and the Netherlands won the men's gold.



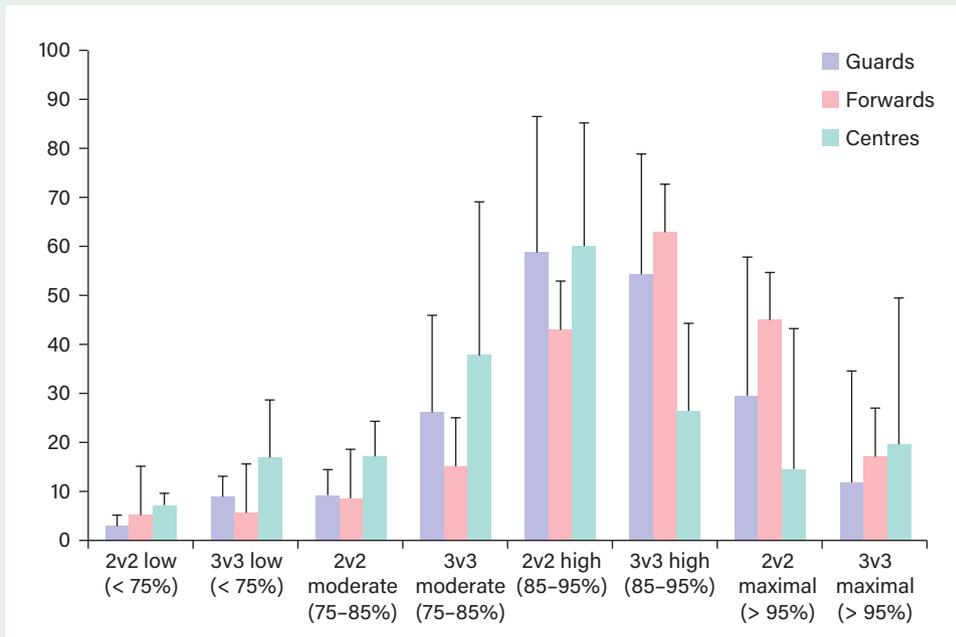
**FIGURE 9.20** 3x3 basketball was popular with spectators when it was first included in the Olympic Games in Tokyo in 2021.

**LOOKING FORWARD****Training principles****Chapter 12**

In Chapter 12 you will be taken through the major training principles, including specificity, which also has applications when considering fitness test selection.

## 9.4 CHECK-IN QUESTIONS

- List** two limitations of using a smart watch to collect heart rate data during a team sport such as netball or football.
- Suggest** two sporting activities where it would be unsuitable to collect heart rate data. For each, clearly discuss why you would not recommend trying to collect heart rate data.
- The heart rate data shown in Figure 9.21 was obtained from a group of elite basketball players involved in 2v2 and 3v3 competitions. Games consisted of three 4-minute bouts separated by 1-minute rest periods.



**FIGURE 9.21** Mean and standard deviation of frequency of occurrence of four different heart rate zones for guards, forwards and centres during 2v2 and 3v3 basketball competitions

Adapted from Delextat, A. & Kraiem, S. (2013), 'Heart-rate responses by playing position during ball drills in basketball', in *International Journal of Sports Physiology and Performance* 8(4): 410–418

- After considering the data, **justify** which intensity you would recommend players train at if they were going to compete in the Olympic 3v3 event.
  - Propose** a reason why there would be higher frequencies of low-intensity efforts in these modified basketball competitions than in traditional 5v5 games.
  - Explain** how the data confirms that training needs to be individualised and made specific to the different roles performed by guards, forwards and centres.
- After the initial minute or so during each 4-minute playing bout, the players' heart rates tended to remain fairly constant (see Figure 9.22). Briefly **discuss** why you believe this to be the case.
    - During the 4-minute bouts, the aerobic energy system would have produced most of the energy/ATP for movements to occur. As a coach for a traditional 5v5 basketball team these players belong to, **justify** which type of modified training drills (2v2 or 3v3) you recommend players engage in to improve the amount of ATP supplied by the aerobic energy system.



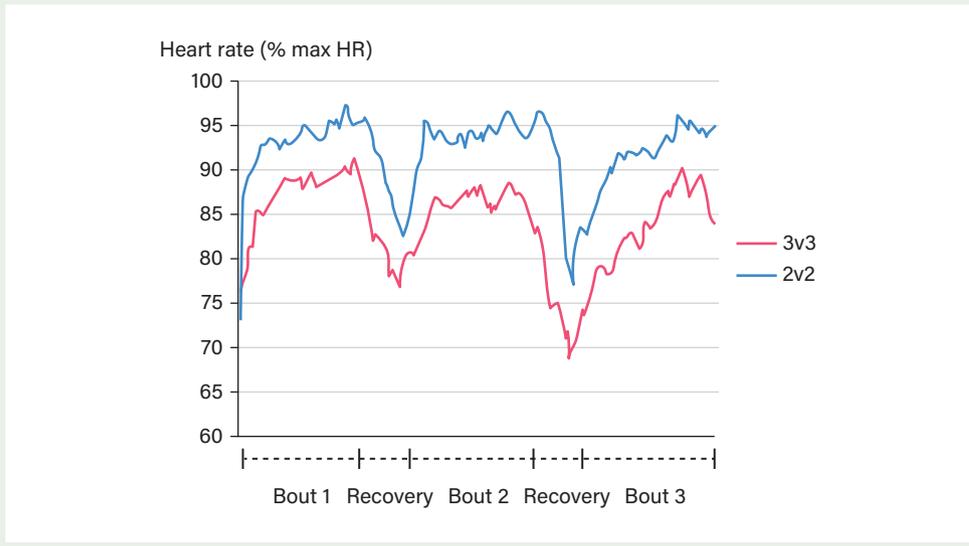
**Assessment**  
9.4 Check-in questions

### Command term

#### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions





**FIGURE 9.22** Heart rate response, as a percentage of maximum heart rate, during 2v2 and 3v3 basketball competitions

Adapted from Delestrat, A. & Kraiem, S. (2013), 'Heart-rate responses by playing position during ball drills in basketball', in *International Journal of Sports Physiology and Performance* 8(4): 410–418

## 9.5 WORK-TO-REST RATIO (W:R) ANALYSIS

In this module you will learn about:

- work-to-rest ratios providing information about energy system involvement in activities
- objective vs subjective ways of recording work and rest periods and learn to:
- assign intensities to periods of work
- link work-to-rest ratios to specific game requirements and training activities.

**LEARNING HACK**  
'W:R' is the abbreviation for work-to-rest ratio.

As the name suggests, this type of data compares the amount of time engaged in physical activity (work) with the time spent recovering (rest). Work-to-rest ratios are not relevant when analysing continuous activities. As mentioned previously, work-to-rest ratios should be reproduced during training activities to ensure specificity is adhered to.

Simply measuring the amount of work and rest during performances can be misleading unless the intensity of work is also considered, as this provides better insights into energy system interplay and recovery.

For example, Table 9.10 reveals the work and rest periods at the start of netball game.

**TABLE 9.10** Work and rest periods (in seconds) during the first 2 minutes of a netball game

W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
5	15	3	2	3	15	15	10	14	5	5	5	7	5	4	7

The work-to-rest ratio (W:R) in this example is 56:64, which can be rounded off to 1:1. As a rough guide, Table 9.11 reveals the work-to-rest ratios associated with the major energy system used during sporting performances. Table 9.10 suggests that, for the 2-minute passage of play at the start of the netball game, the major energy system producing ATP is the aerobic energy system. However, as no indication of intensity has been included in the data collected, the 56 seconds of work could have been made up mainly of low-, medium- or high-intensity efforts, and this would significantly change the energy system interplay and contribution. For example, a player with a W:R of 1:3, made up of 30 seconds of medium-intensity efforts and 90 seconds of rest, would have a very different energy system contribution from a player with the same W:R (1:3) made up of 30 seconds of high- to very high intensity efforts with 90 seconds of rest.

**TABLE 9.11** Work-to-rest ratios and major energy system usage

Work-to-rest ratio (W:R)	Major contributing energy system
1:5+ (rest is much higher than work periods)	ATP-CP
1:3-1:4 (rest is higher than work periods)	Anaerobic glycolysis
1:1-1:2 (similar rest and work periods) or 2+:1 (work is higher than rest periods)	Aerobic

PLAYING INTENSITY RECORDING SHEET																						
Player:	<i>Sasha</i>										Date:	<i>3 July</i>					Time:	<i>10:06</i>				
Time (seconds)	5	3	3	15	14	5	7	4	6	5	4	8	4	7	10	10	5	8	4	5	2	15
Intensity	M	H	H	M	L	V	H	V	H	L	M	H	H	H	L	L	M	H	L	M	H	M
Rest (seconds)	15	2	15	10	5	5	5	7	2	25	10	16	12	20	14	14	15	12	10	25	3	20

L = Low, M = Medium, H = High, V = Very high



**Template**  
Playing intensity recording sheet

**FIGURE 9.23** Example of a playing intensity recording sheet, showing work periods and intensities vs rest periods during the first quarter of a netball game

The area highlighted yellow on the recording sheet shows consecutive areas of very high or high-intensity actions with limited rest, and thus limited ability to restore creatine phosphate. Having only limited CP restoration breaks during team sports brings more and more of the anaerobic glycolysis system into play when producing energy/ATP. This also results in increased accumulation of metabolic by-products and associated fatigue, requiring players to rest more and/or perform at reduced workloads. The more often this occurs during a game, the more it needs to be prepared for, and replicated, during training.

## LOOKING BACK

### Three energy systems

#### Chapter 6

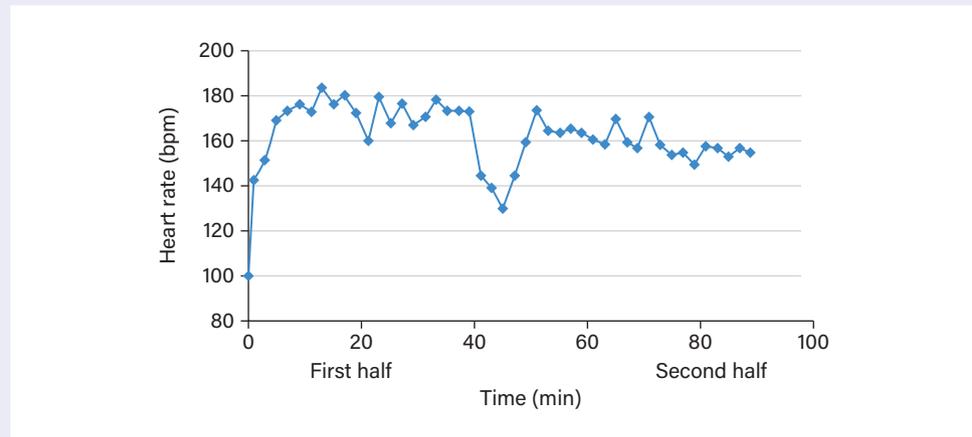
Recall that all three energy systems are constantly working to produce energy/ATP for muscle contractions. One energy system will produce the majority of the ATP. In intermittent team sports, the ability to reuse the two anaerobic energy systems relies heavily on the type and duration of recovery.

**Video**

In focus: Unpacking an activity analysis on hockey

## CASE STUDY HOCKEY

Field hockey is a team sport played between teams of 11 players, including a goalkeeper. The remaining players are distributed among different positions such as fullbacks, midfielders and forwards. Substitutes are allowed, and players can rotate positions during the game. The following data was collected during a national-level game from a 21-year-old midfielder player.



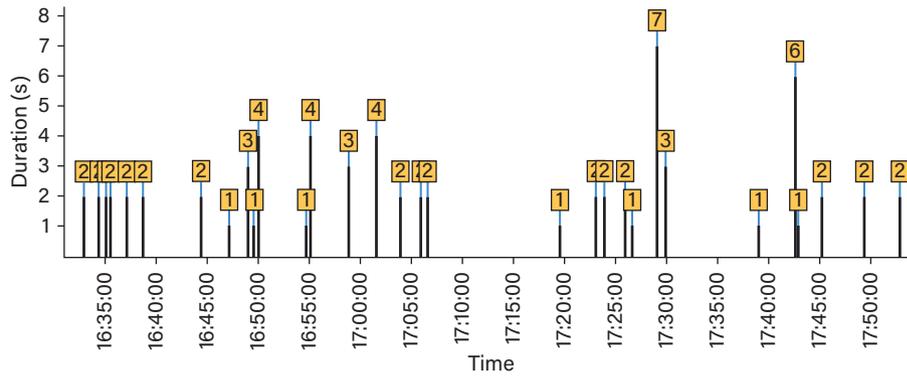
**FIGURE 9.24** Heart rate for a hockey midfielder player

Adapted from Kusnani, N.W. et al. (2018), 'Physiological demands of playing field hockey game at sub elite players', in IOP Conference Series: *Materials Science and Engineering* 288 (1): p. 012112

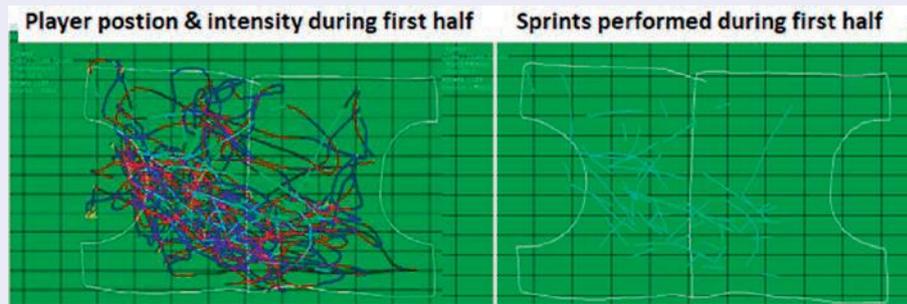
### HEART RATE ANALYSIS

- A 21-year-old should have a maximum heart rate of about 200 bpm (since max HR is estimated to be 220 minus your age).
- 70–85% max HR indicates aerobic-related work periods. The heart rate equivalent range is 140–170 bpm, and most of the work period is spent in this range, indicating high reliance on aerobic power and the aerobic energy system.
- The fact that the midfielder worked above 170 bpm consistently for extended periods indicates they have a lactate inflection point (LIP) that is higher than 85% max HR.
- The duration of the match (more than 80 minutes) confirms the heavy reliance on the aerobic energy system.
- Heart rates in the second half are lower than those in the first half, indicating possible fatigue or a change in the pace of the game: the performer's heart rate could have slowed due to the style of play they were applying.
- While the intensity of effort is mainly consistent, the midfielder also demonstrates 'bursts' of higher intensity, most likely related to sprints. These would be accompanied by increased contribution from the anaerobic glycolysis system.
- Note: a resting heart rate of 100 for a midfielder is exceptionally high and may have been due to anticipation/excitement about the upcoming game. An elite midfielder hockey player would normally have a resting heart rate of around 55–60 bpm.





**FIGURE 9.25** Distribution and duration of sprints performed by a hockey midfielder



**FIGURE 9.26** GPS data for midfielder player during first half and focus on sprints performed

**TABLE 9.12** GPS zone/intensity data for hockey midfielder player over the course of a game

Speed zone			First half		Second half		Combined total	
			Metres	% of distance	Metres	% of distance	Metres	% of distance
Zone 1	0–2 km/h	Standing still	136	2.8	132	3.1	268	3.0
Zone 2	2–6 km/h	Walking	1,106	21.1	1,176	27.7	2,282	25.4
Zone 3	6–12 km/h	Jogging	1,640	36.6	1,678	39.5	3,318	37.0
Zone 4	12–16 km/h	Running	938	19.6	748	17.6	1,686	18.8
Zone 5	16–20 km/h	Fast running	586	14.4	344	8.1	930	10.4
Zone 6	20+ km/h	Sprinting	312	6.5	172	4.0	484	5.4
<b>Distance</b>			<b>4,718</b>		<b>4,250</b>		<b>8,968</b>	

GPSsports software



**FIGURE 9.27** Decreased sprint distances in the second half indicate that fatigue is occurring.

### GPS ANALYSIS

- The player performed more sprints in the first half than the second, mirroring the heart rate data when 'recording lags' are taken into consideration
- Most sprints last for 2–3 seconds and there is no significant recovery time before repeat efforts. This suggests the midfielder mainly sprints 15–20 metres. However, longer sprints of 6 and 7 seconds are seen in the second half, indicating possible leads to space, with distances likely to be 45–55 metres. Both observations provide clues as to the distance that relevant speed tests should replicate: 20-metre, 30-metre or 50-metre sprints would be appropriate.
- Repeat effort sprints with short recovery periods increasingly point to the importance of anaerobic capacity and the need to train this fitness component and the anaerobic glycolysis system as well (most likely through intermediate interval training).
- Note: the short course phosphate recovery test would better replicate the game patterns of sprints than the long course version, and should be chosen due to specificity.
- The creatine phosphate system will activate during high-intensity sprints *only* if CP is available. This occurs if CP has not been totally depleted, or if the midfielder has had a chance to restore/replenish this fuel while standing still and/or walking.
- The midfielder spends more time in offence than defence, which is to be expected, and performs frequent movements at, or within, the goal circle as well. This provides the coaching staff with vital tactical information.
- The work-to-rest ratio (% work above walking pace : % walking and standing still) is 71.6:28.4, which, when rounded, works out to be 2.5:1. This supports the fact that the major energy system the midfielder calls on during the match is the aerobic energy system.



- The player covers almost 9 kilometres during the match, suggesting that aerobic power, driven by the aerobic energy system, is a crucial fitness component for a hockey midfielder.
- Nearly 16 per cent of the distance they cover is while running at either high or very high intensity (zones 5 and 6), reflecting the need to develop speed and anaerobic power in an effort to meet the demands put on a midfielder.

**TABLE 9.13** GPS zone/intensity data for five playing positions in hockey over the course of a game

	Fullback	Half	Centre-half	Inside forward	Striker
Game distance (m)	6,951	6,709	8,304	7,471	7,166
Normalised game distance (m)	7,808	8,553	8,639	8,870	8,806
Zone 5 (16–20 km/h) distance (m)	438	546	794	702	693
Zone 6 (20+ km/h) distance (m)	194	310	385	291	410
Total HI (zones 5 and 6) distance (m)	632	856	1,179	992	1,111
Total normalised HI distance (m)	756	1,088	1,225	1,185	1,381
Top speed (km/h)	25.9	26.8	26.6	26.4	27.9
Number of short sprints (1–2 s)	9.7	12.2	16.7	13.3	18.6
Number of medium sprints (3–4 s)	3.9	5.4	6.2	6.4	7.4
Number of long sprints (5+ s)	1.3	2.4	3.0	2.1	3.3
Total number of sprints	14.8	20.0	25.9	21.8	29.3
Shots at goal	Nil	Nil	2	5	9

### GPS ANALYSIS FOR MULTIPLE PLAYING POSITIONS

- Centre-half players cover a similar distance to midfielders and have a higher reliance on the aerobic energy system than other positions.
- All positional players show similar top speeds (26–27 km/h), indicating the need for this to be included in all training programs for field players. (This probably isn't the case for goalkeepers.)
- Centre-half players and strikers perform longer sprints than fullbacks, halves and inside forwards, as well as spending longer working in zones 5 and 6. Specific training needs to include both elements for players in these two positions.
- Nearly all positions cover more than 8 kilometres during the match, again signalling the importance of aerobic power and the aerobic energy system.
- The fullback performs the fewest and shortest sprints, indicating less reliance on speed than the other players.
- If it was necessary to make a positional 'swap' (for tactical reasons), the most suitable players to swap would be the centre-half and the striker, who have the closest matching GPS data based on this table.
- These findings emphasise the importance of individualising training programs to meet the specific demands of the different playing positions.





**TABLE 9.14** Skill description and frequency during the first half for a hockey midfielder player

Skill	Summary	Frequency
First touch	Moving the ball to a desired position with one touch	3
Pass	Moving the ball left or right to a teammate (mostly while in motion)	17
Hit	Striking the ball with maximal force to create high ball speed	5
Deception/ directional change	Baulking or faking directions with the body or stick to confuse opponents and get around them	43
Leading	Moving into space to create opportunity to receive an unobstructed pass (usually performed at high intensity)	19
Flat-stick tackle	Trying to win possession of the ball from an opponent while maintaining control of own stick	4
Dribble	Running while in possession of the ball, with close contact between stick and ball	7
Jab	Rapidly and powerfully lunging at a ball in an opponent's possession	2

### SKILL FREQUENCY ANALYSIS

- The high number of deception/directional changes indicate agility is a very important fitness component for a hockey midfielder.
- Coordination (while not trained in most school training programs) is required to successfully dribble with the ball, perform jabs and successfully execute flat-stick tackles. Without coordination, the midfielder player would not be able to either control, or gain control of, the ball. The ability to direct a ball to a teammate or area 'first touch' also requires high levels of coordination.
- We have already highlighted the importance of speed given the high frequency of zone 5 and zone 6 efforts and repeat sprints, which are mostly 2–3 seconds in duration but can range up to 6–7 seconds.
- Note: passing can occur at different intensities. For example, a push pass can travel very quickly from point A to point B, whereas a gentle flick pass to a nearby (but unopposed) teammate travels much more slowly. More detailed information on types of passing would have been useful.
- Hitting the ball is performed with great range of motion (flexibility), speed and muscular power – mainly from the upper-body muscles (pectorals, deltoids, trapezius, biceps and triceps).
- All the stick skills the midfielder performs require a combination of muscular strength – to enable a contraction to be applied over a period of time – and muscular endurance, which allows repeated or isometric contractions without much rest between efforts.



**Assessment**  
9.5 Check-in questions

## 9.5 CHECK-IN QUESTIONS

- 1 **a** Work-to-rest ratio data can be somewhat limited. **Outline** two reasons why simply expressing a work-to-rest ratio of 1:4 for a game of European handball might not be all that useful when trying to plan a training program.
- b** **Suggest** two ways in which work-to-rest information can be improved in the above example to make it more useful when selecting fitness tests and training activities.
- 2 **©VCAA** Exam 2017, Section B, Q7

The following data was collected during an activity analysis of an under-16 soccer game.

Work period			Rest period	
Sprint	Run	Jog	Walk	Stand

Based on the data, the correct work-to-rest ratio (W:R) and the dominant energy system for this game are:

- A** 1:5 and ATP-CP system.
- B** 1:3 and anaerobic glycolysis.
- C** 3:1 and aerobic energy system.
- D** 5:1 and aerobic energy system.
- 3 The following data was obtained by comparing work and rest efforts and distances in elite senior and under-18 Australian Rules footballers in three key positions.

Position/playing standard		Total game distance (m)	Total game 'working' distance (m)	Total game 'resting' distance (m)	Total game no. of 'working' efforts	Total game no. of 'resting' efforts
<b>Midfield</b>	Elite senior	16,979	11,537	5,442	644	381
	Elite U18	11,537	8,924	2,613	162	149
<b>Ruck</b>	Elite senior	15,393	10,618	4,775	641	407
	Elite U18	9,213	6,631	2,573	161	166
<b>Small forward</b>	Elite senior	16,278	9,249	7,029	574	397
	Elite U18	11,545	8,903	2,642	180	182

Source: Veale J.P. et al. (2007), 'Player movement patterns in an elite junior Australian Rules football team: an exploratory study,' in *J Sports Sci Med* 6(2): 254-60

- a Calculate** the work-to-rest ratio for an elite senior Australian Rules midfielder player.
- b i** Based on your answer to part **a**, which energy system do you believe provides most of the energy for an Australian Rules midfielder player?
- ii Identify** any other data that might suggest the energy system you have selected plays a significant role in the midfielder's game.
- c** The small forwards have a different work-to-rest ratio from those in midfield and ruck positions. **Discuss** the effect this would have on preparing a much more specific training program for small forwards, rather than having them complete the same aerobic-based training the midfield and ruck players perform.

### Command term

#### calculate

Determine from given facts, figures or information; obtain a numerical answer showing the relevant stages in the working; determine or find (e.g. a number, answer) by using mathematical processes

# CHAPTER SUMMARY



## Resource

Self-assessment checklist

## Video

Masterclass: Chapter 9

## 9.1 Purpose of an activity analysis

- Data is collected in order to determine the physiological, technical and/or tactical requirements of a performance or game.
- Coaches and performance analysts use the data collected in an activity analysis to inform them about:
  - major muscle groups involved in the execution of movements
  - intensity and duration (time and distance) of efforts
  - movement types, patterns and field-of-play coverage
  - skill frequencies and efficiency
  - energy system interplay and contribution throughout performances
  - efficiency of movement and biomechanical applications to technique/skill execution
  - team and opposition playing strategies and tactics.
- Data that is collected is then used to create a benchmark against which other performances are compared.

## 9.2 Data collection methods

- There are *only two* ways to collect data: direct observation (with or without note-taking) and digital recording.
- Direct observation allows for immediate changes to performances, but has limitations such as memory recall; an inability to store and review data; not being able to show the performer 'what is being provided as improvement feedback'; and restricted viewing of players.
- Digital recording can zoom in on specific parts of a performance; store and replay what is collected; pair with performance-analysis software to fine-tune and improve movement efficiencies; and consider the actions of multiple players at the same time provided they are in view of digital recording devices.
- Inexperienced observers collect highly subjective data, whereas digital recording is objective and often more accurately depicts what is occurring during games and performances.

## 9.3–9.5 Collecting and analysing different types of data

### Skill frequencies

- Skill frequency data is mainly used to inform coaches and analysts about the major fitness components and muscle groups required to bring about successful performances.
- Skill effectiveness should be considered in an effort to improve technical and tactical aspects of the performance from a skill acquisition and biomechanical perspective.
- Major fitness components and muscle groups need to be trained in ways that replicate their use during the game or competition (specificity).
- Muscle use and force application conducted in association with a skills analysis can reveal whether or not players need to focus on muscular strength, power or endurance.

## Movement patterns

- These are also referred to as 'locomotor patterns' and reveal where a player moves during a match as well as distances and intensities associated with each type of movement.
- Movement patterns are best collected by GPS units, which can isolate specific-intensity efforts when they are used with suitable software.
- Movement patterns with associated playing intensities are vital when considering energy system interplay used by performers.
- GPS live transmissions enable coaches to see decreased workloads and associated fatigue, allowing them to make better decisions about rotating and resting players throughout a match.
- 'Heat maps', which show playing intensities and distribution over a playing field, are not as useful to coaches as the quantitative data GPS units provide.

## Heart rates

- Heart rate data provides insights into playing intensities and workloads, with direct reference to energy system interplay experienced by players.
- Smart watches (with wrist sensors) have made heart rate data accessible to recreational and amateur performers, whereas this was previously only available to professionals due to cost.
- Chest strap/band heart rate recording devices provide higher levels of accuracy than wrist-based devices. These have decreased in size, but cannot be worn in most contact sports such as Australian Rules football and rugby – GPS units fill this gap.
- There is a 'lag' between increases in heart rate and when most devices record them. A person sprinting from rest will be working maximally, but their heart rate will only rise slightly after a few seconds.

## Work-to-rest ratios

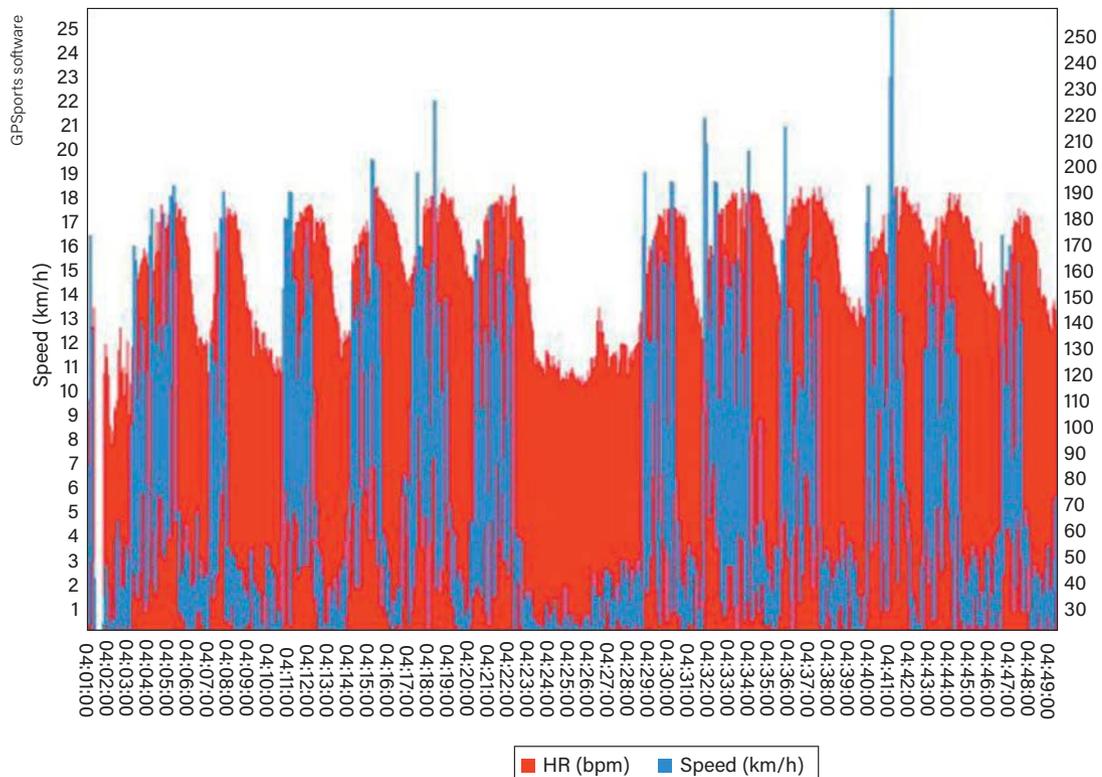
- These contrast the period of work to the period of rest (rest can be a combination of players being stationary and walking).
- Work-to-rest ratios that are combined with intensity of efforts are far more useful than simply contrasting work-to-rest periods based on distances covered or elapsed time during performances.
- Work-to-rest ratios (W:R) can provide information about the major energy system used throughout a performance:
  - 1:5+ = ATP-CP energy system
  - 1:3-1:4 = anaerobic glycolysis energy system
  - 1:1-1:2 or 2+:1 = aerobic energy system.
- Rest periods are critical in all intermittent sports where performers are involved in frequent repeat high-intensity efforts. High reliance on anaerobic capacity during games signals that this needs to improve through short and/or intermediate interval training that replicates game scenarios.

# CHAPTER REVIEW



Assessment  
Chapter 9 Review

- Which one of the following types of data would provide a coach with the clearest indication of relevant fitness components and energy systems?
  - movement patterns and GPS
  - heart rates and work-to-rest ratios
  - skill frequencies and GPS
  - GPS and heart rates
- The most relevant type of data a coach could use when analysing the performance of a 50-kilometre cross-country ski racer in an effort to improve performances would be:
  - GPS data.
  - movement patterns.
  - skill frequencies.
  - work-to-rest ratios.
- Skill frequency data revealing that a player performs a high number of leaps would indicate reliance on which one of the following fitness components?
  - agility
  - speed
  - muscular power
  - flexibility
- The following GPS data was obtained from a rugby sevens player representing her country at the Olympic Games in 2021.



- a** By referring to heart rate data, **discuss** which energy system you believe to be the major contributor in both halves.
- b i** Would you describe rugby sevens as a continuous or an intermittent sport?
- ii** How might your response to part **i** influence the type of training a coach could consider using with this player?
- c** Clearly **discuss** why GPS data cannot be used to bring about improvements to the skill techniques used by rugby sevens players.
- 5 Explain** why, for a soccer coach, having access to GPS data would be preferable to having access to heart rate data.
- 6** Digital recording of a volleyball match reveals the following skills:
- overarm serve
  - dig
  - set
  - spike
  - block
  - sideways leap
  - change of direction.
- a List** two advantages of digital recording compared to direct observation.
- b** Select any three of the above skills and **identify** the major muscles involved in performing them.
- c** For each of the skills you chose in part **b**, select a training activity that replicates the actions seen during a volleyball game that make them a suitable and specific inclusion to training.

# CHAPTER 10

## ASSESSMENT OF FITNESS

UNIT 4 - AREA OF STUDY 1



WavebreakMedia/Micro/Adobe Stock

**FIGURE 10.01** Elite laboratory testing

### Quizzes

Chapter 10 Pulse check

- 10.1** Check-in questions
- 10.2** Check-in questions
- 10.3** Check-in questions
- 10.4** Check-in questions

Chapter 10 Review

### Videos

Masterclass: Chapter 10

- 10.1** In focus: How results are established
- 10.3** In focus: Specificity of fitness testing

### Resources

- 10.4** Test: Running-based anaerobic sprint test (RAST)
- 10.4** Test: Partial curl-up
- 10.4** Test: Pull-ups
- 10.4** Test: 30-second endurance jump
- 10.4** Test: Trunk and neck extension
- 10.4** Test: Ankle extension
- 10.4** Test: Shoulder rotation
- 10.4** Test: Groin flexibility

Chapter 10 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



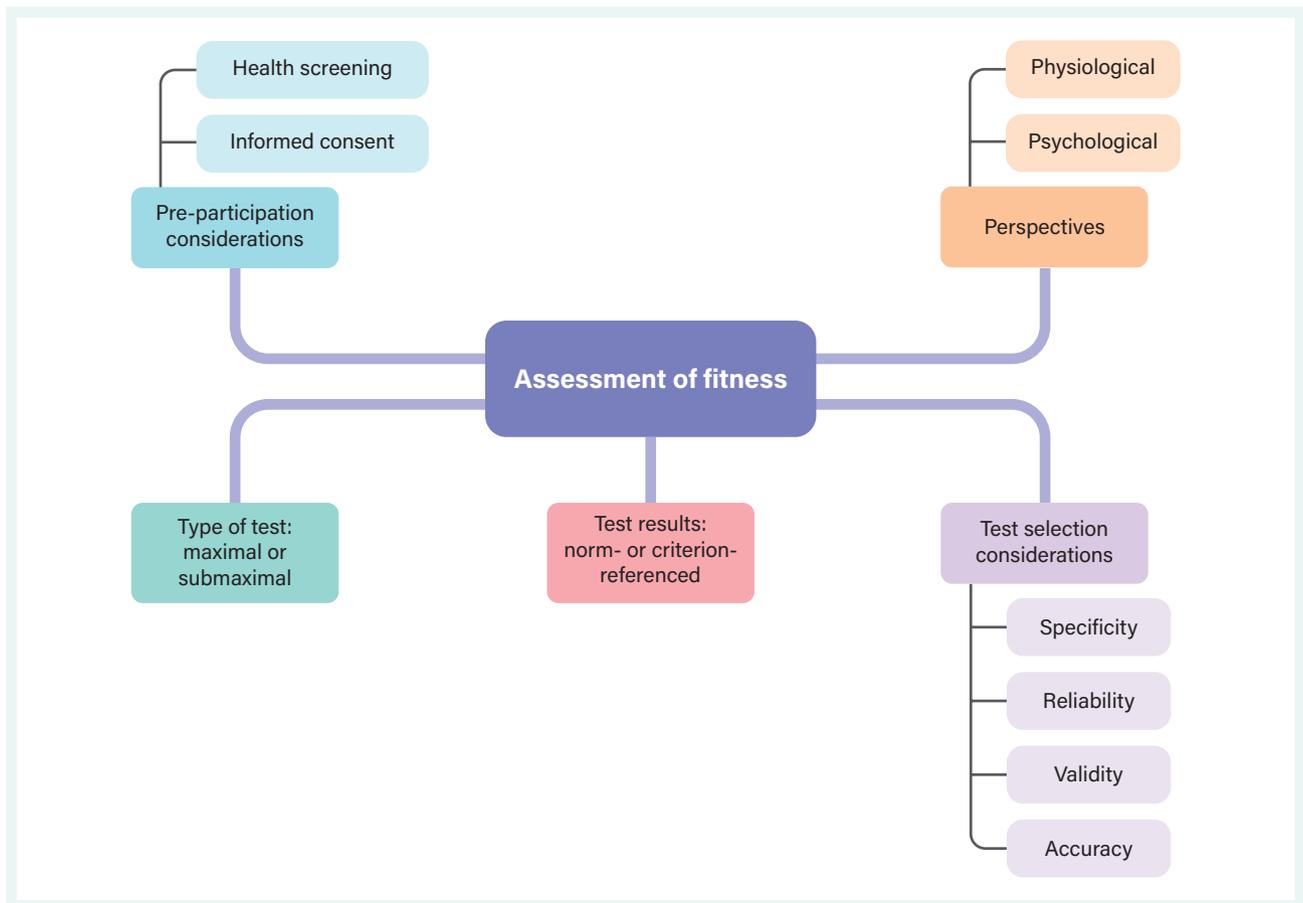
- » assessment of fitness for an activity:
  - the purpose of fitness testing from physiological and psychological perspectives
  - pre-participation health screening and informed consent
  - standardised, recognised fitness tests that test appropriately identified physiological requirements
  - test reliability, validity and accuracy

## KEY KNOWLEDGE

- » justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity
- » perform and observe a reliable, valid and accurate assessment of fitness

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)





Video

Masterclass: Chapter 10

Assessment

Pulse check

The term 'being fit' is a general one that doesn't really help us to understand the important physiological requirements for a sport or activity. To enable a better understanding of specific requirements, we classify fitness into actual fitness components – for example, aerobic power and speed.

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 Why are health screening and informed consent important considerations before conducting fitness testing?
- 2 Can you **identify** reasons for fitness testing?
- 3 **Discuss** how specificity relates to fitness testing.
- 4 **Outline** the difference between maximal and submaximal testing.
- 5 Do you know the difference between 'norm-referenced' and 'criterion-referenced' results?

## 10.1 THE PURPOSE OF FITNESS ASSESSMENT

In this module you will learn about:

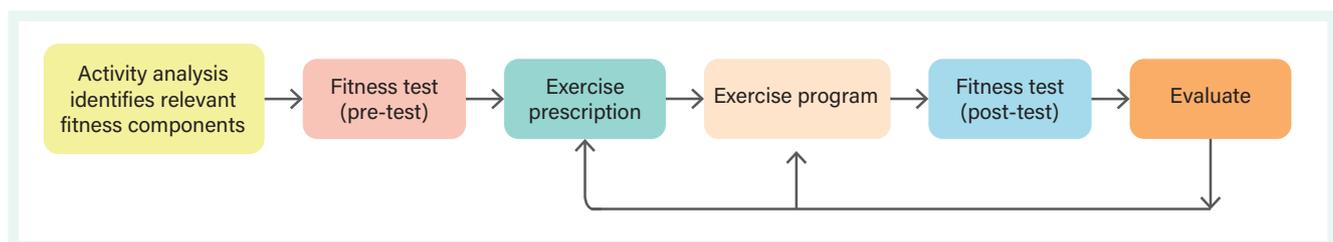
- the aim of fitness testing and learn to:
- identify its role in a well-designed training program.

An activity analysis enables a coach to determine the major fitness components, energy system usage, movement patterns and skill frequency required for a specific player. The collection of skill frequencies enables the coach to better determine the major muscle groups required to compete successfully. This combination of information enables the creation of a fitness **testing battery** that can specifically assess the capabilities of these requirements.

The relevance of fitness assessment to the creation of a training program that will enhance the overall physiological capacity and psychological considerations of the individual is depicted in Figure 10.02.

### testing battery

A variety of different tests selected to assess multiple fitness components for an individual



**FIGURE 10.02** The role of fitness assessment in developing a specific training program

From the athlete's point of view, fitness assessment usually evokes a range of psychological responses, and even anxiety, before testing begins. A more favourable response can be achieved if there is a clear purpose for performing the fitness test and this purpose is communicated to the athlete undertaking the test. Purposes of fitness assessment include both physiological and psychological considerations and may include:

- determining fitness component strengths and weaknesses
- establishing a baseline
- modifying a training program
- mental toughness
- motivation
- determining team positions
- predicting future potential
- selection criteria.

## Determining fitness component strength and weaknesses

To determine fitness component strengths and weaknesses, results are usually compared to a set of **normative results** (norms) or **criterion-referenced results**. A profile of the performer can then be developed, and a more specific training program can be designed based on these results, in conjunction with the information obtained from the activity analysis.

## Establishing a baseline

Often referred to as pre-and-post testing, initial test results provide a baseline for future comparison. By referring to Figure 10.02 we can see the significance of establishing a baseline. If little improvement has been achieved, further testing enables the coach to reassess the program. Improvement from the baseline could be minimal for a number of reasons, including:

- insufficient time between tests to register significant improvement
- inappropriate exercise prescription to achieve improvement
- failure to adhere to exercise prescription for a variety of reasons, including injury or lack of motivation
- that the performer is approaching their genetic potential, and the rate of improvement is slow due to the principle of diminishing returns.



Russell Freeman/AFL Photos/Getty Images Sport/Getty Images

**FIGURE 10.03** Would Nick Daicos use the norms for the 20-metre shuttle run test from this textbook?



### Video

In focus: How results are established

### normative results

In fitness assessment, results whose distribution is based on a particular reference group

### criterion-referenced results

In fitness assessment, results that are not based on a comparison to a reference group and typically identify an acceptable standard

## LOOKING FORWARD

### Principle of diminishing returns

#### Chapter 12

Improvement is rapid in the early stages of initial training and slows significantly as a performer approaches their genetic potential.

## Modifying a training program

Regular fitness testing is important to ensure that the assigned training program is meeting its aim of developing one or more specific fitness components. Results that demonstrate slower improvement than expected provide an opportunity to revisit the training program prescription for potential modification.

## Mental toughness

Maximal tests such as a  $VO_2$  max test or the phosphate recovery test require a participant to mentally push through the desire to slow down or stop. This demonstrates the participant's psychological strength when physical pressure is exerted and is a crucial component of success in a variety of sports.



Dean Mouhtaropoulos/Getty Images Sport/Getty Images

**FIGURE 10.04** Rowing requires psychological strength for successful performance.

## Motivation

A performer may be more conscientious in completing a training program if they realise retesting will take place. Goal-setting, which can be a very powerful motivator, could also be established, with a performer aiming to achieve a certain result in the next test. Setting and achieving goals will also help increase a participant's confidence. Increased motivation may also be achieved through enlisting social support for both the testing and any subsequent training program.

## Determining team positions

More suitable team positions could be determined based on a performer's fitness test results. For example, if a goalkeeper achieves an outstanding result in the 20-metre shuttle run test, the coach may consider moving them into a more aerobic-dominated position such as midfielder.

## Predicting future potential

Fitness assessment can help predict a future performer's physiological potential. Several nations conduct wide-ranging testing programs as part of a talent identification program, often helping to direct performers into a particular type of sport – for example, into endurance-based sport if they are identified at a younger age as having outstanding aerobic power.

## Selection criteria

Fitness testing can form part of selection criteria for employment. This is particularly common where minimum fitness requirements are essential in the daily work performed – for example, in fire and rescue services, police and defence forces. The fitness tests and minimum standards required for entry into the Victoria Police are presented in Table 10.01.

**TABLE 10.01** Minimum fitness test scores required as part of the selection criteria for the Victoria Police

Beep test (20 m SRT)	5.01
Grip test	30 kg in each hand
Illinois agility run	20 seconds
Push-ups	Five successive push-ups on toes
Prone bridge	Hold for 60 seconds
Obstacle climb	1.3 m
Swim 100m	4 minutes



**Weblink**  
Victoria Police entry requirements

### LEARNING HACK

The 20-metre shuttle run test (SRT) is often referred to as the 'beep test'. For exam purposes, use the test's correct name of '20 m SRT'.



AAP Image/JAMIES ROSS

**FIGURE 10.05** Victoria Police recruits chat with the Chief Commissioner, Shane Patton. Are the physiological requirements for entry into the police force too high, too low or appropriate? Do you think you would be able to reach this level of fitness?

**Assessment**

10.1 Check-in questions

**Command terms****explain**

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

**suggest**

Put forward for consideration a solution, hypothesis, idea or other possible answer

**discuss**

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions



**Weblink**  
Get Active  
Questionnaire

**LOOKING BACK****The musculoskeletal system****Unit 2, Chapter 12**

It is important to remember that many health professionals are looking to Functional Movement Assessments (FMA) before prescribing an exercise program.

**10.1 CHECK-IN QUESTIONS**

- 1 **Explain** why an activity analysis should be considered and undertaken before fitness testing.
- 2 **Suggest** why it is important to establish the intended outcome of fitness testing with the participant.
- 3 **Explain** two purposes of fitness testing.
- 4 **Discuss** one potential negative consequence of fitness testing.

**10.2 PRE-PARTICIPATION HEALTH SCREENING**

In this module you will learn about:

- the importance of health status before undertaking fitness assessment and learn to:
- select appropriate health screening.

Becoming more physically active is an important contributor to improved quality of life and helps to prevent many lifestyle illnesses. Both federal and state governments are significantly increasing funding to create more opportunities for Australians to increase their physical activity.

However, it is important to consider your current health status before undertaking fitness testing or commencing an exercise regime. For some people, particularly those with a history of poor health, it may also be prudent to check with a medical practitioner first.

**Pre-exercise screening questionnaires**

Pre-exercise screening questionnaires are available to help determine your readiness for fitness testing or an exercise program. These are particularly important for older adults and those with known health risks. The most well-known of these is the Physical Activity Readiness Questionnaire (PAR-Q). Many organisations still use the PAR-Q, though the Canadian Society for Exercise Physiology, which developed it, has replaced it with the Get Active Questionnaire. A link to this questionnaire can be found on their website.

## PAR-Q AND YOU

The questionnaire is suitable for those aged between 15 and 69. Read the questions carefully and answer each one honestly.

	Yes	No
Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke?	<input type="checkbox"/>	<input type="checkbox"/>
Do you ever feel unexplained discomfort or pain in your chest when exercising or being physically active?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have chest pain when not doing physical activity?	<input type="checkbox"/>	<input type="checkbox"/>
Do you ever feel faint, dizzy or lose balance or consciousness?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have any pre-existing issues with joints or bones that could be made worse by increasing your physical activity?	<input type="checkbox"/>	<input type="checkbox"/>
Has a doctor prescribed any medication for your blood pressure or heart condition?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have any other conditions that may require special consideration for you to exercise?	<input type="checkbox"/>	<input type="checkbox"/>

### If you answered YES

If you answered 'yes' to one or more questions, share your PAR-Q results with your doctor and seek their advice before you start becoming more active or before you undertake a fitness test.

### If you answered NO

If you answered 'no' to all of the questions, you can be reasonably confident that you can begin increasing your physical activity over time or undertake a physical fitness test.

### Things change

It is important that you revisit your answers to this questionnaire over time and adapt your physical activity plan depending on your health, for example if you are feeling unwell, or if you are or might be pregnant. If your health changes and you answer 'yes' to any of the above questions, check with your fitness or health professional about changing your physical activity plan.

Australia has established a more contemporary adult pre-exercise screening system (APSS), put together by members from Sports Medicine Australia (SMA), Exercise and Sports Science Australia (ESSA) and Fitness Australia. ESSA has also published a screening system for young people 16–17 years old (see Figure 10.06), as well as one for children aged 5–15.

### 🚩 SIGNPOST

Visit the ESSA website for more information on pre-exercise screening, including information for adults and children aged 5–15 years.



**Weblink**  
ESSA screening systems

# PRE-EXERCISE SCREENING SYSTEM FOR YOUNG PEOPLE

## YOUNG PERSON TOOL (PSS-YP)

To be completed by a young person 16-17 years old



**Important Information:** This tool is part of the Pre-Exercise Screening System and should be used in conjunction with the PSS User Guide which covers how to use the information collected and to address the aims of each stage. This does not constitute medical advice. These guidelines and the PSS (together 'the material') is not intended for use to diagnose, treat, cure or prevent any medical conditions, is not intended to be professional advice and is not a substitute for independent health professional advice. Exercise & Sport Science Australia, Fitness Australia, Sports Medicine Australia and Exercise is Medicine (together 'the organisations') do not accept liability for any claims, howsoever described, for loss, damage and/or injury in connection with the use of any of the material, or any reliance on the information therein. While care has been taken to ensure the information contained in the material is accurate at the date of publication, the organisations do not warrant its accuracy. No warranties (including but not limited to warranties as to safety) and no guarantees against injury or death are given by the organisations in connection with the use or reliance on the material. If you intend to take any action or inaction based on the guidelines and/or the PSS, it is recommended that you obtain your own professional advice based on your specific circumstances.

### Child/Young Person's Details:

Full Name: \_\_\_\_\_

Date of Birth: \_\_\_\_\_ Age: \_\_\_\_\_ Gender: Male  Female  Prefer not to say  Other

Pre-exercise screening results will be kept as confidential files and shared only among individuals involved in the event of urgent medical care, and/or with the consent of the young person and/or parent/guardian.

## STAGE 1 (COMPULSORY)

To be completed with an exercise professional or individual who is responsible for the medical care of the young person.



These questions are part of a system designed for young people participating in exercise. The aim is to identify any young person with medical conditions or warning signs that may put them at a higher risk of an unwanted event during activity or exercise sessions. Unwanted events may include something unexpected during exercise leading to illness, physical harm or death.

Please tick your response

Do you have, or previously had:	YES	DON'T KNOW	NO
1. A heart condition?			
2. A close relative who has died suddenly from a heart condition before the age of 50?			
3. Uncontrolled epilepsy or seizures/convulsions?			
4. Fainting or dizzy spells with physical activity/exercise?			
5. Diabetes?			
6. An asthma attack requiring immediate medical attention at any time over the last 12 months?			
7. Anaphylactic reactions?			
8. Surgery in the last month?			
9. Any other conditions that may require special consideration for you to exercise?			
<b>IF YOU ANSWERED 'YES' or 'DON'T KNOW' to any of the 9 questions above, please discuss with the exercise leader or the person administering this form prior to undertaking exercise.</b>			
<b>IF YOU ANSWERED 'NO' we recommend you proceed to Stage 2 with the exercise leader or those providing medical care.</b>			
10. Over the past seven days, on how many days were you physically active for a total of 60 minutes or more per day?	Number of days:		

**Young Person** - I hereby acknowledge that:

- » To the best of my knowledge, all of the information I have supplied within this screening tool is correct.
- » I will inform the exercise leader or person administering this form if there are any changes to the answers above.

Name: \_\_\_\_\_ Signature: \_\_\_\_\_ Date: \_\_\_\_\_

**Parent/Guardian Consent (\*required if young person 15 years old or younger)** - I hereby acknowledge that:

- » To the best of my knowledge, all of the information supplied within this tool is correct.
- » I will inform the exercise leader or those providing medical care immediately if there are any changes to the information provided.

Name: \_\_\_\_\_ Signature: \_\_\_\_\_ Date: \_\_\_\_\_



FIGURE 10.06 The ESSA pre-exercise screening tool for young people 16–17 years old

### 24-hour Physical Activity Guidelines

Following these guidelines may be challenging at times; however, meeting them will benefit health. Achieving these guidelines is associated with better health and leads to improved body composition, cardiorespiratory and musculoskeletal fitness, cardiovascular and metabolic health, improved cognition, mental health and emotional regulation. For those not currently meeting these guidelines, a progressive adjustment towards them is recommended.

**Figure 1. 24-hour physical activity guidelines**

<http://www.health.gov.au/internet/main/publishing.nsf/Content/health-24-hours-phys-act-guidelines>

 <b>SLEEP</b> 14-17 yr olds = 8-10 hours per night	 <b>PHYSICAL ACTIVITY</b> Aim for 60 mins or more per day – the more you huff & puff the better!	 <b>INACTIVITY</b> Move more & sit less in your free time
--	---	--

## STAGE 2 (RECOMMENDED)

This stage is to be completed with an activity or exercise leader, or a relevant health professional, to highlight possible medical conditions or warning signs that may put a young person at a higher risk of an unwanted event during activity or exercise sessions.

#### 11. Do you take any regular medications or supplements?

YES  NO

If you are taking any regular medications or supplements, provide details:

---

#### 12. Do you have any current health or medical management plans (e.g. anaphylaxis, asthma or diabetes)?

YES  NO

If yes, provide details:

---

If yes to above, do you always carry any required medication?

- » Anaphylaxis - EpiPen? YES  NO  NA
- » Diabetes - insulin or glucose? YES  NO  NA
- » Asthma - reliever (Ventolin or other)? YES  NO  NA

#### 13. Have you experienced heat related illness previously?

YES  NO

If yes, provide details:

---

**14. Have you spent time in hospital (including day admission) for any medical condition/ illness/ injury during the last 12 months?**

YES  NO

If yes, provide details:

---

**15. Do you have any muscle, bone or joint problems and/or pain that could be made worse by participating in activity?**

YES  NO

If yes, provide details:

---

**16. In the last month have you suffered an episode of concussion?**

YES  NO

If yes, provide details:

---

17. Which of the following behaviours did you do in the last 7 days?	YES/NO	How many times?	For how long (average)?
Sport (including training)			
Physical Education class			
School physical activity (e.g. fitness, lunch-time sports)			
Active travel (e.g. walk or cycle to shops/school/work)			
Other physical activity (e.g. gym, walking the dog, play at the playground)			

Over the last week, what time did you go to bed (Sunday to Thursday evening)?	
Over the last week, what time did you wake up (Monday to Friday morning)?	
On the weekend (Friday or Saturday evening), what time did you go to bed?	
On the weekend (Saturday or Sunday morning), what time did you wake up?	

On the last 5 weekdays (Monday to Friday), how much time on average did you spend:	Hours
- watching movies or TV shows on any device (TV, computer, tablet or smartphone?)	
- surfing the internet for fun?	
- texting or messaging, or using social media?	
- playing videogames on smartphones, computers, tablets or consoles like Playstation?	

**\*OPTIONAL\***

**18. Are you pregnant or have you recently given birth?**

YES  NO

If yes, provide details:

---

**🚩 SIGNPOST**

The American College of Sports Medicine (ACSM) also publishes information about health screening. Visit the ACSM website for more information.

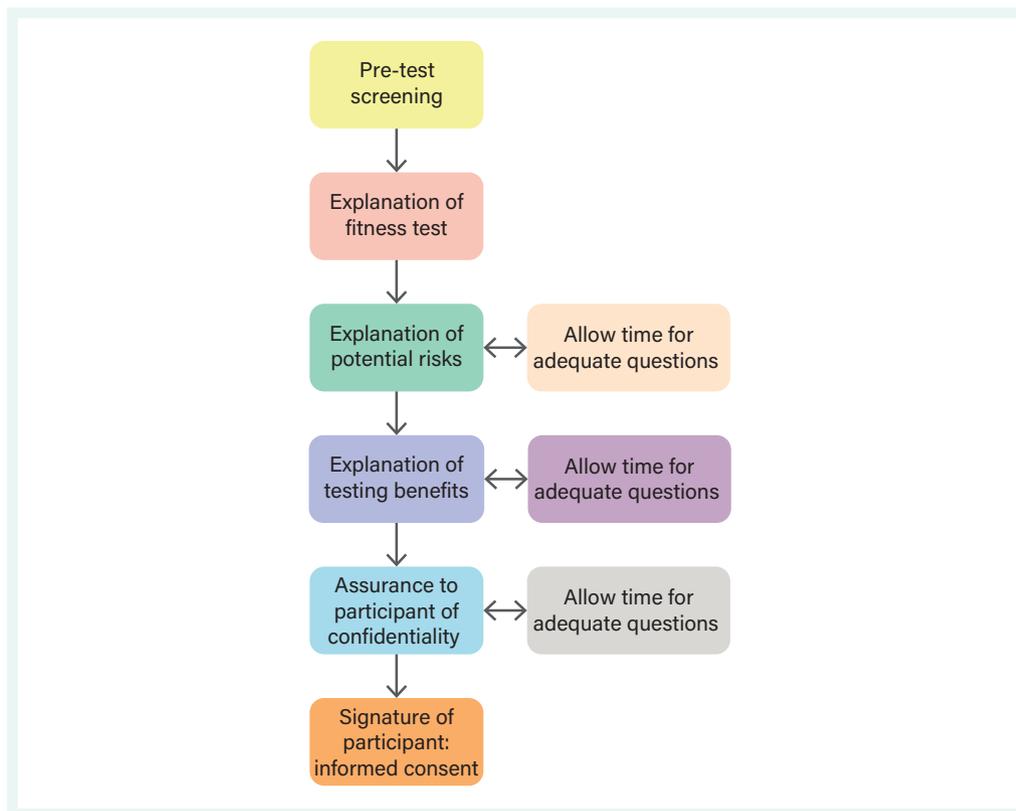


**Weblink**  
American College of Sports  
Medicine (ACSM)

## Informed consent

Informed consent is a process designed to protect the interests of both the athlete and the test administrator, and can also be applied to fitness programming. Its relation to fitness testing can be represented by the flow chart in Figure 10.07. An example of an informed consent form is shown in Figure 10.08.

Often, information about a pre-exercise screening test will be sent to the participant in advance. This should explain the nature and purpose of the test, and any risks involved. Before commencing the test, the participant must be given the opportunity to ask questions and should also be aware that they can withdraw their consent at any time before or during the test.



**FIGURE 10.07** The informed consent process

## FORM 2.4 Informed Consent

I (print name), \_\_\_\_\_, consent to participate in the physiological assessment on the following terms:

1. I have read the Explanation of Physiological Assessment Procedures attached and understand what I will be required to do. I have had the opportunity to ask questions and have received satisfactory explanations about the tests being conducted.
2. I understand that I will be undertaking physical exercise at or near the extent of my capacity and there is possible risk in the physical exercise at this level, such as episodes of transient light-headedness, fainting, abnormal blood pressure, chest discomfort, and nausea.
3. I understand that this may occur although the staff in the laboratory will take all and proper care in the conduct of the assessment, and I fully assume the risk.
4. I understand that I can withdraw my consent, freely and without prejudice, at any time before, during, or after testing.
5. I have told the person conducting the assessment of any illness or physical defect I have that may contribute to the level of that risk.
6. I understand that the information obtained from the test will be treated confidentially with my right to privacy assured. However, the information may be used for statistical or science reasons with privacy retained. (Note: Members of sports teams should have made special arrangements about treatment of individual data with team coach or manager.)
7. I release this laboratory and its employees from any liability for any injury or illness that I may experience during this assessment as well as any subsequent injury or illness that is connected to or to any extent influenced by the assessment.
8. I will indemnify this laboratory in respect to any liability it may incur in relation to any other person in connection with the assessment.
9. I hereby agree that I will present myself for testing in a suitable condition having abided by the requirements for diet and activity prescribed to me by laboratory staff.

Participant signature: \_\_\_\_\_

Date

\_\_\_\_\_

Parent/guardian name (required if age less than 18)

Signature

Date

\_\_\_\_\_

\_\_\_\_\_

Witness name:

Signature

Date

\_\_\_\_\_

\_\_\_\_\_

Source: Australian Institute of Sport & Champaign, IL: Human Kinetics

**FIGURE 10.08** An example of an informed consent form

## WORKED EXAMPLE

The following question is from the 2021 VCE Physical Education exam. The question provides two different data sets and asks students to design the conditioning phase of a fartlek training program.

©VCAA Exam 2021, Section B, Q3

A strength and conditioning coach who works with a Rugby Union team prescribes a 1 repetition maximum (RM) bench press test as part of pre-season fitness testing.

Two marks available per process explained.

It can be assumed that an activity analysis has already been completed as pre-season fitness testing has now been decided.

- a Explain two processes that the strength and conditioning coach should undertake with the players before the pre-season fitness testing. 4 marks

**TIP:** The red circle highlights the command term – that is what you need to do to answer the question. The yellow highlights the relevant information to direct you to answering the question.

### Steps to answer the question

Understand that an activity analysis would have been completed as the coach is now ready to undertake pre-season fitness testing.

### Sample response

*The conditioning coach would firstly want to ensure the safety of the players by completing health screening. The conditioning coach would then want to protect themselves from a negligence/legal claim by obtaining informed consent from the participants.*

## 10.2 CHECK-IN QUESTIONS

- Outline** two potential risks associated with fitness testing.
- Discuss** why a participant would continue with testing when they have been made aware of some of these potential risks.
- Referring to Figure 10.07, the performer is given three opportunities to ask questions. **Explain** why this is so important.
- If sporting clubs do not follow the informed consent flow chart, **discuss** two possible consequences of club-based fitness testing the club administrators and officials may face.



**Assessment**  
10.2 Check-in questions

### Command term

#### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

## 10.3 FITNESS TEST SELECTION CONSIDERATIONS

In this module you will learn about:

- processes to ensure the integrity of fitness testing and learn to:
- apply these to any fitness testing regime.

Once the commitment to complete fitness testing has been made, the following factors should be carefully considered to ensure that the benefits of completing the fitness testing regime are maximised. Ideally, a test should demonstrate:

- reliability
- validity
- accuracy
- specificity
- result comparison (relevant norm availability).

## Reliability

Will the chosen test produce consistent results? That is, if the test is performed multiple times in succession (assuming appropriate recovery etc.) will the same result be obtained?

External factors such as time of day, nutritional status and facility can all impact on the reliability of the testing protocol. To increase reliability, the following points should be considered:

- Tests should be conducted at the same time of day.
- The same warm-up should be conducted before each specific test.
- Testing should be completed in the same order each time; this should include prioritising ATP-CP dominated tests, such as the vertical jump test, to minimise the effects of fatigue.
- If possible, avoid completing tests on the same day that rely heavily on the anaerobic glycolysis energy system and aerobic energy system. Avoid, for example, completing the phosphate recovery test and the 20-metre shuttle run test in succession.
- Whenever possible, testing should be conducted in similar environmental conditions such as temperature, humidity, indoors or outdoors.
- There should be similar nutrition and hydration levels; these should be part of a performer's daily routine.
- The performer should be well rested prior to testing.
- The same equipment, clothing and footwear should be used.
- The same test should be used for the specific fitness component.
- The performer's health status should be unchanged.
- The performer's activity levels prior to testing should be similar, if not the same.

For elite athletes, a pre-testing routine involving many of these points is often prescribed to ensure reliability of testing results.

## Validity

Is the test measuring what it claims to test? There is an array of both laboratory and field tests to measure aerobic power, including  $\text{VO}_2$  max treadmill or cycle tests and the 20-metre shuttle run test. Even though muscular endurance would be required to perform well in these fitness tests, they specifically assess aerobic power, while other tests, such as the 60-second push-up test, specifically assess muscular endurance.

For several fitness components there are what are known as gold standard tests. Generally, these are laboratory-based, such as a  $\text{VO}_2$  max test. Field tests are often validated, or compared, against these gold standard tests to ensure they meet their stated objective – that is, they are measuring what they claim. The 20-metre shuttle run test correlates successfully as an aerobic power test.

### LEARNING HACK

A correlation is the strength or degree of an association between two variables.

## Accuracy

To ensure reliability, testing also needs to be accurate. Elite testing is generally performed in sports science laboratories. The cost of the laboratory equipment is beyond the scope of most amateur sporting organisations, and trained professionals are required to carry out testing. To guarantee accuracy, the testing equipment needs to be regularly calibrated and maintained. The Australian Sports Commission provides a quality assurance scheme for interested sports science laboratories to standardise testing protocols, ensuring that testing integrity is maintained.

Field testing can be inaccurate if specific testing protocols are not followed. An example of such a protocol involves the 20-metre shuttle run test (20 m SRT). If the performer does not make the line twice in a row, they should be removed from the test. If this is not followed stringently, then different results could be obtained, diminishing the accuracy of the testing.

Timing gates, used for speed testing, are too expensive for most sporting organisations. Handheld timers are the usual substitute. In this instance, accuracy would be improved by having the same person perform the timing for both pre- and post-tests, using the same procedure. Timing variations in a 10-metre sprint test can make a significant difference to the result.



Adam Pretty/Getty Images

**FIGURE 10.09** How are accuracy and reliability affected if subjects do not pivot on the 20-metre line and simply turn when they hear the 'beep', as happens in some situations?

## Specificity

When assessing the various fitness components for a chosen sport, it is important to keep the testing as specific as possible to the requirements established in an activity analysis. For example, a 50-metre sprint test for speed is not very specific to the explosive distances sprinted by a netballer; a 10- or 20-metre sprint test would be more specific to their requirements. If assessing aerobic power for a Tour de France cyclist, then a  $VO_2$  max test on a bicycle would be more specific than a similar test on a treadmill.



**Video**  
In focus: Specificity of fitness testing

**LEARNING HACK**

A percentile compares a specific score with the scores of the rest of a group performing the same test. If a score is on the 75th percentile, then 75 out of 100 people who complete the test would score lower.

Specificity should also take into consideration both the age and the ability of the participant. There may be little value in assigning a specific fitness test to a participant who will not be able to achieve some level of success – for example, a participant about to start training for a 50-kilometre charity walk. Is their fitness level sufficient to make a  $\text{VO}_2$  max test on a treadmill worthwhile, or would a submaximal test, such as the Rockport 1.6-kilometre walking test, be more suitable?

## Result comparison

There are two ways in which results can be compared. It can be done through:

- normative tests
- criterion-based tests.

### Normative tests

Normative data, or 'norms', represent the distribution of results of a particular reference group. These results are typically based on percentiles, where a performer's result is compared with those of the group. A subject who scores at the 80th percentile has achieved a result better than 80 per cent of the reference group; 20 per cent of the group achieved a higher result. When using norms, it is important to compare to similar reference groups. General population norms, such as those in this book, are appropriate for most participants. However, elite talent, such as those testing for the AFL draft, will use norms based on previous combined draft results. General population norms would be irrelevant for these performers given the higher performance levels of elite sportspeople.

Particularly in adolescent participants, normative results generally favour those who already have higher fitness levels based on regular participation in, or training for, sports. Conversely, those participants who are less advanced may become discouraged by their performance.

### Criterion-based tests

Some tests use a criterion-referenced approach to standards, such as body mass index (BMI), waist circumference or blood-pressure readings, rather than a comparative rating. The goal of the criterion-referenced approach is to identify a level of fitness appropriate for health promotion. With sufficient levels of physical activity, all students should be able to achieve an acceptable level. Using this method of testing, comparison with others is irrelevant. Results are based on meeting acceptable parameters for improved health, and do not depend on the performance of a population group.

Referencing to existing data may not always be possible: the various Yo-Yo tests, for example, lack normative data at present. A coach, a personal trainer or even an individual may be using a specifically designed or customised test; or the normative reference group may not be appropriate, or may be out of date in terms of when the norms were established. Provided that the test is both valid and reliable, these results will still be valuable in a pre- and post-test scenario to assess the success of the training regime.

### Test sequencing

In selecting a fitness testing battery, it is important to consider sequencing of tests. Where possible, avoid conducting two maximal tests in a row, as the fatigue from one test may have a carryover effect on the next, diminishing the subsequent test's reliability. For example, performing a 20-metre shuttle run test and a phosphate recovery test on the same day will not allow the best possible outcome for both tests.

Finally, resourcing will also affect the choice of tests available for a testing battery. Resources include facilities, access to testing equipment and the availability of appropriate staff to execute the testing.

### 10.3 CHECK-IN QUESTIONS

- 1 **Distinguish** between validity and reliability.
- 2 The Harvard step test is being used less frequently than it once was as a field test to assess aerobic power. It has a correlation of between 0.8 and 0.9 as a measure of aerobic power – in other words, it is only 80–90 per cent ‘accurate.’ Apart from a lower correlation, **identify** and **discuss** another likely reason for its demise as a field test.
- 3 **Explain** why fitness tests requiring the majority of energy to be supplied by the ATP–CP energy system should be completed before those with a greater anaerobic glycolysis or aerobic energy system contribution.
- 4 **Contrast** normative test results with criterion-based results.



**Assessment**  
10.3 Check-in questions

#### Command terms

##### **distinguish**

Make clear the differences between two or more arguments, concepts, opinions, narratives, artefacts, data points, trends and/or items

##### **identify**

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

##### **contrast**

Show how things are different or opposite

## 10.4 TYPES OF FITNESS ASSESSMENT

In this module you will learn about:

- a variety of different fitness tests for the various fitness components and learn to:
- apply appropriate fitness tests to the needs of the participant.

### Laboratory and field testing

Sports science laboratory testing is usually reserved for elite performers, where accuracy in fitness testing is paramount. ‘Gold standard’ tests, performed by sports scientists, are readily available in this setting. The cost of facilities, equipment and maintenance is very high, which generally makes it prohibitive to test anyone other than elite performers.

Field testing can still be very functional and accurate, provided the protocols discussed earlier are followed. The advantage of field testing is that several people can be tested at once. For example, the 20-metre shuttle run test is only limited by the number of people who can fit into the available space. Most people would be familiar with field testing from their school or local sporting club environment.

### Maximal and submaximal testing

A maximal test is one that is performed as close as possible to exhaustion. Maximal testing is often associated with laboratory tests such as a  $\text{VO}_2$  max test or Wingate anaerobic test.

Field tests can also be maximal, as athletes who have undertaken the 20-metre shuttle run test will confirm. The 20-metre shuttle run test is, however, not a maximal test if athletes drop out a couple of shuttles before pushing themselves and reaching their maximum result.

Submaximal tests are those that are not performed to exhaustion. An example of a submaximal aerobic test is the Rockport 1.6-kilometre walking test. The performer’s  $\text{VO}_2$  max is predicted on the basis of both completion time and heart rate. This reflects the fact that heart rate and oxygen consumption increase linearly as intensity increases. The performer’s  $\text{VO}_2$  max is extrapolated from this relationship.



Cavan Images/Alamy Stock Photo

**FIGURE 10.10** A  $\text{VO}_2$  max test is highly accurate but not easily accessible.

## Fitness tests for the components of fitness

The fitness tests listed in Table 10.02 are available for assessing performance in each of the components of fitness. The associated fitness testing protocols/procedures for those tests marked with a page reference have also been supplied.

These tests have been chosen because:

- they are easy to administer
- they require minimal equipment
- norms are generally available for rating performance.

**TABLE 10.02** Fitness tests for the components of fitness

Component of fitness	Fitness test	Page reference
Aerobic power	• $\text{VO}_2$ max	p. 421
	• 20-metre shuttle run test	p. 422
	• Cooper's 12-minute run	p. 424
	• Astrand-Rhyming cycle ergometer test	p. 425
	• Yo-Yo intermittent recovery test	p. 426
Anaerobic capacity	• Phosphate recovery test	p. 428
	• 30-second Wingate test	p. 429
	• Repco peak power test	p. 429
Muscular strength	• Handgrip dynamometer strength test	p. 430
	• 1RM bench press test	p. 431
	• 1RM back squat test	p. 431
	• 1RM leg press test	p. 431
	• 7-stage abdominal strength test	p. 432
Muscular endurance	• 30-second sit-up test	p. 433
	• Maximal push-ups in 60 seconds	p. 433
	• Flexed-arm hang test	p. 434
Flexibility	• Modified sit-and-reach test	p. 435
	• Shoulder and wrist elevation test	p. 436
	• Ankle (dorsi)flexion test	p. 436



Component of fitness	Fitness test	Page reference
Muscular power	• Vertical jump test	p. 437
	• Standing long jump test	p. 438
	• Seated basketball throw	p. 439
Speed	• 20-metre sprint test	p. 440
	• 35-metre sprint test	p. 440
	• 50-metre sprint test	p. 440
Agility	• Illinois agility test	p. 441
	• SEMO agility test	p. 442
	• 5-0-5 agility test	p. 443

## DID YOU KNOW?

Absolute  $VO_2$  is the maximum amount of oxygen that a person can consume in 1 minute and is given in litres per minute (L/min).  $VO_2$  maximums are always represented as relative measures, in mL/min/kg, taking into consideration the participant's weight. This allows equitable comparison between two individuals of different, or similar, weights, and therefore relative effective oxygen intake, transport and utilisation per kilogram of body weight.

## Aerobic power tests

There are many tests available to measure, or predict, aerobic power. The 'gold standard' for directly assessing aerobic power is a  $VO_2$  maximum ( $VO_2$  max) laboratory test, where gas analysis is used to determine oxygen utilisation.

### $VO_2$ max test

$VO_2$  max tests can be performed on a treadmill, a bicycle ergometer, a rowing ergometer or a swimming plume. In tests of this type, the performer exercises to exhaustion, and a gas analysis machine determines the precise amount of oxygen being used – that is, the maximum volume of oxygen that a performer can intake, transport and utilise, or  $VO_2$  max. This is measured in millilitres of oxygen consumed per minute per kilogram of body weight (mL/min/kg). Heart rate data, which directly increases with exercise intensity, is also recorded during this test.

See Table 10.03 for normative data on  $VO_2$  max results from the American College of Sports Medicine for males and females aged 20–29.

### Advantages of a $VO_2$ max test

- It permits precise measurement of  $VO_2$  max.
- Maximum heart rate can be accurately established at the same time. (This is important, as maximum heart rate predictors such as  $220 - \text{age}$  have an error of  $\pm 12$  beats per minute.)
- The performer's lactate inflection point (LIP) as a given percentage of their  $VO_2$  max, as well as for a corresponding heart rate, can be predicted.
- Training programs using heart rate training zones can now be accurately tailored for a performer. While, as a general rule, the aerobic training zone is 70–85% max HR, a  $VO_2$  max test will accurately set the limits of this zone, which may differ from that generalised prescription.

### 🚩 SIGNPOST

Watch the following YouTube videos to learn more about this test:

- *What Is a  $VO_2$  Max Test? How to Use  $VO_2$  Max Testing for Triathlon Training* from Supertri
- *METS  $VO_2$  Max Test* from METS Performance Consulting.



**Weblinks**  
METS  $VO_2$  max test  
What is a  $VO_2$  max test?

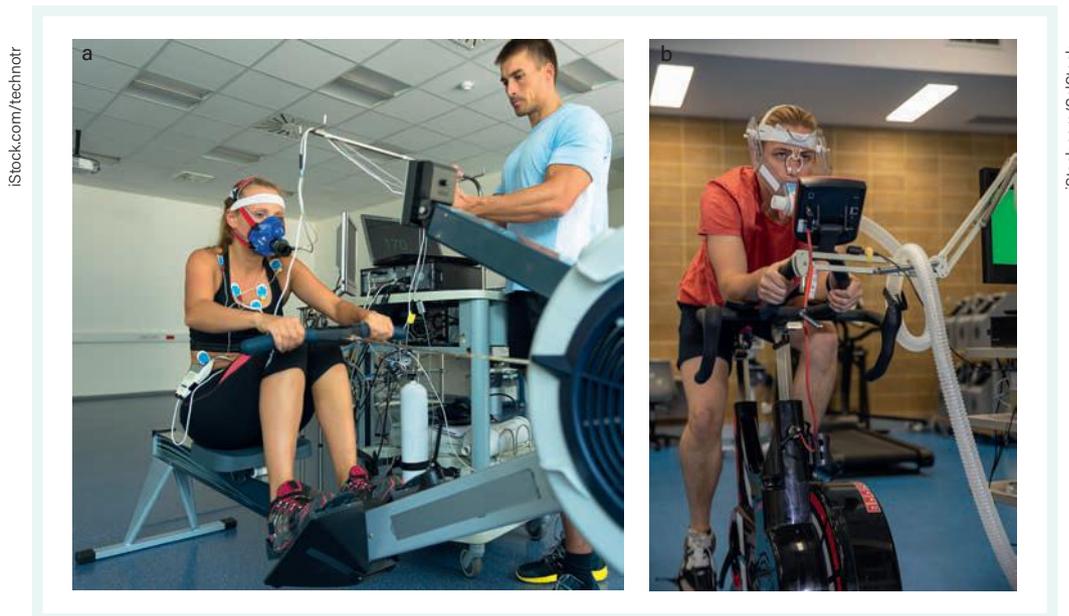
## Disadvantages of a VO<sub>2</sub> max test

- Trained professionals in a laboratory setting are required to perform the test.
- Testing is time and labour intensive; only one person can be tested at a time.
- Testing is expensive (\$300 or more).
- There are limited numbers of testing venues.
- Generally, only elite performers who require precise information will undergo VO<sub>2</sub> max tests, as there are several less expensive and less stressful tests available that will accurately predict a person's VO<sub>2</sub> max.

**TABLE 10.03** Normative data for VO<sub>2</sub> max

Age	Very poor	Poor	Fair	Good	Excellent	Superior
<b>Female (values in mL/kg/min)</b>						
<b>13–19</b>	< 25.0	25.0–30.9	31.0–34.9	35.0–38.9	39.0–41.9	> 41.9
<b>20–29</b>	< 23.6	23.6–28.9	29.0–32.9	33.0–36.9	37.0–41.0	> 41.0
<b>Male (values in mL/kg/min)</b>						
<b>13–19</b>	< 35.0	35.0–38.3	38.4–45.1	45.2–50.9	51.0–55.9	> 55.9
<b>20–29</b>	< 33.0	33.0–36.4	36.5–42.4	42.5–46.4	46.5–52.4	> 52.4

Data from van der Steeg, G. E. & Takken, T. (2021), 'Reference values for maximum oxygen uptake relative to body mass in Dutch/Flemish subjects aged 6–65 years: the LowLands Fitness Registry', in *European Journal of Applied Physiology*, 121(4), pp. 1189–1196, and Cooper Institute of Aerobics research (<https://www.verywellfit.com/vo2-max-norms-for-women-3120275#toc-why-vo2-max-varies-for-women>)



**FIGURE 10.11** How is the principle of specificity being applied in these VO<sub>2</sub> max tests?

## 20-metre shuttle run test

The 20-metre shuttle run test (20 m SRT) – or beep test, as it is commonly known – is one of the most popular field tests in Australia for predicting aerobic power.

### Advantages of a 20-metre shuttle run test

- Correlation with VO<sub>2</sub> max tests is very high.
- The test increases work rate every minute by decreasing the time between beeps, compelling the participant to keep up with the increase in speed, and thereby intensity. This eliminates the need for pacing, such as in the Cooper's 12-minute run.

- As the test increases in intensity, it will allow someone who is less aerobically fit to discontinue the test earlier, giving them longer to recover if further activities have been planned.
- Whole teams can perform the test at the same time; space is the only limiting factor.
- As is the case with all aerobic power field tests, it is cost-effective compared to completing a VO<sub>2</sub> max test in a laboratory.

### Disadvantages of a 20-metre shuttle run test

While extremely accurate, this test – like all aerobic field tests – is still only a predictor of aerobic power. Some sports teams, particularly overseas soccer clubs, prefer to use the Yo-Yo intermittent recovery test as it more closely replicates the demands of intermittent sport.

**TABLE 10.04** Shuttles per level, speed per level and time per shuttle for the 20 m SRT

Level	Shuttles	Speed (km/h)	Shuttle time (s)	Level	Shuttles	Speed (km/h)	Shuttle time (s)
1	7	8.0	9.0	12	12	14.0	5.14
2	8	9.0	8.0	13	13	14.5	4.97
3	8	9.5	7.58	14	13	15.0	4.80
4	9	10.0	7.20	15	13	15.5	4.65
5	9	10.5	6.86	16	14	16.0	4.50
6	10	10.0	6.55	17	14	16.5	4.36
7	10	10.5	6.26	18	15	17.0	4.24
8	10	12.0	6.00	19	15	17.5	4.10
9	10	12.5	5.76	20	15	18.0	4.00
10	10	13.0	5.54	21	16	18.5	3.89
11	12	13.5	5.33				

Source: Courtesy of Topend Sports, www.topendsports.com

**TABLE 10.05** Predicted maximum oxygen uptake (VO<sub>2</sub> max) in mL/min/kg for the 20 m SRT

Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max
4	2	26.8	9	2	43.9	14	2	61.1	18	2	74.8
4	4	27.6	9	4	44.5	14	4	61.7	18	4	75.3
4	6	28.3	9	6	45.2	14	6	62.6	18	6	75.8
4	9	29.5	9	10	46.8	14	8	62.7	18	8	76.2
						14	10	63.2	18	10	76.7
5	2	30.2	10	2	47.4	14	13	64.0	18	12	77.2
5	4	31.0	10	4	48.0				18	15	77.9
5	6	31.8	10	6	48.7	15	2	64.6			
5	9	32.9	10	8	49.3	15	4	65.1	19	2	78.3
			10	10	50.2	15	6	65.6	19	4	78.8
6	2	33.6				15	8	66.2	19	6	79.2
6	4	34.3	10	2	50.8	15	10	66.7	19	8	79.7
6	6	35.0	10	4	51.4	15	13	67.5	19	10	80.2
6	8	35.7	10	6	51.9				19	12	80.6
6	10	36.4	10	8	52.5	16	2	68.0	19	15	81.3
			10	10	53.1	16	4	68.5			
7	2	37.1	10	12	53.7	16	6	69.0	20	2	81.8





Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max	Level	Shuttle	Predicted VO <sub>2</sub> max
7	4	37.8				16	8	69.5	20	4	82.2
7	6	38.5	12	2	54.3	16	10	69.9	20	6	82.6
7	8	39.2	12	4	54.8	16	12	70.5	20	8	83.0
7	10	39.9	12	6	55.4	16	14	70.9	20	10	83.5
			12	8	56.0				20	12	83.9
8	2	40.5	12	10	56.5	17	2	71.4	20	14	84.3
8	4	41.1	12	12	57.1	17	4	71.9	20	16	84.8
8	6	41.8				17	6	72.4			
8	8	42.4	13	2	57.6	17	8	72.9	21	2	85.2
8	10	43.3	13	4	58.2	17	10	73.4	21	4	85.6
			13	6	58.7	17	12	73.9	21	6	86.1
			13	8	59.3				21	8	86.5
			13	10	59.8				21	10	86.9
			13	13	60.6				21	12	87.4
									21	14	87.8
									21	16	88.2

Source: *British Journal of Sports Medicine* by British Association of Sport and Medicine, reproduced with permission of BMJ Publishing Group via Copyright Clearance Center

**TABLE 10.06** Male fitness ratings for the 20-metre shuttle run test

Age	Very poor	Poor	Fair	Average	Good	Very good	Excellent
12–13	< 3/3	3/4–5/1	5/2–6/4	6/5–7/5	7/6–8/8	8/9–10/9	> 10/9
14–15	< 4/7	4/7–6/1	6/2–7/4	7/5–8/9	8/10–9/8	9/9–12/2	> 12/2
16–17	< 5/1	5/1–6/8	6/9–8/2	8/3–9/9	9/10–10/3	10/4–13/7	> 13/7
18–25	< 5/2	5/2–7/1	7/2–8/5	8/6–10/1	10/2–10/5	10/6–13/10	> 13/10

Source: Courtesy of Topend Sports, [www.topendsports.com](http://www.topendsports.com)

**TABLE 10.07** Female fitness ratings for the 20-metre shuttle run test

Age	Very poor	Poor	Fair	Average	Good	Very good	Excellent
12–13	< 2/6	2/6–3/5	3/6–5/1	5/2–6/1	6/2–7/4	7/5–9/3	> 9/3
14–15	< 3/3	3/3–5/2	5/3–6/4	6/5–7/5	7/6–8/7	8/8–10/7	> 10/7
16–17	< 4/2	4/2–5/6	5/7–7/1	7/2–8/4	8/5–9/7	9/8–10/10	> 10/10
18–25	< 4/5	4/5–5/7	5/8–7/2	7/3–8/6	8/7–10/1	10/2–12/7	> 12/7

Source: Courtesy of Topend Sports, [www.topendsports.com](http://www.topendsports.com)

### DID YOU KNOW?

VO<sub>2</sub> max can also be predicted from the Cooper's 12-minute run by applying the following formula: VO<sub>2</sub> max = (22.351 × kilometres) – 10.288.

## Cooper's 12-minute run

Before the 20-metre shuttle run test became popular, the Cooper's 12-minute run was an extremely popular test to measure aerobic power. Like all aerobic power field tests, it is cost-effective.

This test involves running as far as possible in 12 minutes. The further you can run, the higher your level of aerobic power. You should do this test on a 400-metre track that has been measured out in 20-metre intervals.

The major disadvantage of this test is that a performer must hold their highest intensity for the full 12 minutes to ensure the reliability of the test, but to run for the full 12 minutes at higher aerobic intensities seems to be difficult for many performers.

**TABLE 10.08** Male ratings for the Cooper's 12-minute run test in metres covered

Age	Excellent	Above average	Average	Below average	Poor
15–16	> 2,800	2,500–2,800	2,300–2,499	2,200–2,299	< 2,200
17–20	> 3,000	2,700–3,000	2,500–2,699	2,300–2,499	< 2,300

Source: Data from Cooper (1968) sourced via 'Cooper test (12 minute run) explained with data', <https://sportsscienceinsider.com/cooper-test/>

**TABLE 10.09** Female ratings for the Cooper's 12-minute run test in metres covered

Age	Excellent	Above average	Average	Below average	Poor
15–16	> 2,100	2,000–2,100	1,700–1,999	1,600–1,699	< 1,600
17–20	> 2,300	2,100–2,300	1,800–2,099	1,700–1,799	< 1,700

Source: Data from Cooper (1968) sourced via 'Cooper test (12 minute run) explained with data', <https://sportsscienceinsider.com/cooper-test/>

## Astrand-Rhything cycle ergometer test

The major advantage of this test is its submaximal nature, which enables aerobic power to be estimated without the need to complete a maximal test. It is based on the predictive relationship between heart rate, workload and aerobic power. Results are based on a 'nomogram', though there are online calculators available for converting results to a predicted  $\text{VO}_2$  maximum.

Participants are required to pedal on a cycle ergometer for 6 minutes at a constant workload that enables them to maintain a steady state heart rate within the range of 125–170 bpm.

Disadvantages of this test include the difficulty of obtaining normative data, and its favourable results for participants with a cycling background.



GaudiLab/Shutterstock.com

**FIGURE 10.12** The Astrand-Rhything test is a submaximal test of aerobic power that is conducted on a cycle ergometer.



Weblink

Yo-Yo intermittent recovery test

## Yo-Yo intermittent recovery test, levels 1 and 2

The Yo-Yo intermittent recovery test was developed by Danish physiologist Jens Bangsho and his colleagues and is a very popular test of aerobic power in the UK and Europe. The goal was to establish a field test that more closely resembled the intermittent demands of soccer – that is, the ability to perform repeated high-intensity activity relying on a combination of both aerobic and anaerobic energy supply. Many intermittent sporting codes, such as the rugby codes, netball and hockey, now use the test to assess aerobic power.

There are two variations to the Yo-Yo test:

- the Yo-Yo intermittent recovery test, with an active recovery of 10 seconds to walk/jog 5 metres
- the Yo-Yo intermittent endurance test, with an active recovery of 5 seconds to walk/jog 2.5 metres.

Each test has two levels. The level 1 test is aimed at recreational performers starting at 10 kilometres per hour, while the level 2 test is directed towards more elite performers commencing at 13 kilometres per hour.

While norms are limited, the internet offers comparisons to many of the world's leading soccer players and intermittent team sports.

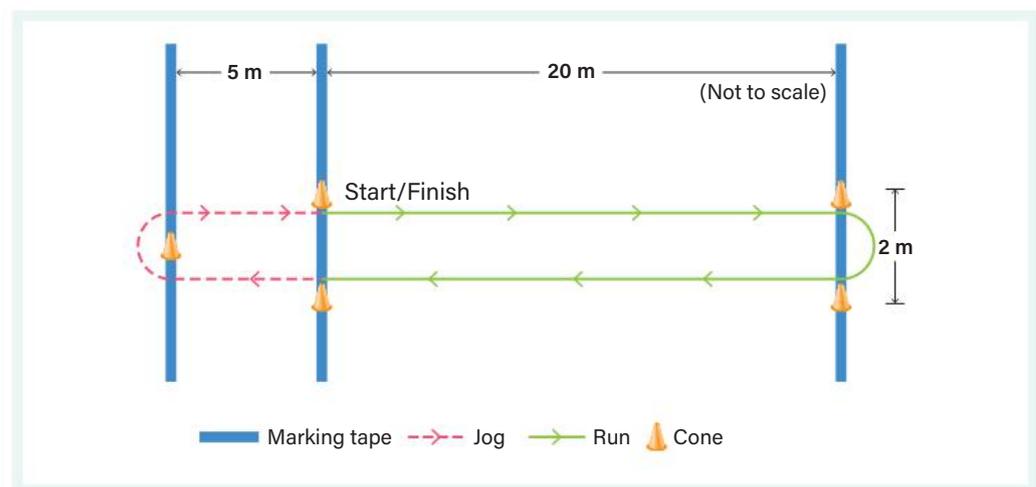
The following testing protocol has been supplied courtesy of the National Sport Science Quality Assurance (NSSQA) Program at the Australian Institute of Sport.

### Equipment

- measuring tape
- marking tape and cones
- test audio (MP3 file available to download online)
- recording sheets

### Test set-up

- 1 Using a measuring tape and marking tape, measure out a 20-metre test course. Mark a line at 0 metres and a line at 20 metres.
- 2 At each end of the course, place two markers spaced 2 metres apart horizontally.
- 3 In addition to the 20-metre line, measure out a 5-metre distance behind the 0-metre line.
- 4 Place a marker on the 5-metre line, in the middle of the two 0-metre line markers, as shown below. The markers should be parallel to each other along the marked lines. Ensure that there is one course set up per athlete.



**FIGURE 10.13** Set-up for Yo-Yo intermittent recovery test

Source: Kate Fuller, National Sport Science Quality Assurance (NSSQA) Program, Australian Institute of Sport

## Procedure

- 1 Instruct athletes to line up on the 0-metre line.
- 2 Start playing the Yo-Yo test audio.  
Note: There are two levels for this test: level 1 and level 2. Currently, the standard testing criteria are level 1. If an athlete is able to run faster than the speed-level 23, they should perform the level 2 test on the next occasion.
- 3 At the first signal, athletes run towards the 20-metre line. At the sound of the second signal, athletes should arrive at the 20-metre line and then turn and run back to the 0-metre line, arriving on the next beep. When the start marker is passed (0 metres), the athletes continue forward at a reduced pace (jogging) towards the 5-metre mark, where they then make a turn around the cone and return to the start line. At this point the athletes stop and wait for the next signal to sound.  
Note: Athletes are required to place one foot either on or behind the 0-metre, 5-metre and 20-metre lines at the start and end of each test interval.
- 4 Athletes should continue running for as long as possible, until they are unable to maintain the speed indicated by the audio track.
- 5 The end of the test is indicated by the inability of an athlete to maintain the required pace for two successive trials. The first time the start marker is not reached, a warning is given. The second time, the athlete must withdraw.
- 6 When the athlete withdraws, the last speed and the number of  $2 \times 20$ -metre intervals performed at this speed are recorded. (N.B. The last  $2 \times 20$ -metre interval is included, even if the athlete has not made the complete distance.)
- 7 Upon completion of the test, all athletes should warm down.
- 8 The final Yo-Yo intermittent recovery speed and interval score obtained by each athlete is used to calculate the total distance covered by the athlete during the test (refer to the Yo-Yo Calculator to calculate the corresponding total distance attained for Level 1 and Level 2).  
Note: The Yo-Yo intermittent recovery test is effort-dependent, so for valid results athletes must attempt to reach the highest level possible before stopping. Verbal encouragement should be given to the athletes throughout the test.

**TABLE 10.10** Norms for adult men in the Yo-Yo intermittent recovery test (Level 1)

Rating	Metres	Level
Elite	> 2,400	> 20.1
Excellent	2,000–2,400	18.7–20.1
Good	1,520–1,960	17.3–18.6
Average	1,040–1,480	15.7–17.2
Below average	520–1,000	14.2–15.6
Poor	< 520	< 14.2

Source: [www.theyoyotest.com/results.htm](http://www.theyoyotest.com/results.htm)

**TABLE 10.11** Norms for adult women in the Yo-Yo intermittent recovery test (Level 1)

Rating	Metres	Level
Elite	> 1,600	> 17.5
Excellent	1,320–1,600	16.6–17.5
Good	1,000–1,280	15.6–16.5
Average	680–960	14.6–15.5
Below average	320–640	14.6–15.5
Poor	< 320	< 13.1

Source: [www.theyoyotest.com/results.htm](http://www.theyoyotest.com/results.htm)

**Test**

Running-based anaerobic sprint test (RAST)

## Anaerobic capacity tests

Anaerobic capacity tests can be used for two purposes:

- where there is a recovery period involved between repetitions, such as in the phosphate recovery test, aimed at measuring the ATP–CP system's ability to quickly replenish its high-energy phosphate bonds to dominate the next repetition
- if there is no recovery period, such as in the 30-second Wingate test, which measures the ability of the two anaerobic systems to supply high-intensity energy over a relatively short period.

### Phosphate recovery test

The aim of the phosphate recovery test is to challenge the ability of the body to replenish high-energy phosphates in between repetitions of the test. This style of effort is required in sports such as Australian Rules football, the rugby codes, netball, hockey, basketball, squash and tennis. Table 10.12 demonstrates two versions of the test. Instructions are given for the short course.

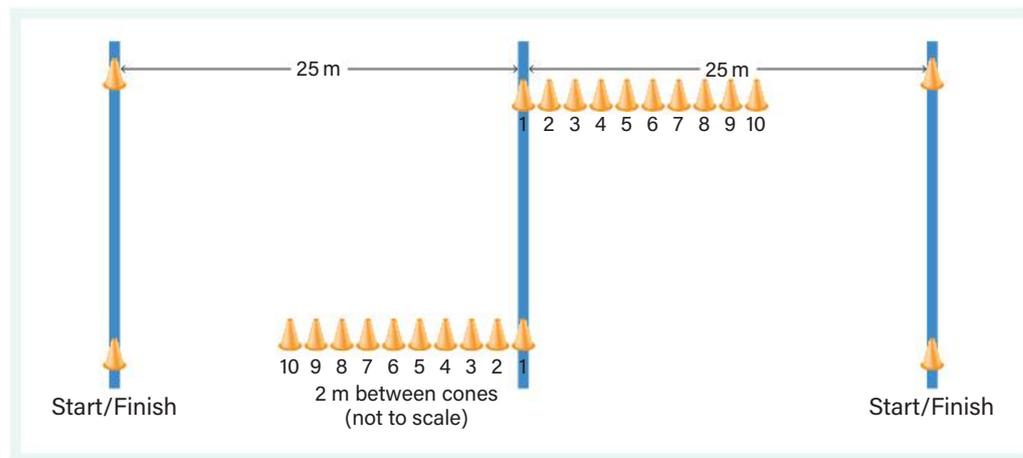
**TABLE 10.12** Two versions of the phosphate recovery test

Course	Number and duration of sprints	Starting every:	Work-to-rest ratio
Short course (25 m)	8 × 5 seconds	30 seconds	1:5
Short course (25 m)	8 × 7 seconds	30 seconds	1:3.3

Adapted from <https://www.topendsports.com/testing/tests/phosphate-recovery.htm>

### Equipment

You will need two sets of 10 cones (numbered 1 to 10), additional cones to mark start and finish lines, stopwatches, whistles and scorecards. Set up the short course as shown in Figure 10.14. (For the long course, 25 metres becomes 40 metres.) The numbers on the cones must face towards the scorer.



**FIGURE 10.14** Set-up for the phosphate recovery test (short course)

### Procedure

- 1 Choose a partner to work with (one person performs the test, the other records the results) and a timekeeper. Each participant should be thoroughly familiar with the procedure.
- 2 The performers line up at the left. After giving a 5-second warning, the timekeeper blows a whistle and starts two stopwatches. The performer sprints to the right, at maximal effort. Each performer's score is the number of the cone in the top right-hand section of the course reached at the 7-second mark.

- 3 The performers jog to the start/finish line at the right and line up ready to sprint to the left when the second stopwatch reaches 30 seconds. For this sprint, the cones in the bottom left-hand part of the course are used for scoring.
- 4 The process is repeated until the performers have sprinted eight times.

### Calculations and norms

Complete the calculations on the scorecard (see Figure 10.15 for template) to find the percentage decrement. The lower the decrement, the better the result. Ratings for the test are shown on the scorecard in Figure 10.15.

PHOSPHATE RECOVERY TEST: SHORT COURSE									
8 × 7-second sprints (every 30 seconds)									
Name: _____									
Sprint number	1	2	3	4	5	6	7	8	Total
Score									
(Circle your best score and calculate your total score.)									
Best possible score = best score × 8 = _____ × 8 = _____									
Total decrement = best possible score - total score = _____ - _____ = _____									
Percentage total decrement = $\frac{\text{total decrement}}{\text{best possible score}} \times 100 = \text{_____}\%$									
Norms for the test									
(Circle your rating)									
Good	Average			Below average			Poor		
12-20%	20-30%			30-40%			>40%		

**FIGURE 10.15** Scorecard for the phosphate recovery test

## 30-second Wingate test (Wingate anaerobic test)

The 30-second Wingate test is a laboratory-based maximal test requiring the participant to pedal a mechanically braked bicycle ergometer maximally for 30 seconds. Both anaerobic power and anaerobic fatigue results can be obtained.

## Repco peak power test

This test requires a Repco front-access cycle ergometer and is designed to assess the maximal power that can be generated and maintained for 10 seconds. While it is not specifically a laboratory-based test, more meaningful data can be obtained if the test is conducted by trained professionals with access to the right computer software.



#### Weblinks

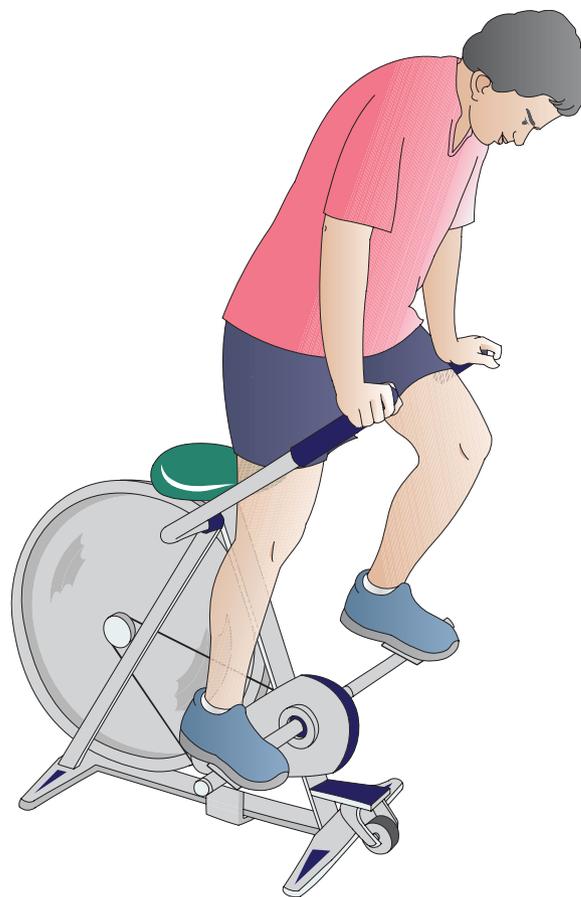
[30-second Wingate test](#)

[Wingate anaerobic test](#)

Jen Fuller/Getty Images



**FIGURE 10.16** Wingate bike test



**FIGURE 10.17** A Repco front-access cycle ergometer

HandeXer



**FIGURE 10.18** This dynamometer measures grip strength. What other kinds of dynamometers test the strength of other body parts?

## Muscular strength tests

### Handgrip dynamometer strength test

#### Equipment

- handgrip dynamometer

#### Procedure

Adjust the handgrip size to a position that is comfortable for the individual. The subject should stand upright, with their arms at their sides. They hold the dynamometer parallel to their side, with the dial facing away from their body. The subject squeezes the dynamometer as hard as possible without moving their arm. There are usually three trials for each hand, with a 1-minute rest between trials. Norms are provided in Tables 10.13 and 10.14.

**TABLE 10.13** Norms for static strength using a grip dynamometer for males

Grip strength ratings for males (kg)			
Age	Weak	Normal	Strong
10–11	< 12.6	12.6–22.4	> 22.4
12–13	< 19.4	19.4–31.2	> 31.2
14–15	< 28.5	28.5–44.3	> 44.3
16–17	< 32.6	32.6–52.4	> 52.4
18–19	< 35.7	35.7–55.5	> 55.5

**TABLE 10.14** Norms for static strength using a grip dynamometer for females

Grip strength ratings for females (kg)			
Age	Weak	Normal	Strong
10–11	< 11.8	11.8–21.6	> 21.6
12–13	< 14.6	14.6–24.4	> 24.4
14–15	< 15.5	15.5–27.3	> 27.3
16–17	< 17.2	17.2–29.0	> 29.0
18–19	< 19.2	19.2–31.0	> 31.0

Source: Courtesy of Topend Sports, www.topendsports.com

## 1-repetition maximum (1RM) bench press, back squat and leg press tests

The aim of these three tests is to assess maximal strength of the upper body and leg musculature. It is crucial for injury management to use correct, controlled technique always. Practice sessions to ensure performers are familiar with the correct technique are highly recommended.

The following testing guidelines are recommended to determine the 1-repetition maximum (1RM):

- 1 The subject should warm up by completing several repetitions at a lower weight.
- 2 Begin the test with a weight/resistance of about 50–70 per cent of the subject's capacity.
- 3 Progressively increase the weight/resistance by increments of between 2.5 and 20 kilograms until the subject cannot complete the selected repetition. All repetitions should be performed at the same speed of movement and range of motion to ensure consistency between trials.
- 4 Complete four trials, with rest periods of 3–5 minutes between trials.
- 5 The final weight lifted successfully is recorded as the absolute 1RM.

Results are based on dividing the weight lifted by actual body weight for both the bench press and leg press.

$$\text{Bench press ratio} = \frac{\text{weight lifted}}{\text{body weight}}$$

$$\text{Back squat ratio} = \frac{\text{weight lifted}}{\text{body weight}}$$

$$\text{Leg press ratio} = \frac{\text{weight lifted}}{\text{body weight}}$$

**TABLE 10.15** Ratings for 1RM bench press, back squat and leg press

Rating	Bench press, back squat and leg press ratios	
	Boys < 20 years	Girls < 20 years
Excellent	1.34+	0.77+
Good	1.19–1.29	0.65–0.76
Fair	1.06–1.16	0.58–0.64
Poor	0.76–1.01	0.41–0.57
Very poor	< 0.76	< 0.41

Adapted from: ACSM, 2014



**FIGURE 10.19** When performing a 1RM test, it is crucial to have someone 'spotting' for you.

## 7-stage abdominal strength test

The aim of this test is to assess abdominal strength.

### Equipment

2.5-kilogram and 5-kilogram weights

### Procedure

- 1 The subject lies on their back with their knees at right angles and feet flat on the ground.
- 2 They attempt to complete one sit-up from each of the levels described in Table 10.16.
- 3 Each level is completed satisfactorily if one full sit-up can be performed without the performer's feet leaving the floor.

Performers with heavy upper bodies may find this test difficult because it is harder to keep their feet on the ground.

**TABLE 10.16** Ratings for the 7-stage abdominal strength test

Level	Rating	Description
0	Very poor	Cannot curl up at all
1	Poor	With arms extended, the athlete curls up so that the wrists reach the knees
2	Fair	With arms extended, the athlete curls up so that the elbows reach the knees
3	Average	With the arms held together across abdominals, the athlete curls up so that the chest touches the thighs
4	Good	With the arms held across the chest, holding the opposite shoulders, the athlete curls up so that the forearms touch the thighs
5	Very good	With the hands held behind the head, the athlete curls up so that the chest touches the thighs
6	Excellent	As for level 5, with a 2.5 kg weight held behind the head, chest touching the thighs
7	Elite	As for level 5, with a 5 kg weight held behind the head, chest touching the thighs

Source: Courtesy of Topend Sports, [www.topendsports.com](http://www.topendsports.com)

**Tests**

Partial curl-up

Pull-ups

30-second endurance jump

# Muscular endurance tests

## 30-second sit-up test

### Equipment

- stopwatch
- yoga mat or similar

### Procedure

- 1 The performer takes up the starting position, lying on a mat with their knees bent at a 90-degree angle, arms straight and fingers flat.
- 2 A partner helps, placing their forearm across the subject's knees, and counting the number of sit-ups performed. A sit-up is completed each time the subject slides their hands along the top of their thighs, touches their partner's forearm and returns the back of their head to the mat.
- 3 The number of sit-ups completed in 30 seconds is recorded.
- 4 If a performer is unable to perform two consecutive sit-ups with the correct procedure, at the required rate, they withdraw from the test and record the number of correctly completed sit-ups.

Table 10.17 shows the national norms for 16- to 19-year-olds.

Gender	Excellent	Above average	Average	Below average	Poor
Male	> 30	26–30	20–25	17–19	< 17
Female	> 25	21–25	15–20	9–14	< 9

Source: Fitness2u, 2013

## Maximal push-ups in 60 seconds

The push-up test will assess upper-body muscular strength and endurance for each push-up. Table 10.18 provides the norms.

### Procedure

- 1 The person being tested assumes the standard push-up position: legs together and hands pointing forward, shoulder width apart, positioned directly under the shoulders (see Figure 10.20).
- 2 A partner places a fist on the floor directly under the person's chest.
- 3 The performer lowers themselves until their chest touches the fist, keeping their body straight and rigid, and then pushes themselves back up to the starting position. This counts as one repetition. The toes are the pivotal point. Rest is allowed in the up position only.
- 4 The score is the total number of push-ups completed in 60 seconds.



**FIGURE 10.20** Correct push-up technique

**TABLE 10.18** Norms for maximal push-ups in 60 seconds for youths aged 15–19

	Males	Females
Excellent	39+	33+
Very good	29–38	25–32
Good	23–28	18–24
Fair	18–22	12–17
Needs improvement	17 or less	10 or less

Source: Canadian Society for Exercise Physiology

## Flexed-arm hang test

An alternative to the pull-up test is the flexed-arm hang test. Table 10.19 provides the norms for youths aged 15–17+.

### Equipment

- pull-up bar

### Procedure

- 1 Set the bar slightly higher than the performer's standing height.
- 2 The performer should grip the bar using an overhand grip, with their thumbs wrapped around it.
- 3 Spotters lift the performer so that their chin is above the bar but not touching it. The performer's arms should be flexed, and their chest close to the bar.
- 4 Once the performer is in position, the spotter lets go. The time is recorded from the moment the spotters let go to the moment that the individual's chin touches the bar or falls below it.

**TABLE 10.19** Flexed-arm hang norms (in seconds) for youths aged 15–17+

Percentile	Boys			Girls		
	15	16	17+	15	16	17+
90	62	61	56	34	30	29
80	49	46	45	23	21	20
70	40	39	39	15	16	15
60	35	33	35	10	10	10
50	30	28	30	7	7	7
40	25	22	26	5	5	5
30	20	18	20	4	3	4
20	14	12	15	2	2	2
10	8	7	8	1	0	1

## Static flexibility tests

### Modified sit-and-reach test

The modified sit-and-reach test measures hip and trunk flexibility. Table 10.20 provides the norms.

#### Equipment

- ruler
- sit-and-reach box

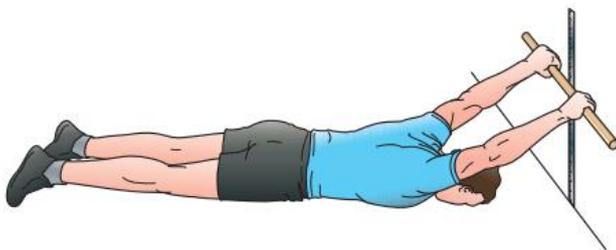
#### Procedure

- 1 Sit with your legs fully extended and the bottom of your feet against the sit-and-reach box.
- 2 Place your hands one on top of the other and gradually reach forward, sliding your fingers along the ruler.
- 3 Hold the final position for 2 seconds (see Figure 10.21).


**FIGURE 10.21** Correct sit-and-reach procedure


#### Tests

- Trunk and neck extension
- Ankle extension
- Shoulder rotation
- Groin flexibility



**FIGURE 10.22** Correct shoulder and wrist elevation procedure

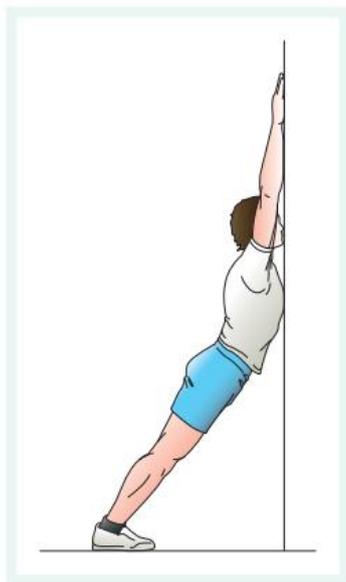
## Shoulder and wrist elevation test

### Equipment

- wooden rod
- vertical scale (a metre ruler taped to the wall, with the zero end at floor level)

### Procedure

- 1 Lying prone on the floor with arms fully extended overhead, grasp the wooden rod with your hands shoulder-width apart.
- 2 Raise the rod as high as possible while keeping your chin on the floor.
- 3 Your partner should read the score from underside of the wooden rod (against the metre ruler taped to the wall).
- 4 Measure your arm length from acromial process to fingertips and subtract your best trial score from your arm length. Table 10.20 provides the norms.



**FIGURE 10.23** Correct ankle flexion test procedure

## Ankle (dorsi)flexion test

### Procedure

- 1 Stand facing the wall and keep your heels flat on the floor while leaning into the wall.
- 2 Your hands, chin and chest should be touching the wall.
- 3 Put as much distance between the wall and your heels as possible while keeping your body and knees fully extended and your chest in contact with the wall (see Figure 10.23).
- 4 Measure the distance between your toe line and the wall. Table 10.20 provides the norms.

**TABLE 10.20** Norms (in centimetres) for flexibility tests

Test item	Men	Performance rating	Women
<b>Modified sit-and-reach test</b>			
	> 9	Excellent	> 16
	6–9	Good	13–16
	2–5	Average	10–12
	–5–1	Fair	6–9
	< –5	Poor	< 5
<b>Shoulder and wrist elevation test</b>			
Difference between arm length and best score	< 15.0	Excellent	14.0 or less
	15.0–21.0	Good	14.0–19.0
	21.1–29.0	Average	19.1–27.3
	29.1–32.0	Fair	27.4–30.0
	> 32.0	Poor	> 30.0
<b>Ankle dorsiflexion test</b>			
Distance between toe line and wall	> 89.0	Excellent	> 81.0
	82.6–89.0	Good	77.6–81.0
	75.1–82.5	Average	67.1–77.5
	67.0–75.0	Fair	61.5–67.0
	< 67.0.0	Poor	< 61.5

Adapted from: Johnson & Nelson, 1986

## Muscular power tests

Muscular power is used in sports where explosive movements are required. It is critical in many sporting pursuits, from high-intensity running to the throwing of a projectile.

### Vertical jump test

#### Equipment

- chalk
- measuring board

#### Procedure

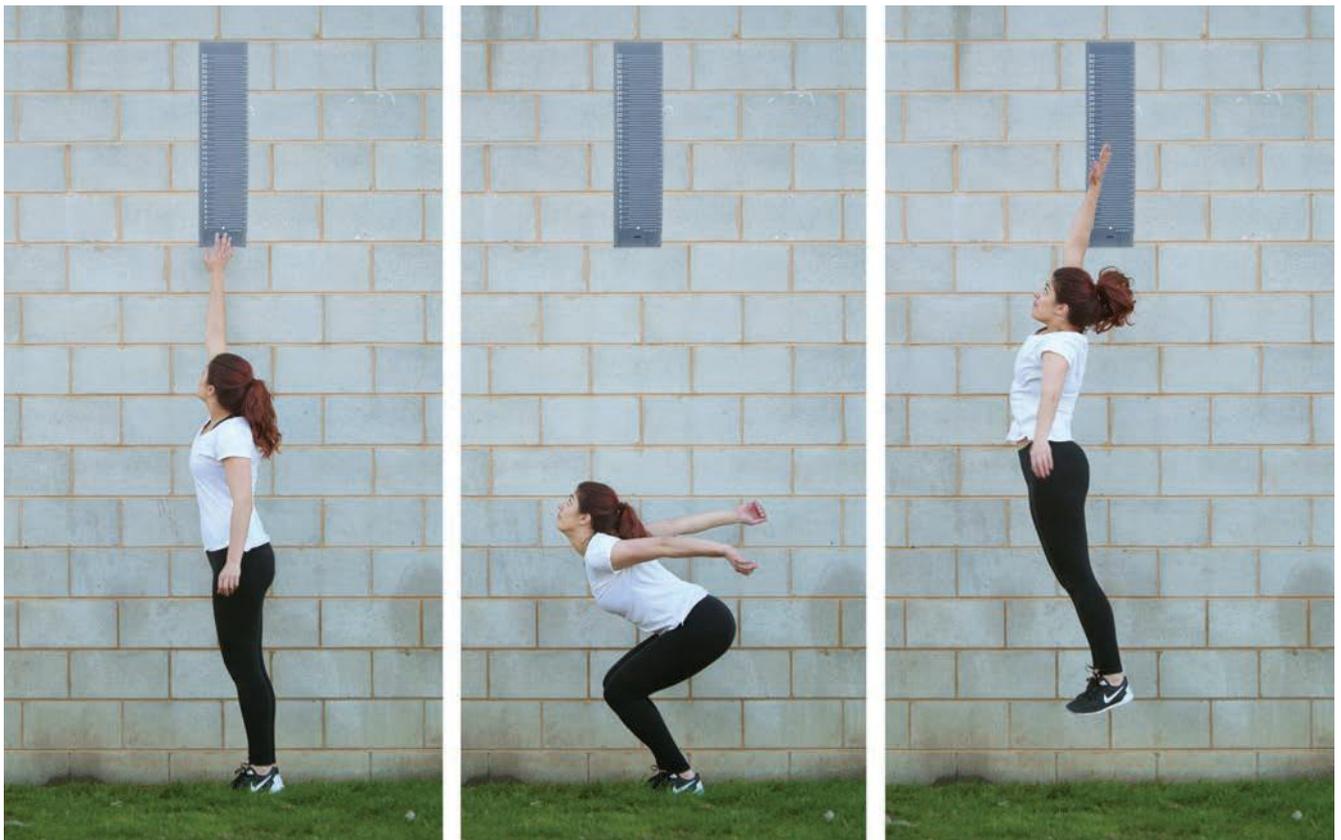
- 1 Stand sideways to the wall with one arm extended.
- 2 Make a chalk mark at the height of your reach. Don't elevate your shoulder.
- 3 Lower your arm and, without moving your feet, squat down and jump as high as possible, making a chalk mark on the wall as high as you can reach at the peak of the jump.
- 4 Measure the distance between the starting mark and the jump mark.

Three trials are allowed, with the best result used for rating (see Table 10.21 for ratings).



Robert Cianfione/Getty Images

**FIGURE 10.24** A commercial product specifically designed for vertical jump testing



**FIGURE 10.25** Vertical jump test

**TABLE 10.21** Rating chart for vertical jump (in centimetres)

	Poor	Fair	Average	Good	Excellent
Boys (15–16 years)	< 43.2	43.3–50.8	50.9–55.9	56.0–68.6	> 68.6
Girls (15–16 years)	< 33.5	33.6–37.8	37.9–40.6	40.7–47.0	> 47.0

Adapted from: Hoffman, 2006

## Standing long jump test

### Equipment

- measuring tape
- non-slip surface
- preferably, a soft surface on which to land

### Procedure

- 1 Stand behind a line with feet slightly apart.
- 2 Jump as far as you can from a two-footed take-off and measure the distance from the take-off line to the back of the closer foot on landing.
- 3 Participants should slightly bend their knees and swing their arms backwards before attempting to jump (see Table 10.22 for ratings).

**TABLE 10.22** Rating chart for power in standing long jump (centimetres)

Rating	Males	Females
Excellent	250+	200+
Very good	241–250	191–200
Above average	231–240	181–190
Average	221–230	171–180
Below average	210–220	161–170
Poor	191–210	141–160
Very poor	190 or below	140 or below

Source: Courtesy of Topend Sports, [www.topendsports.com](http://www.topendsports.com)

## REAL WORLD APPLICATIONS

### Variations of the vertical jump test

The Australian Institute of Sport's National Sport Science Quality Assurance program (NSSQA) has introduced several variations on the standing jumps test to cater for the specific requirements of individual sports.

#### Basketball

The vertical jump protocol for basketball incorporates a one-step movement prior to the jump.

#### Tennis

Vertical jump height is recorded for both legs as well as right and left legs independently. Also, the vertical jump protocol for tennis incorporates a one-step movement prior to the jump for the jump on both legs.

#### Volleyball

Uses two sport-specific vertical jumps. The first is a two-handed block jump. The second is a one-handed spike jump.





### Australian Rules football

Footballers also complete a running vertical jump after completing the standard standing vertical jump protocol.

#### QUESTIONS

- 1 What fitness component is being assessed by the tests described above?
- 2 Why has the AIS introduced these tests?
- 3 What norms, if any, would be available for these tests?

## Seated basketball throw

There are very few norm-referenced upper-body tests for muscular power. While the seated basketball throw does not have suitable ratings, it could be used for a pre-and-post comparison to assess the effectiveness of an upper-body power training program.

### Equipment

- basketball
- measuring tape

### Procedure

- 1 The performer sits with their back against a wall, facing in the direction of the intended throw. Their back must remain in contact with the wall.
- 2 The basketball is thrown as far as possible with a chest pass.
- 3 The distance is measured from the wall to where the basketball lands.

### Scoring

Allow two practice attempts. Two throws are then completed, and the better score is recorded.

## Speed tests

Speed can refer to either whole-body speed or part-body speed. Testing is usually focused on whole-body speed and involves timing how long it takes to cover a set distance. Typical sprint distances for assessing running speed are 10 metres, 20 metres, 35 metres, 40 metres and 50 metres. Specificity can be applied to speed tests by applying an appropriate distance – for example, the AFL draft camp uses a 20-metre sprint test.

There may be reliability issues when assessing speed over shorter distances, such as timing 10- or 20-metre sprints with a handheld stopwatch. Testing at the elite level will often use electronic timing gates to increase reliability, but this may be too expensive for schools or non-elite sporting clubs.



**FIGURE 10.26** Electronic light timing gates greatly increase the reliability of testing results.

## 20-metre, 35-metre and 50-metre sprint tests

Tables 10.23 and 10.24 show norms for 35-metre and 50-metre running sprint tests, respectively. There is a lack of available norms for the shorter sprint distances (10 and 20 metres), other than for elite performers. However, these distances are quite common in many team sports and could form part of a pre-and-post testing scenario to assess the effectiveness of a training program. Either distance could be timed as part of testing a longer distance, such as 35 metres.

### Equipment

- measuring tape
- stopwatch
- cones

### Procedure

Testing involves running a single maximum sprint over a set distance. A thorough warm-up should be completed first.

**TABLE 10.23** Ratings for the 35-metre sprint test (seconds)

Rating	Male	Female
Excellent	< 4.80	< 5.30
Good	4.80–5.09	5.30–5.59
Average	5.10–5.29	5.60–5.89
Fair	5.30–5.60	5.90–6.20
Poor	> 5.60	> 6.20

**TABLE 10.24** Ratings for the 50-metre sprint test (seconds)

Rating	Male	Female
Excellent	7.57 or less	8.1 or less
Good	7.58–7.85	8.2–8.6
Average	7.86–8.40	8.7–8.9
Below average	8.41–8.78	9.0–9.3
Needs work	8.79 or more	9.4 or more

Source: Courtesy of Topend Sports, [www.topendsports.com](http://www.topendsports.com)

# Agility tests

As we discovered in Chapter 8, agility is a rapid change of direction in response to a stimulus. The agility tests that follow focus on the rapid change of direction component of agility. There are very few actual agility tests, and none with norms at present. Specific agility tests, with both a stimulus and a rapid change of direction, are being developed by elite sporting clubs. Visit the Science for Sport website to explore this further.



**Weblink**  
Science for Sport:  
Illinois agility test

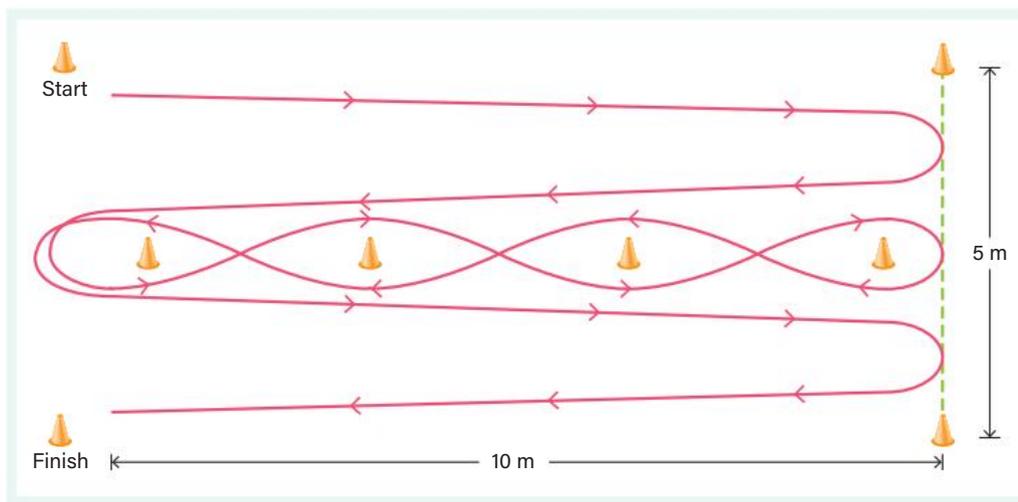
## Illinois agility test

### Equipment

- stopwatch
- cones to mark out the course
- 4 chairs

### Procedure

- 1 Using the cones, mark out the course as shown in Figure 10.27.
- 2 Begin by lying behind the start line, with your hands near your shoulders and your head behind the line.
- 3 On the command 'go', jump up and run through the course. You must touch the end lines with your foot.
- 4 The time taken should be recorded as you cross the finish line. Table 10.25 gives norms for this test.



**FIGURE 10.27** Floor plan for the Illinois agility test

**TABLE 10.25** Ratings for the Illinois agility test (seconds)

	Excellent	Above average	Average	Below average	Poor
Girls	< 17.0	17.0–17.9	18.0–21.7	21.8–23.0	> 23.0
Boys	< 15.2	15.2–16.1	16.2–18.1	18.2–18.3	> 18.3

Source: Davis et al., 2000

## SEMO agility test

The SEMO agility test measures the general agility of the body in manoeuvring forwards, backwards and sideways.

### Equipment

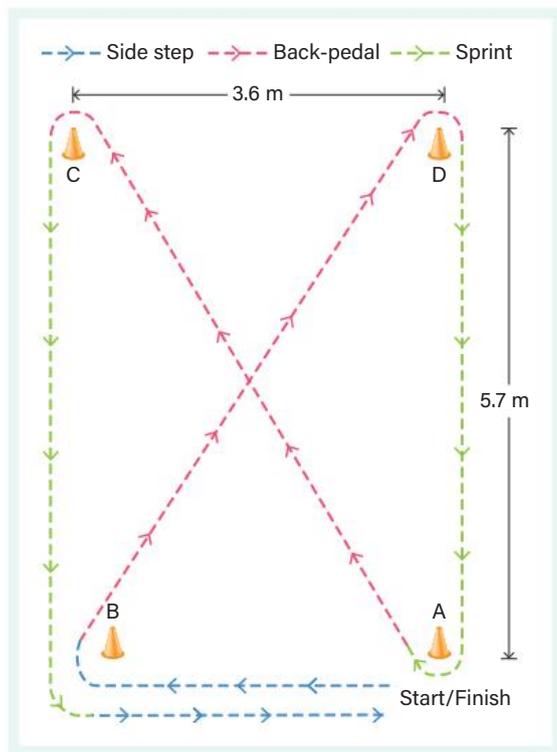
- a smooth area of 3.6 × 5.7 metres with adequate running space around it (a basketball key is ideal)
- 4 plastic cones
- stopwatch
- basketball key

### Procedure

- 1 Place the cones in each corner of the area, as shown in Figure 10.28.
- 2 Line up at 'A' with your back to the square.
- 3 At the signals 'ready, go', sidestep from A to B and pass outside the corner cone; then run backwards, or backpedal, from B to D and pass to the inside corner of the cone; then sprint forwards from D to A and pass outside the corner cone; then backpedal from A to C and pass to the inside of the corner cone; then sprint from C to B and pass outside the corner cone; and finally sidestep from B to the finish line at A. Two trials are allowed.

### Scoring

The better of the two trials (recorded to the nearest tenth of a second) is recorded as the score. Table 10.26 shows the appropriate norms.



**FIGURE 10.28** The SEMO agility test course

Adapted from: Johnson & Nelson, 1986

### Important notes

- When performing the sidestep, the crossover step cannot be used.
- When performing the back-pedal, you must keep your back perpendicular to an imaginary line connecting the corner cones.
- Incorrect procedure makes the trial invalid, and you should be tested until one correct trial is completed. At least one practice trial should be given.

**TABLE 10.26** Norms for US college students in the SEMO agility test (in seconds)

Performance level	Score	
	Men	Women
Advanced	10.72 and below	12.19 and below
Advanced intermediate	10.49–10.73	12.99–12.20
Intermediate	13.02–10.50	13.90–13.00
Advanced beginner	13.79–13.03	14.49–13.91
Beginner	13.80+	14.50+

Source: Johnson & Nelson, 1986

## 5-0-5 agility test

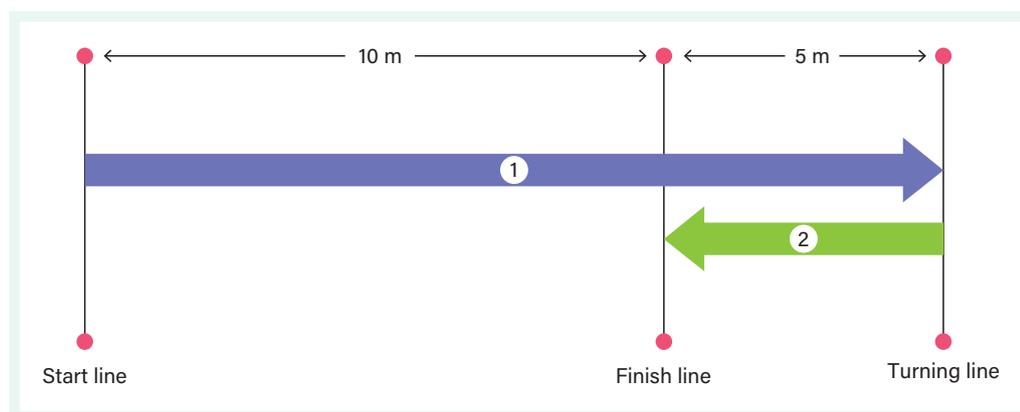
### Equipment

- stopwatch
- cones to mark out the course
- tape measure

### Procedure

- 1 Using the cones, mark out the course according to the illustration below (Figure 10.29).
- 2 The participant sprints towards the 15-metre turning point, turns on the line and sprints back past the 5-metre marker.
- 3 Record the time from when the participant passes the 5-metre marker on the way to the turning point until they pass the 5-metre marker on their way back (a total of 10 metres).
- 4 Two trials should be attempted, alternating the turning leg. Allow at least 2 minutes recovery before each attempt.

Please note: There are limited norms available for the 5-0-5 agility test.



**FIGURE 10.29** The 5-0-5 agility test

## 10.4 CHECK-IN QUESTIONS

- 1 **State** two advantages and two disadvantages of  $VO_2$  max testing in a laboratory.
- 2 **Identify** a submaximal aerobic power test and **explain** the principle that submaximal testing is based on.
- 3 A performer reaches cone 8 for the first three repetitions of the phosphate recovery test, before their performance drops off dramatically for the next five sprints, demonstrating that they can develop good speed.
  - a **State** the fitness component that this test is assessing.
  - b **Identify** the fibre type of which the performer is likely to have a higher percentage.
  - c It has been suggested that the performer should also complete an aerobic power test. **Discuss** the relevance of this to the result of the phosphate recovery test.
- 4 a **Distinguish** between absolute and relative  $VO_2$  max results, including the units of measurement.
  - b **Justify** which of these testing results is more beneficial.



**Assessment**  
10.4 Check-in questions

### Command terms

#### state

Give a specific name or value or other brief answer without explanation or calculation

#### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

# CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 10

## 10.1 The purpose of fitness assessment

- There are a variety of reasons for undertaking fitness testing. These include determining fitness component strengths and weaknesses; establishing a baseline or benchmark; monitoring progress; identifying more appropriate team positions; identifying talent; and including as part of an employment selection process.
- Particularly with maximal testing, psychological factors also need to be considered.
- Validity in testing ensures that the test is measuring the fitness component it claims to be assessing.
- Reliability in testing ensures that the test results obtained are repeatable – that is, if the same test were performed again after suitable rest, the same result would be obtained. Several factors can increase the reliability of testing, such as ensuring the test is performed in the same environmental conditions.
- Accuracy of testing increases the reliability of results. Following testing protocols will increase accuracy.

## 10.2 Pre-participation health screening

- Pre-activity health screening is valuable for the elderly or those with health risk factors.
- Informed consent minimises the potential harm to both the tester and the performer. It is vital that both parties are aware of the inherent risks with any test undertaken, as well as the benefits of performing the test.

## 10.3 Fitness test selection considerations

- Specific testing protocols are based on the rules or procedures to be followed for each fitness test. Factors to be considered include specificity, result comparison and the type of test to be undertaken.
- Specificity refers to choosing a test that closely resembles activities undertaken by the performer.
- Result comparison can be either norm- or criterion-referenced. Where norms or criteria are not available, results can still be used to assess the effectiveness of a training intervention.
- Confidentiality needs to be considered before results are shared.

## 10.4 Types of fitness assessment

- There are a variety of fitness tests available for the various fitness components. These are classified as maximal or submaximal and laboratory- or field-based.

# CHAPTER REVIEW

- 1 Which of the following tests would be the most appropriate for a state basketball coach to use to measure muscular power in her rebounding players?
  - A standing broad jump
  - B 1RM bench press
  - C vertical jump
  - D 35-metre sprint
  
- 2 Which of the following testing sequences would produce the most reliable results?
  - A sit and reach, 20-metre shuttle run, vertical jump, 50-metre sprint
  - B 50-metre sprint, vertical jump, 20-metre shuttle run, sit and reach
  - C vertical jump, 50-metre sprint, 20-metre shuttle run, sit and reach
  - D vertical jump, 20-metre shuttle run, 50-metre sprint, sit and reach
  
- 3 When completing the 20-metre shuttle run test, you will be disqualified if:
  - A you fail to make the line.
  - B you reach the end well in advance of the beep.
  - C you fail to make the line twice consecutively.
  - D you power-walk the early stages instead of jogging.
  
- 4 **©VCAA** Exam 2022, Section A, Q11  
 Which one of the following is the most suitable to test anaerobic capacity for an under-16 basketball team?
  - A vertical jump
  - B phosphate recovery test
  - C 30-second Wingate test
  - D multi-stage fitness test
  
- 5 Informed consent is increasingly becoming part of fitness-testing practices.
  - a **Describe** the process of informed consent.
  - b **Discuss** the importance of informed consent.
  
- 6 The Yo-Yo intermittent recovery test can be used as an alternative to the Cooper's 12-minute run test.
  - a **Identify** the fitness component both tests aim to measure.
  - b **Discuss** the circumstances in which each test may be more appropriate.
  - c Participants will usually show signs of fatigue towards the end of either test. Why is this?
  - d **Suggest** a more suitable alternative test for a sedentary person.
  
- 7 There is a shortage of normative data available for 10-metre and 20-metre sprint times for non-elite performers. **Suggest** two likely reasons for this.



**Assessment**  
Chapter 10 Review

### Command term

#### **describe**

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

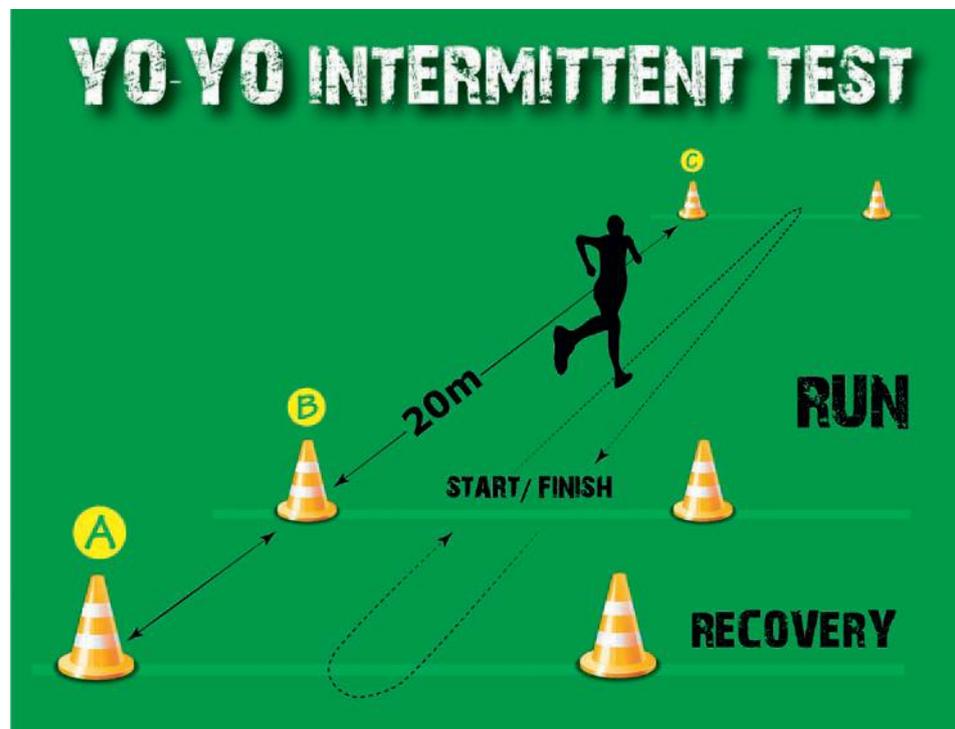
## 8 ©VCAA Exam 2022, Section B, Q6

The table below shows data resulting from an activity analysis of 17-year old male handball players during a state-level tournament.

Speed of movement	Distance covered (m)
sprint	98
high-intensity running	163
jogging	1136
walking	362

Data: M.S. Chelly et al., 'Match analysis of elite adolescent team handball players,' *Journal of Strength and Conditioning Research*, vol. 25, no. 9, 2011, p. 2414

The handball players were also required to complete the Yo-Yo intermittent recovery test shown in the diagram below. This is a fitness test that involves running at increasing speeds between markers placed 20 metres apart and recovering in between runs. The test continues until the runner is exhausted.



Source: R. Wood, 'The Complete Guide to the Yo-Yo Test', 2018, [www.theyoyotest.com](http://www.theyoyotest.com)

### Command terms

#### name

Provide a word or term (something that is known and distinguished from other people or things) used to identify an object, person, thing, place etc.

#### define

Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity

- Name** and **define** the fitness component that is assessed in the Yo-Yo intermittent recovery test.
- Using the data provided in the table above, **justify** why, from a physiological perspective, the Yo-Yo intermittent recovery test was selected to assess the handball players' fitness.

## 9 ©VCAA Exam 2023, Section B, Q2

Jai Hindley is a road cyclist who was the first Australian to win the Giro d'Italia bicycle race, in 2022. The riders complete 21 stages over a three-week period, with the total distance of the stages being approximately 3500 km. Each stage varies in distance and duration, with the average stage taking around four hours to complete.



Andrea Soresina/Shutterstock.com

The  $VO_2$  maximum cycle ergometer test is a common fitness test performed by professional cyclists.

- a **State** the fitness components tested using the  $VO_2$  maximum cycle ergometer test.
- b **Justify** the selection of the  $VO_2$  maximum cycle test from a physiological and psychological perspective for Jai Hindley.

## CHAPTER

# 11

## MONITORING AND RECORDING TRAINING VARIABLES

UNIT 4 - AREA OF STUDY 2



iStock.com/Phynart Studio

**FIGURE 11.01** A digital training program that an athlete has shared with his coach is being reviewed.

### Quizzes

Chapter 11 Pulse check

**11.1** Check-in questions

**11.2** Check-in questions

Chapter 11 Review

### Videos

Masterclass: Chapter 11

**11.1** In focus: Training program diaries, reflections and future improvements

### Resources

**11.1** Template: Training diary

Chapter 11 Self-assessment checklist



 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)

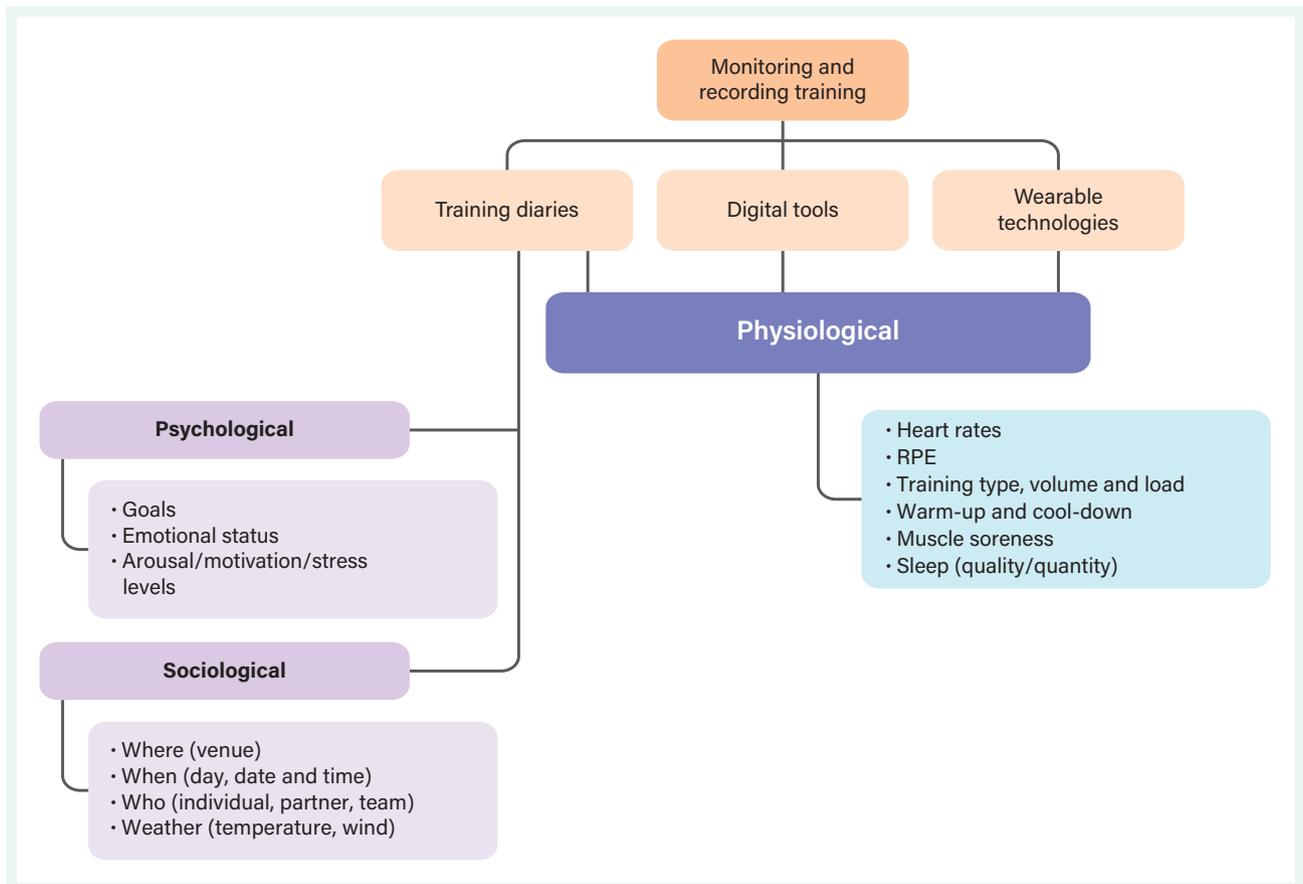
- » strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital tools and wearable technologies

## KEY KNOWLEDGE

- » participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 11

There are many different options that can be considered when it comes to monitoring and recording training. Training aims to best prepare a person for an activity or competition they are going to participate in, and this is affected by physiological, psychological and sociological factors. There is an 'interplay' between these factors and all three contribute to the overall performance and outcomes of training. Recording details of these factors provides a means by which their influence can be further evaluated and training can be much more effectively monitored with the possibility of making future improvements. Rapid advances in digital monitoring instruments and systems have allowed many more variables than just heart rate to be recorded. Ultimately the choice of which ones to select comes down to the level of performance under consideration and the type of data that will be useful to, and inform, the training being undertaken.

**Assessment**

Pulse check

**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 Why is it important to prepare a training diary record sheet and enter data during and after training has been completed?
- 2 Many coaches believe it is as important to include training goals in a training diary as it is other variables such as heart rate, sets/reps and resistances or work-to-rest ratios (W:R). **Propose** why this may be the case.
- 3 **Consider** how training with others can have a positive influence on the way training is undertaken.
- 4 What influence can poor sleep have on training and why is sleep an important variable to keep track of throughout the training year?
- 5 Wearable technologies have become smaller and more comfortable for use during training. **Outline** two different types of wearable technologies and the type of data they can capture and record. Other than cost, what might stop some people from using these wearable technologies during training?

## 11.1 TRAINING DIARIES

In this module you will learn about:

- the purpose of using a training diary
- objective and subjective data considerations
- training diary inclusions and the importance of personal reflections and learn to:
- design and/or use a training diary to record different parts of a training session (warm-up, conditioning and cool-down).

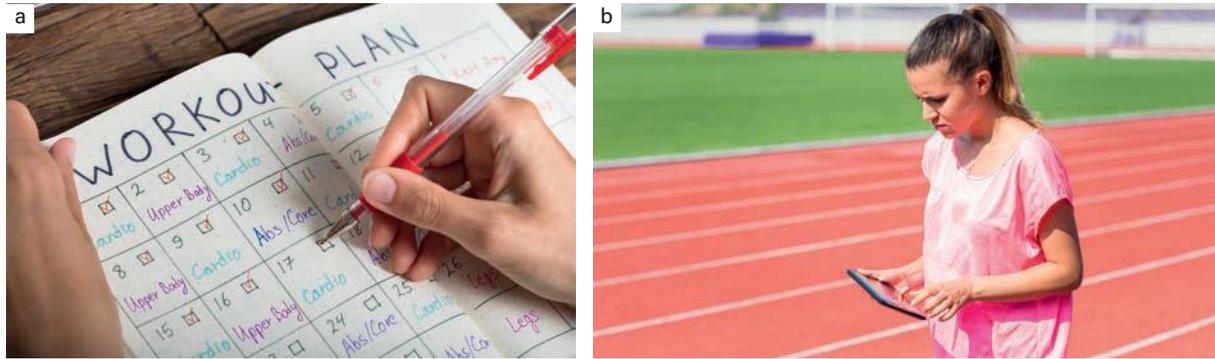
**objective data**

Information that can be observed or measured and that is highly verifiable and reliable

**subjective data**

Information that is derived from feelings, experiences, opinions and thoughts

Training diaries consist of either manual or handwritten entries, or digital entries captured on a smartphone, tablet or laptop. They typically contain both objective and subjective data. **Objective data** is non-opinion-based and includes variables such as the number of sets or repetitions, resistances or exercise duration. It can further be supplemented by data obtained from digital devices, including heart rate, body temperature and work output. **Subjective data** is based on what the subject believes or feels, and can include emotions, energy levels, rate of perceived exertion, muscle soreness and readiness to train.



**FIGURE 11.02** A training diary can be either: **a** manual; or **b** digital.

Both the objective and subjective data entries provide great insight into how physiological, psychological and sociological variables influence the training being undertaken. Collecting and documenting this data in a training diary provides a permanent record that allows training to be monitored and tracked, which assists with:

- higher levels of motivation and **training adherence**
- review of training goals and objectives
- correct application of training principles
- increased input from coaches, sports specialists and other professionals
- minimising or avoiding **overtraining** and injury
- identifying patterns and trends
- evaluating the effectiveness of training
- making evidence-based modifications to current training activities and programming
- more effective reference and return to in-season training after the 'off-season'.

Encouraging athletes and people undertaking any form of physical activity or exercise to use a training diary creates greater 'buy-in'. This will increase their own knowledge about how their body is performing and responding to exercise/training. Furthermore, it allows them to have an active input to their own development, rather than simply following a program that has been designed by others.

## LOOKING FORWARD

### Training methods

#### Chapters 12, 13 and 14

Chapters 12 and 13 will provide more information about the training methods used in the conditioning phase and the associated principles, while Chapter 14 will unpack aspects of a warm-up, conditioning and cool-down to add to your understanding of how these areas are all linked.

## 📌 SIGNPOST

Students will use a reflective folio throughout their senior Physical Education studies to record their experiences in and through participation in practical activities. You can read more about your reflective folio in the Gameplan section at the start of this book.



### training adherence

The extent to which a person acts in accordance with the intended exercise and/or training program

### overtraining

When a person cannot consistently perform at a desired level of training, usually as a result of inadequate recovery or excessive training volume

### LEARNING HACK

'Buy-in' is an acceptance of, and a willingness to actively support and participate in, something such as a proposed exercise plan or training program.

## Training diary inclusions

Training diaries tend to be presented in table format. Most will contain:

- general information such as the day, date, time, venue and weather conditions
- stage of the training year (periodisation)
- emotional and physiological status
- session focus/goals
- warm-up activities
- condition phase methods, exercises and prescriptions (sets, reps, volume, W:R etc.)
- cool-down activities
- space for data collection and **personal reflection**.

Training diary inclusions and planning occur before the training starts, while the training is being undertaken and, importantly, once it has been completed, and take the form of physiological, psychological and sociological entries. Table 11.01 summarises some of the information that may be included under each of these entry classifications.

### personal reflection

The process of taking time to evaluate and give serious thought to our own behaviours, thoughts, attitudes, motivations and desires

### ambient

Relating to the immediate surroundings

**TABLE 11.01** Physiological, psychological and sociological considerations that affect training and exercise

Physiological	Psychological	Sociological
<ul style="list-style-type: none"> <li>• Heart rate (resting, working and recovery)</li> <li>• Rating of perceived exertion (RPE)</li> <li>• Training load and volume</li> <li>• Warm-up and cool-down</li> <li>• Muscle soreness</li> <li>• Nutritional/hydration status</li> <li>• Perspiration (water loss)</li> <li>• Sleep (quality and quantity)</li> </ul>	<ul style="list-style-type: none"> <li>• Training goal(s)/focus</li> <li>• Emotional status (arousal, motivation and concentration levels)</li> <li>• Energy levels</li> </ul>	<ul style="list-style-type: none"> <li>• Training solo, with a partner, with others (who)</li> <li>• Training method(s) and exercises (what)</li> <li>• Day, date and time (when)</li> <li>• Venue (where)</li> <li>• <b>Ambient</b> conditions (weather)</li> </ul>

## General information

This data includes the day, date, time, venue, stage of the training year and ambient conditions. These can all be considered when the subject is looking back on previous sessions to identify trends and possible reasons why training outcomes have been achieved. The stage of the training year is vital because training will vary depending on whether the person is involved in pre-season, in-season or off-season activities. Similarly, when athletes are tapering before a major competition, or reducing training volumes prior to applying progression, training volumes will be deliberately decreased. These changes in training volumes are expected and can be justified.

Ambient conditions extend beyond temperature (heat/cold) and humidity, and can also include air quality and 'noise'. An athlete training for the marathon by running through local streets in a heavily polluted city would experience a very different set of circumstances to someone doing the same in a city where the air quality is considerably better. Noise can refer to sounds measured in decibels, but also refers to possible distractions and inconvenience experienced when exercising in a crowded space such as a gym or athletic track.

### LEARNING HACK

The sociological factors that affect training can be thought of as 'the five Ws': who, what, when, where and weather.

### DID YOU KNOW?

The female menstrual cycle has been shown to impact performance and behaviour, both physiologically and psychologically. Female athletes track their cycle as part of their monitoring of training.



Lucky Business/Shutterstock.com

**FIGURE 11.03** Training in a busy gym might mean waiting for equipment to become available and have a negative impact on W:R. It might also create frustration, anxiety and loss of concentration, all of which would affect training quality and outcomes.

## Emotional and psychological status

All athletes have experienced training sessions where they feel 'flat' and lethargic, and these sessions are invariably of a poorer quality than those we undertake when energised and highly motivated. Psychological status has a significant impact on how people exercise and train and must be recorded for future reference. A person may be following the correct **exercise prescription**, applying the training principles effectively and with purpose, but simply be in a **headspace** that is not conducive to positive training outcomes. Alternatively, they may not have had enough sleep, or a good night's rest, which can also have a negative impact on training.

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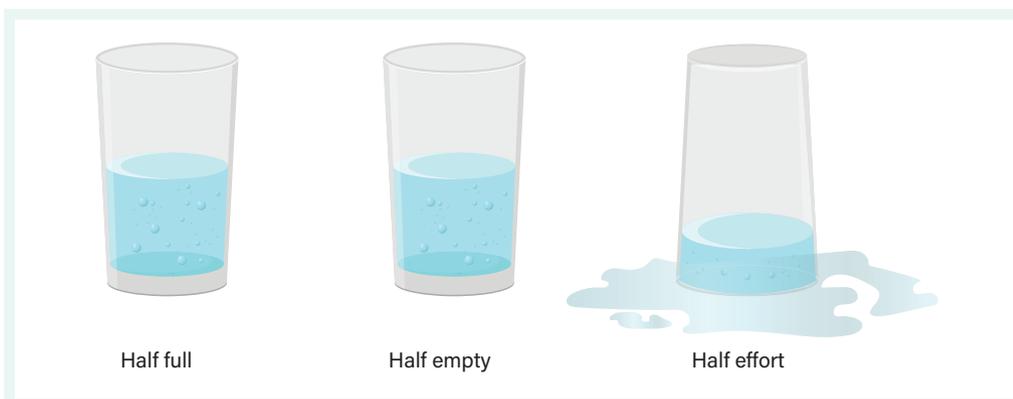
### exercise prescription

A specific plan consisting of fitness-related exercises and activities that are designed for a particular purpose and are usually summarised within a training program

---

### headspace

A person's state of mind, mindset or attitude



**FIGURE 11.04** Mindset and attitude have a significant impact on how we perform tasks.

## Session focus/goals

Every training session should be undertaken with one or more specific goals in mind. Even more importantly, these goals should be clearly stated. Goals that are written down can motivate subjects to by providing them with clear and achievable training targets. As well as providing focus, goals can keep subjects 'on track' and accountable.

These goals might relate to specific fitness components or energy systems, dedicated training methods or the specific movements that need to be considered while performing training exercises. Goals should take into consideration previous training sessions and experiences. For example, if a person found it difficult to complete the last few repetitions of a resistance program at the required speed, or could not maintain the required intensity for part of a HIIT session, this might be identified in subsequent diary goals.

### LOOKING BACK

#### Goal-setting and SMART goals

##### Chapter 2

Revisit Chapter 2 to recall the important of goal-setting and SMART goals.

## Warm-up activities

This should not be left blank or simply entered as, for example, '10 mins warm-up'. The RAMP protocol sets out specific details that should be recorded about what is being done to:

- **raise** body temperature
- **activate** muscles
- **mobilise** joints
- **potentiate/prepare** the body via specific exercises.

Warm-up activities need to prepare a person for the exercises/activities they are about to undertake and should be highly specific. Additionally, recording the warm-up that is actually being undertaken allows variety to be considered during a training period. This is recommended to maintain motivation and keep engagement levels high.



**FIGURE 11.05** The continuous part of the warm-up aims to raise the heart rate, the respiratory rate and the supply of oxygen and fuels to working muscles.

## Conditioning phase methods, exercises and prescriptions

The conditioning phase is undoubtedly the most important phase of any training session because it is where training principles and methods intersect. The main goal, of encouraging training adaptations to take place and lead to performance improvements, is also targeted during this part of the training session.

What training methods, and specific activities/exercise within these, are planned? Once these have been considered and stated, it is vital also to provide information about the load that is going to be placed on the body – in other words, what workload is going to be undertaken? The overall loading placed on a person's body will depend on the following five variables:

- sets
- repetitions
- resistances
- intensity of effort
- recovery time and type, including work-to-rest ratio (W:R).

### LOOKING FORWARD

#### The five variables

#### Chapters 12, 13

Chapters 12 and 13 will further explain these key variables and how they can be manipulated to ensure that progression is applied effectively and safely. Additionally, several examples of each are provided to improve your key knowledge.

#### LEARNING HACK

Training volume = sets ×  
reps × resistance applied

## Cool-down activities

As with the warm-up, simply recording 'cool-down exercises' in a training diary really doesn't give sufficient information to let you make judgements and modifications. Is the cool-down active in nature? If so, what activities are being undertaken and for how long? It is important to record the length of any passive recovery incorporated after the conditioning phase. The cool-down is also a part of training where some people often include flexibility stretches. In Chapter 13 you will discover that dedicated flexibility training is very different to stretches performed as part of a cool-down or active recovery.

## Space for data collection and personal reflection

A well-designed training diary will have scope for the multiple datasets we have considered so far to be included and annotated. It is vital to record personal reflections as well, and this is an area that should not be underestimated or simply left out. Personal reflections, used in consultation with a Physical Education teacher, personal trainer, coach or sports specialist, allow judgements to be made about the effectiveness of training from the subject's perspective. These are often used in making adjustments to future training sessions to improve the quality of training and increase levels of satisfaction and engagement, and to make any other modifications that may be needed to bring about improvements.

The subject should be encouraged to complete various personal ratings throughout and after the training session. These include the RPE mentioned in Chapter 7 (when considering training intensities) and could also include a 'rating of training effectiveness' (RTE; see Table 11.02) and 'rating of training fatigue' (RTF; see Table 11.03). Both variables can simply be entered as a number ranging from 1 to 5 or 1 to 3.

**TABLE 11.02** Rating of training effectiveness

RTE scale	RTE descriptor
1/3 Not effective	I do not believe my training goals would have been achieved and need to review principles, methods and volume of training.
2/3 Moderately effective	Most of the training activities were completed but I feel some of them could be modified to be more specific to my goal(s).
3/3 Highly effective	Training was optimal and I completed all prescribed exercises to the best of my ability and met my goal(s).

Note: 'RTE' is not an accepted training abbreviation.



Vadim Zakharishchev/Shutterstock.com

**FIGURE 11.06** Excessive fatigue or exhaustion following training usually signals the need for major modifications to be made to training after consulting with a sports professional.

**TABLE 11.03** Rating of training fatigue

RTF scale	RTF descriptor
1/3 Slight/expected fatigue	Slight (non-lasting) muscle soreness/stiffness but returned to pre-training levels fairly quickly. Feeling energised and looking forward to the next session in a couple of days.
2/3 High fatigue suggesting modifications required	Some exercises were not completed and the planned volume was too difficult. Feeling a little more muscle soreness than usual, but not restrictive. Should be 'good to go' again in a couple of days.
3/3 Cause for concern and injury likely	Totally exhausted (lingering muscle soreness from previous session has increased). Likely to need 4–5 days to recover fully.

Note: 'RTF' is not an accepted training abbreviation.

Other subjective measures that need to be recorded post-training are ‘the five Ws’: who, what, when, where and weather. As stated earlier, these all have an impact on the way training is undertaken as well as on the outcomes achieved. There is a longer list of variables and metrics that can be collected and recorded, but these are only useful if they are going to be referred to when evaluating and reflecting on training in the hope of making improvements.

Training scheduling (tick): Pre-season <input type="checkbox"/> In-season <input type="checkbox"/> Off-season <input type="checkbox"/>	
Day and date:	Time of day:
Venue/location:	
Training completed by/with (tick): self <input type="checkbox"/> partner <input type="checkbox"/> team-mates <input type="checkbox"/>	
Weather conditions:	Temperature:
Ambient conditions/level of comfort: __ /10. More detail:	
Motivation level: __ /10	
Attitude (tick): positive <input type="checkbox"/> neutral <input type="checkbox"/> negative <input type="checkbox"/>	Mood: __ /10
Sleep quantity: __ hours Sleep quality: poor/interrupted <input type="checkbox"/> good <input type="checkbox"/> very good <input type="checkbox"/>	
Resting heart rate:	Exercise heart rate (max):
Nutritional status 1–2-hours prior(tick): none <input type="checkbox"/> snack <input type="checkbox"/> meal <input type="checkbox"/>	
Hydration status (tick): low <input type="checkbox"/> medium <input type="checkbox"/> high <input type="checkbox"/>	
Muscles/joints feeling (tick): sore <input type="checkbox"/> tight <input type="checkbox"/> normal <input type="checkbox"/>	
Weight (pre-training):	Weight (post-training):
Session goal(s):	
Warm-up activities:	
Conditioning phase: training method 1 and exercise prescriptions:	
Training method 2 (if relevant) and exercise prescriptions:	
Cool-down activities:	
Rating of training effectiveness (RTE): __ /3	Rating of training fatigue (RTF) : __ /3
Post-training reflections and future recommendations:	
Happy with?	
Not happy with?	
Next time I would like:	



**Video**  
In focus: Training program diaries, reflections and future improvements

**Template**  
Training diary

**FIGURE 11.07** Sample training diary template

## CASE STUDY

## TRAINING DIARY ANALYSIS

Training scheduling (tick): Pre-season <input checked="" type="checkbox"/> In-season <input checked="" type="checkbox"/> Off-season <input type="checkbox"/>	
Day and date: Monday 14 July	Time of day: 1.30 pm
Venue/location: Stafford St Gymnasium	
Training completed by/with (tick): self <input type="checkbox"/> partner <input checked="" type="checkbox"/> team-mates <input type="checkbox"/>	
Weather conditions: mild and humid	Temperature: 19°C
Ambient conditions/level of comfort: 9/10. More detail: only a few others around	
Motivation level: 7/10	
Attitude (tick): positive <input type="checkbox"/> neutral <input checked="" type="checkbox"/> negative <input type="checkbox"/>	Mood: 7/10
Sleep quantity: 8 hours Sleep quality: poor/interrupted <input type="checkbox"/> good <input checked="" type="checkbox"/> very good <input type="checkbox"/>	
Resting heart rate: 62 bpm	Exercise heart rate (max): 185 bpm
Nutritional status 1-2-hours prior (tick): none <input type="checkbox"/> snack <input checked="" type="checkbox"/> meal <input type="checkbox"/>	
Hydration status (tick): low <input type="checkbox"/> medium <input type="checkbox"/> high <input checked="" type="checkbox"/>	
Muscles/joints feeling (tick): sore <input checked="" type="checkbox"/> tight <input type="checkbox"/> normal <input type="checkbox"/>	
Weight (pre-training): 71 kg	Weight (post-training): 69.8 kg
Session goal(s): Focus on training speed and anaerobic power via short interval training. Improving muscular power via circuit training (same major energy system). Aim to maintain highest intensity possible (RPE 10) during sprints.	
Warm-up activities: 2 min continuous jog followed by 4 sets of 4 × 15 m run-throughs with progressive increases in running intensity. Set 1 = 50-60%, set 2 = 75%, set 3 = 85%, set 4 = 100%	
Conditioning phase: training method 1 and exercise prescriptions: Short interval training (total time = 20 min) Short interval: Markers set at 5 m, 10 m and 15 m Shuttle sprints performed at 5 m, then 10 m, then 15 m (up and back) Walk back to start and rest for 2 min W:R = 1:9 Repeat × 5 sets	
Training method 2 (if relevant) and exercise prescriptions: Circuit: (total time = 20 min) 5 reps each station with 45 s transition/recovery W:R 1:8 1: box jumps 2: clap push-ups 3: squat jumps for height 4: lateral hops for distance 5: single arm ball throws (2 kg) 6: burpees Repeat × 4 sets	
Cool-down activities: 3-minute light jog Dynamic stretches Lower @ calves, quadriceps, hamstrings, groin, gluteals Upper @ deltoids, trapezius, biceps, triceps, pectorals	
Rating of training effectiveness (RTE): 2/3	Rating of training fatigue (RTF): 2/3





Post-training reflections and future recommendations:

Happy with?

- Short interval shuttle sprints – primarily focusing on anaerobic power, but also training agility with rapid and accurate directional changes
- Ability to remain 'on task' despite feeling a bit indifferent at start of training

Not happy with?

- Inability to maintain high/maximal intensity for plyometric exercises in circuit for all sets. This might have been caused by insufficient rest between training methods and sets of the circuit.

- Muscles feeling sore before session started and still experiencing pain after training

Next time I would like:

- Greater break in between training methods (2+ hours)
- Schedule alternate body parts throughout plyometric activities in circuit to allow for more complete restoration of fuels between alternate stations
- Perform single arm throws with normal tennis ball – 2 kg weighted ball slowed contraction speed down too much

**FIGURE 11.08** Completed training diary with comments and reflections

## QUESTIONS

Answer the following questions by focusing on the highlighted sections in the training diary.

- 1 **Propose** a reason stretching was not performed during the warm-up.
- 2 **Justify** the inclusion of burpees in the circuit based on the training goals.
- 3 Consider whether you would be able to perform the cool-down based on the information provided. Based on your response, what improvements would you suggest in terms of how these diary entries are recorded?
- 4 The subject 'lost' 1.2 kilograms in body weight during the training session, which was most likely in the form of fluid loss/sweating. What implications does this have for post-training rehydration, and would this be different if the subject's weight had not changed?
- 5 **Identify** any 'problems' in the circuit exercises (with scheduling, and relative to goals) and **suggest** modifications based on your findings.
- 6 The subject recorded muscle soreness before training started. Consider the likely cause and any modifications to training that might be considered.
- 7 What role does a training diary play in evaluating the effectiveness of a training session?

## Command terms

### propose

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action

### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

## LOOKING FORWARD

### Stretching

#### Chapter 14

The section headed 'To stretch or not to stretch?' in Chapter 14 (page 577) will be useful for the following collaborative task.



## COLLABORATIVE TASK

### Research

#### Reducing injury through training

Conduct your own research into the reduction of injury during training, or otherwise, as a consequence of performing warm-up stretches. Share your findings with a classmate and, if they have discovered contrary findings, try to convince them that yours are correct.



#### Assessment

11.1 Check-in questions

#### Command term

##### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer

## 11.1 CHECK-IN QUESTIONS

- 1 Multiple data sets/metrics can be recorded as part of a training diary. Why is it important to consider whether or not the data is going to be used?
- 2 Training goals are usually listed prominently at the top of most training diaries. **Justify** why it is so important to consider and list goals before all training sessions.
- 3 **Suggest** why it is beneficial to provide as much detail as possible about warm-up and cool-down activities, rather than simply recording more general entries such as 'warm-up stretches' or '5 min cool-down'.
- 4 **Outline** why it is useful for subjects to rate their training effectiveness once they have completed a training session even though it is a subjective reflection.
- 5 **Discuss** how training with others can influence what occurs during a training session.

## 11.2 WEARABLE TECHNOLOGIES AND DIGITAL TOOLS

In this module you will learn about:

- advantages and disadvantages associated with wearable technologies and digital tools
- the importance of being able to record session/activity goals and learn to:
- appraise wearable technologies and digital tools to decide on usable and useful information.

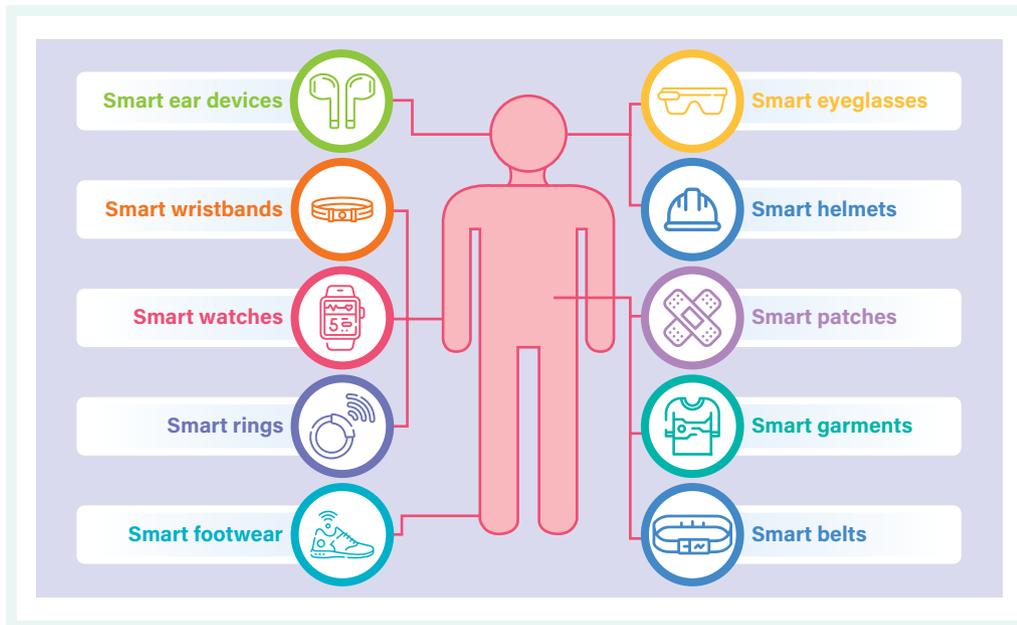
### Wearable technologies

The term 'wearable technologies' refers to a broad range of devices that are designed to be worn on the body while tracking various health and fitness metrics. They can be worn on the finger, wrist, hip/waist, chest, head or upper back. Examples of wearable technologies include fitness trackers, smart watches, heart-rate monitors, GPS units and other devices that collect data such as steps taken, heart rate, intensity of effort, force output, movement patterns and much more. Rapid advances in **e-textile** technologies are increasingly making it possible for micro-sensors and processors to be embedded within sports clothing. Figure 11.09 provides a useful summary of the different devices and wearable technologies that can collect data used to monitor training. We are reminded of two important considerations:

- Software and digital tools need to improve markedly and the collected data must be made 'user-friendly' in order for it to be better understood and contribute to changed behaviours.
- Recorded data is only useful if it can be used to bring about improved outcomes.

#### e-textiles

Fabrics that enable electronic components such as batteries, lights, sensors and microcontrollers to be embedded in them



**FIGURE 11.09** Summary of the different digital devices and wearable technologies that can collect data for use in monitoring training

Source: Moshawrab, M. et al. (2023), 'Smart wearables for the detection of cardiovascular diseases: A systematic literature review', in *Sensors* 23(2): p. 828. CC BY 4.0

According to the American College of Sports Medicine's list of the top 20 fitness trends for 2024, wearable technology was the number one fitness trend for that year, having consistently ranked within the top three fitness trends in the last decade.

Wearable technologies are being used by recreational, amateur and professional sportspeople, who increasingly rely on them to improve training and competition outcomes. They are non-invasive and consist of mobile electronic devices (sensors, communication units and microprocessors) that are connected to the internet so the collected data can be synced with other electronics, such as mobile devices or laptops. Due to power and size limitations in wearable technologies, their 'on-board' processing capacity is limited. More complex analysis and computations are possible when data is transmitted wirelessly to larger computing options. One of the biggest advantages of wearable technologies is their ability to provide **real-time data** that can be used to modify performance.

---

#### real-time data

Information that is delivered as it is being collected

## Physiological sensors

Sensors measure physiological, motion and position changes from various body parts as well as environmental conditions. **Physiological sensors** include:

- EMG – measuring muscle contraction force
- ECG – recording information related to heart function and, importantly, heart rate
- EEG – providing information about brain activity, sleep quality and concentration
- pulse oximeters – providing data on oxygen saturation and heart rate
- blood pressure monitors – cuffs or wristbands that assess blood pressure levels
- electrical conductivity meters – measuring moisture on the skin and rates of sweating
- spirometers – measuring respiratory rate, depth and patterns.

These measurements provide important information that can be used in monitoring training intensity and duration, recovery, and adaptation processes, as well as identifying health issues or risks.

---

#### physiological sensors

Devices that measure physiological changes in various body parts, such as muscle contractions, heart rate and brain activity

## Location sensors

### location sensors

Devices that track changes in a subject's position, speed and movements on a field or performance setting – for example, a GPS device

**Location sensors** track changes in a subject's position and speed and movements on a field or performance setting. The global positioning system (GPS) is the most widely used example of them. Camera-based wearable marker positioning systems are capable of tracking multiple wearable markers with multiple cameras to monitor the user's body part/muscle position and movements. They are primarily used in biomechanical analysis of sporting movements.

### LOOKING BACK

#### GPS

#### Chapters 3 and 9

Chapter 9 considered the use of GPS while conducting a games analysis, and Chapter 3 discussed how marker positioning systems are used to improve the efficiency of movement by contributing to a biomechanical analysis.

### CASE STUDY

### CATAPULT

#### WHY IS ATHLETE MONITORING IMPORTANT?

A key development in sport over the last three decades has been the increased use of scientific methods to inform the preparation for and participation in elite competition.

Recent innovations have enabled teams to closely monitor athlete performance across all sessions and matches, facilitating a much deeper understanding of training methods that benefits athletes and coaches alike.

#### QUANTIFYING STRENGTHS & WEAKNESSES

Given the unique physiology of each athlete, individuals naturally possess different strengths and weaknesses, as well as varying levels of potential to develop the key facets of their game.

By using scientific methods to objectively design and validate a monitoring program to complement an athlete's training schedule, it becomes possible to measure progression relative to appropriate performance targets.

#### PERFORMANCE FEEDBACK

Today's tracking technologies can monitor athlete performance in real-time and give individual feedback in relation to the aims of an individual session or the program as a whole.

For example, Catapult technology has the capacity to deliver feedback both in real-time

and post-session, enabling coaches to make performance decisions based on objective information. This approach helps maximise the safety and effectiveness of training sessions.

#### EDUCATION

By enabling coaching staff to deliver comprehensive feedback to their athletes, monitoring technologies invariably spark dialogue around the implications the relevant data has for the performance of individuals or the team as a whole.

These conversations are opportunities for sports scientists and coaches to help their athletes better understand the meaning and application of key performance metrics. This

educational process can in turn lead to improved training practice and encourage athletes to improve their self-management.

Physical training programs aim to make athletes more efficient in terms of internal:external ratios, i.e. less stress for more output. In its simplest form, feedback to coaches should explain two things:

- how much work the athlete has performed
- how hard the athlete has worked.



Two metrics which will address these questions are 'volume' and 'intensity'. These are particularly useful metrics to use when introducing our technology to coaches, because they can relate directly to the questions above, particularly when data is fed back relative to a known quantity, e.g. a match.

You could feed back that an athlete has completed 60% of a match at 80% of normal match intensity, and it will resonate with athletes and coaches. The complexity of the systems used to report volume and intensity can increase with the sophistication of the technology used.

There are [five] core sports science principles that apply when implementing wearable technology into a performance program:

- **Overload:** To precipitate improvements in performance, in a controlled way, athletes must be exposed to stresses in excess of that which they have been used to.
- **Specificity:** Athlete training programs should contain large elements which mimic the movement demands, metabolic demands, technical and tactical requirements of the sport for which they are preparing.

- **Individualisation:** Don't apply the same training stimulus to a squad of athletes and expect them all to respond in the same way!
- **Reversibility:** If you don't use it – you lose it! Training effects are very quickly lost if training load is not adequate.
- **Variation:** If training programs do not contain adequate variety, there is increased risk of physical or psychological staleness, illness or injury.



AAP Images/PR Handout Image

**FIGURE 11.10** Athletes wearing Catapult vests with inbuilt tracking technology

## WHY USE WEARABLE TRACKING TECHNOLOGY?

Wearable-based tracking technologies are used throughout sport to support performance monitoring.

But how do they work, what do they measure, and how do they benefit athletes and coaches?

### THE BASICS

At the most fundamental level, a wearable tracking device calculates position by timing the signals emitted by GPS satellites orbiting the Earth.

Each satellite continually transmits messages that include the time of transmission and the satellite's position at that time, information that the receiver uses to compute the distance to each satellite using the speed of light. These distances and satellite locations are used to compute the

location of the receiver at a specific point in time using a process known as trilateration.

As objects (or athletes) change position over time, their movement profiles (and thus displacement/distance covered) can be plotted by regular repetition of this process. This is the basis by which wearable technology enables us to analyse player movements and intensities during training and matches.

### INERTIAL MEASUREMENTS

Although velocity and positional information is useful in terms of basic speed and distance calculations, Catapult's wearable tracking devices also contain a number of inertial sensors that enable practitioners to conduct more detailed levels of athlete monitoring.

These inertial sensors comprise an accelerometer (to measure acceleration forces), a gyroscope (to measure rotation), and a magnetometer (to measure body orientation). Inertial sensors collect data in three axes, or directions, allowing sensitive 'maps' of athlete movements and actions to be created.

### ACCELEROMETER

Accelerometers are particularly useful for identifying many athletic movements (e.g. jump or tackle) and understanding large accelerations that may result in small movements.

Catapult devices use tri-axial accelerometers (up/down, forwards/backwards and left/right) to measure acceleration.



## GYROSCOPE

Gyroscopes measure rotation around three axes (the coronal plane, the frontal plane and the sagittal plane). The combination of gyroscope and accelerometer data allows us to create more precise pictures of dynamic

athlete movements than would be possible with one sensor alone. By combining data in this way, wearable tracking units are now able to facilitate far more detailed analysis of an athlete's movement.

## MAGNETOMETER

In essence, magnetometers are an electronic compass that help to understand orientation in relation to magnetic north. In terms of athlete monitoring, magnetometers provide information regarding direction and orientation, helping practitioners to understand the volume of key movements such as changes of direction.

A well-designed training program will expose athletes to a range of stresses, all of which will induce fatigue and adaptations to that stress to differing degrees. Without an objective measure of the stress being imposed on the athlete,

or their response to that stress, coaches and sports scientists are unable to quantify the true effectiveness of their interventions.

The consequences of failing to correctly measure those loads can be under- or overloading of athletes, which can lead to increased risk of injury, illness, and sub-optimal performance levels. So how can practitioners measure the load being placed on their athletes? More importantly, how can they use information to derive meaningful insights to help address performance questions and support the work of coaching staff?

## MEASURING INTERNAL AND EXTERNAL LOAD

At a basic level, external load can be characterised as the work completed by an athlete independent of his or her internal characteristics. In terms of Catapult wearable technology, measures which we think of as locomotive (e.g. distance covered, average velocity, number of sprints, etc.) and mechanical (e.g. player load) are all measures of external load.

Internal load refers to the physiological stresses placed on an athlete during a bout of work. An example of an internal load measure is heart rate, and heart rate-based indicators such

as heart rate exertion (also known as training impulse or TRIMP).

While external load is important in quantifying athlete capacity and work completed, internal load is also critical in measuring training load and assessing subsequent adaptation. As both internal and external load measures inform our understanding of the athlete's training load, a combination of both is essential for an effective monitoring program.

Source: 'Why is athlete monitoring important?', Catapult Sports website

## QUESTIONS

- 1 Clearly **discuss** how location sensors with GPS capability can be used to provide information about training intensity and training loads.
- 2 Monitoring technologies allow sports scientists and coaches to better educate performers under their care about their training and responses. **List** three different ways in which this 'education' can lead to training improvements.
- 3 **Justify** why objective measures provide more valuable data used to improve training programs than subjective data selected to fine-tune training.

## Environmental condition sensors

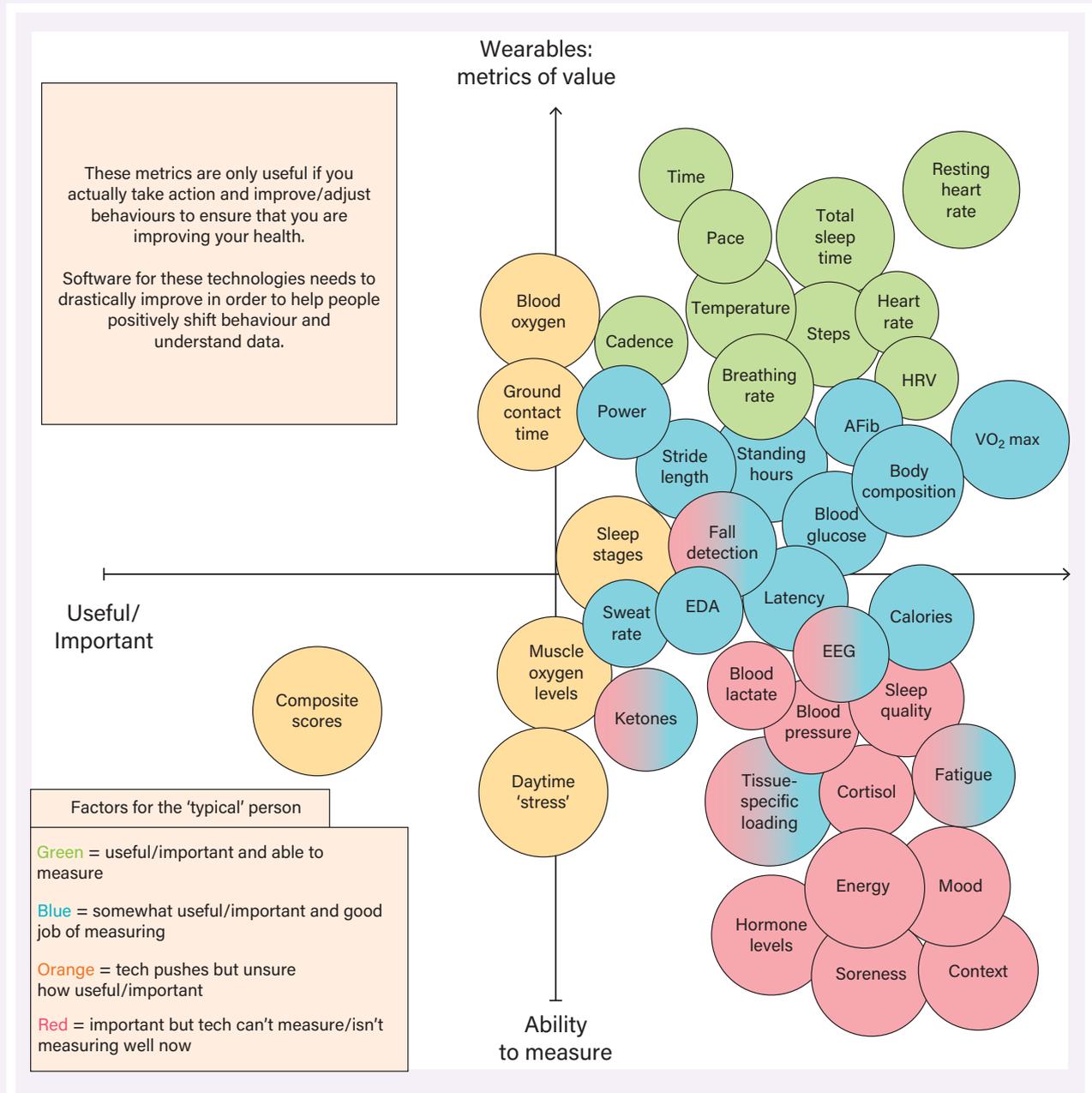
Environmental condition sensors located on wearable technologies measure variables such as air quality, humidity, temperature, air pressure and levels of ultraviolet light (UV). They are used to monitor the condition of the environment where athletes perform.

Coaches, strength and conditioning personnel and sports scientists are increasingly calling upon wearable technologies for athlete tracking and performance analysis. They are capable of tracking a subject's external training loads and exercise intensities, which can influence their adherence to training programs and minimise the risk of overtraining, injury and illness.

## REAL WORLD APPLICATIONS

### Data-collection devices

World Aquatics (formerly FINA) regulations now allow the use of technology-driven automated data-collection devices for swimmers, with the sole purpose of gathering data for later analysis. These devices are forbidden from transmitting data or aiding swimmers in real time and can only be used as data-gathering tools, rather than performance enhancers.

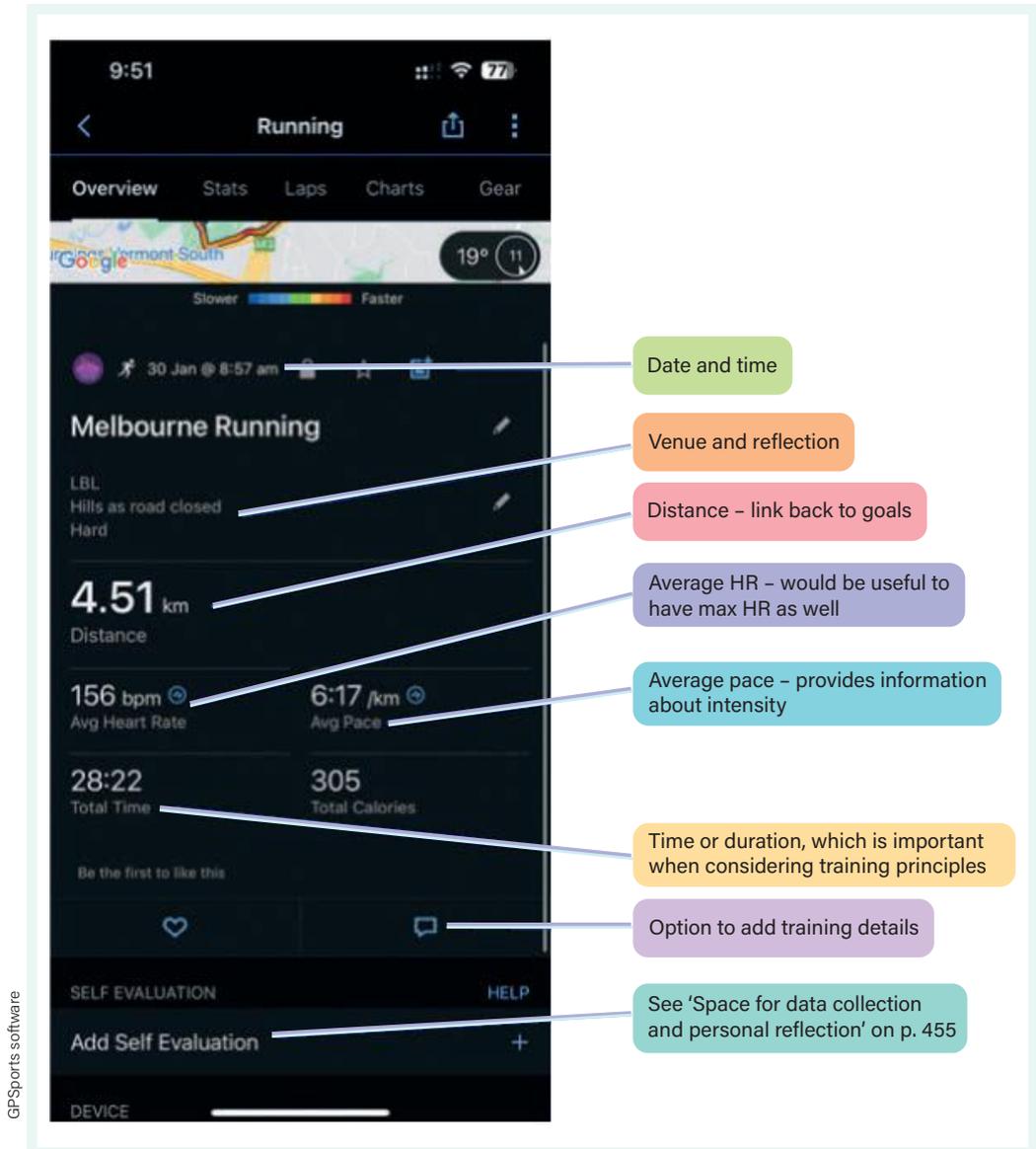


**FIGURE 11.11** Variables/metrics that can be collected by wearable technologies

Source: Peter Tierney/X Corp.

# Digital tools

Digital tools, as defined by the World Health Organization (WHO), include digital and mobile technologies, such as websites, mobile device applications (apps) and wearable devices, including fitness trackers. Increasingly, recreational and amateur sportspeople are using software applications to prescribe and suggest physical exercise programs. These tend to be generic, or very general in nature, compared to those that are individualised and tailored to a person's fitness profile, strengths, weaknesses and training goals.



**FIGURE 11.12** An example of data that can be recorded and entered on a digital device used to monitor training

Early fitness trackers monitored step counts and made people more aware of their physical activity levels, and as a result many people set goals to reach a minimum number of steps per day. These trackers were, and remain, very effective in changing physical activity behaviours and encouraging people to be more active. However, they simply recorded steps taken and, like many digital trackers, varied in the accuracy with which they did so.

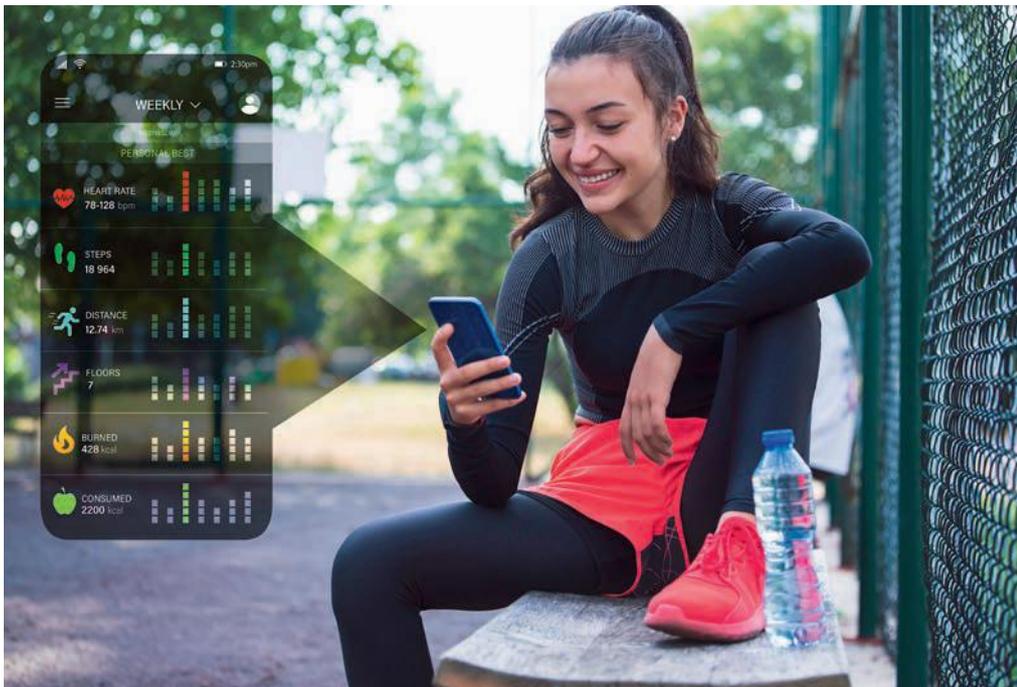
The latest-generation trackers have built-in GPS, and heart rate and other sensors. Most are supported by accompanying **software applications** (apps). These allow users to input many of the physiological, psychological and sociological factors that impact training even though the trackers cannot measure them directly. Similar to digital training diaries, these apps can be accessed via smartphones, tablets or laptops. The requirement to input additional information as quickly as possible after the training session relies heavily on subject motivation and memory.

Whether using training diaries (manual or digital), wearable technologies or digital tools to monitor and record training, it is important that they are user-friendly and allow the user to set goals and monitor physiological, psychological and sociological training data. The increased use of digital devices to monitor and improve training at multiple levels of performance, ranging from recreational through to professional sportspeople, will most likely involve greater use of artificial intelligence (AI). Regardless of the options chosen, careful attention must be paid to ensure that all the data obtained is actually necessary for the level of performance under consideration.

The ability of users to have input into their training, rather than simply following a program prescribed for them, should underpin selection decisions. It is also imperative that the data collected is relevant and can be acted on when modifying training programs in an effort to fine-tune them while minimising the potential for injury or illness.

#### software applications

Commonly referred to as 'apps'; computer software, or programs, most commonly small and specifically designed for mobile devices



**FIGURE 11.13** Data needs to be relevant and there needs to be a way to act on it if it is to be considered useful.

# Using technology to evaluate the effectiveness of a training program

Technologies and digital tools that have been used to record and monitor training should be referred to when making decisions about how effective training has been. This can be either for an individual session or a stage of the training program. The program can be broken down into the following parts:

- microcycle – a training period of 7–10 days
- mesocycle – a 'block of training' made up of 4–6 weeks
- macrocycle – the time from when an athlete starts to train for a season or event to the completion of their post-event/season recovery.

Reflecting on the training undertaken over a longer period than a single session – preferably, 4–6 weeks – allows consideration of a wider and more complete range of training principles to occur. A single session considered on its own will not allow one session to be compared to others. This makes it impossible to view evidence of progression, variety, overtraining and the law of diminishing returns. Additionally, when reviewing a training program, rather than a single training session, users and sports specialists are able to detect, and act on, physical and psychological patterns that emerge over time.

## LOOKING FORWARD

### Training programs

#### Chapter 14

Chapter 14 will consider training program design, implementation and evaluation, and key knowledge covered in this chapter will be revisited and strengthened while considering these key training components.



## COLLABORATIVE TASK

### Devising a hypothesis

#### Compare and contrast data collection on multiple devices

Devise a hypothesis that you can 'test' by comparing and contrasting the data collected from different wearable technologies. For example:

- A Fitbit is more accurate in recording distances covered than a smartphone.
- A heart rate monitor worn on a chest strap provides more accurate data than that obtained from smart watch sensors.
- Intensity data from a GPS unit provides more useful information than that recorded from a smart watch.

**1** Discuss your hypothesis with a classmate, including:

- stating your aim
- explaining how you intend to 'test' your hypothesis (procedure).

**2** Present any relevant results.

**3** Summarise your findings and discuss your overall conclusion at the end of your report.

## 11.2 CHECK-IN QUESTIONS

- 1 **Discuss** why real-time data can be more useful than data that needs to be downloaded after it has been transmitted.
- 2 There is usually a relationship between the practicality of wearable technologies and their accuracy. **Explain** what this means.
- 3 **Outline** one disadvantage associated with inputting training goals and fitness profiles to a training app and having it prescribe a set of suggested exercises.
- 4 **Outline** how EEG sensors worn in headgear can be used to monitor fatigue resulting from training.



### Assessment

11.2 Check-in questions

### Command terms

#### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

#### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

# CHAPTER SUMMARY

**Resource**

Self-assessment checklist

**Video**

Masterclass: Chapter 11

## 11.1 Training diaries

- Training data is only useful if it is recorded, relevant and capable of being utilised.
- Training data can be recorded in either manual or digital format.
- Training data can be collected and recorded by the participant, the coach, a sports specialist or even AI to bring about improved training outcomes.
- Physiological, psychological and sociological factors influencing training should all be recorded and considered when deciding on training improvements.
- All training sessions should be reviewed and reflected on at their completion.
- Real-time data allows immediate changes to be made to a training program.
- Multiple consecutive training session data sets (collected over 4–6 weeks) provide greater scope to consider training patterns and trends along with the application of vital training principles.
- Digital recording of training allows more sophisticated analysis and sharing of information than manual recording.
- The person undertaking training exercises will have greater motivation and adherence to training if they have input into the program.
- Evaluation of training effectiveness requires a clear statement of goals and record of warm-up, conditioning, cool-down and other associated factors that influence training.
- The stages of the training year (pre-season, in-season or off-season) all have different training focuses, and variables under consideration may change.
- While they are subjective, personal reflections should be taken into account when considering training effectiveness (this is self-rated and known as rating of training effectiveness, or RTE).
- When monitoring training, excessive fatigue requires immediate attention and training program review.

## 11.2 Wearable technologies and digital tools

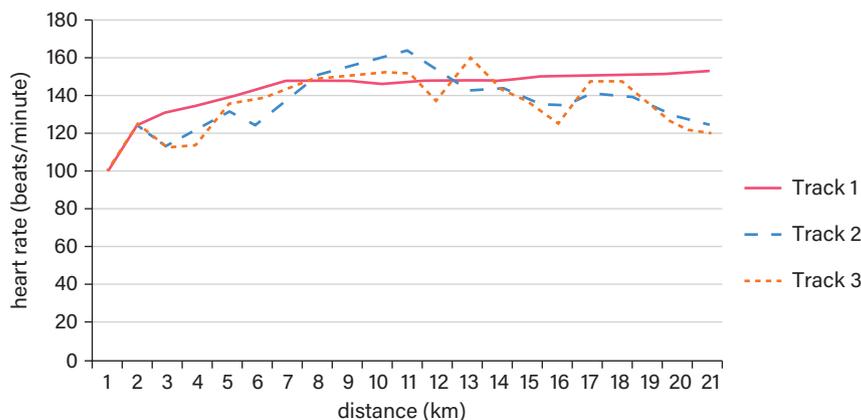
- Wearable technologies are worn on the body while tracking various health and fitness metrics.
- Wearable technologies collect data such as steps taken, heart rate, intensity of effort, force output and movement patterns.
- Digital tools include digital and mobile technologies, such as websites, mobile devices and software applications (apps) and wearable devices.
- Digital tools allow physiological, psychological and sociological factors that impact training to be recorded in real or delayed time.
- User input to their training via digital tools creates greater buy-in or adherence than is achieved by simply following a generic programs suggested by apps.

# CHAPTER REVIEW

- 1 While completing any training program, athletes consider and record many metrics, such as sleep patterns, stress scores, heart rate data and teammates they have trained with. Which one of the following is an example of sociocultural data used to monitor performance?
- A sleep patterns
  - B stress scores
  - C heart rate data
  - D teammates the athletes have trained with

2 **©VCAA** Exam 2013, Section B, Q14 b ii

Alice is a 40-year-old female who enjoys recreational mountain biking. To adjust her training, she varies her choice of riding terrain. The graph below shows her heart rate responses for three different rides that she completed. **Explain** how Alice may use the heart rate data to structure her training sessions.



- 3 **Discuss** why training records need to be monitored at the end of each training session, rather than the end of a training week.
- 4 **Outline** how environmental sensors recording air pressure can be used to provide information about potential fatigue that might occur during a training session in an unfamiliar setting.
- 5 **State** why a person experiencing improved muscular power as a result of training might actually have participated in a program that could be considered moderately effective or not effective.
- 6 **Explain** what is meant by the statement, 'Your training program is only as good as the training records that are collected and monitored'?
- 7 Some exercise scientists do not consider that smartphones should be classified as 'wearable technologies'. Provide a response to **persuade** a classmate why you agree with this group of exercise specialists.



**Assessment**  
Chapter 11 review

### Command terms

#### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

#### state

Give a specific name or value or other brief answer without explanation or calculation

#### persuade

Induce (someone) to do something through reasoning or argument; convince

**Command terms****clarify**

Make a statement or situation more comprehensible

**evaluate**

Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information

8 **Clarify** why having access to 4–6 weeks of training records is more useful than simply considering a single session.

9 **©VCAA** Exam 2021, Section B, Q10 b

An Australian Football League Women's (AFLW) midfield player has been provided with the following pre-season training session to improve her aerobic power for the upcoming season. The conditioning phase of the running session lasts 20 minutes and consists of the sequence outlined in the table below, involving continuous running and bursts of higher-intensity running. For example, continuous running of 90 seconds at an intensity of 70% HR max. is immediately followed by a burst of higher-intensity running for 90 seconds at an intensity of 90% HR max. This sequence is then repeated, as indicated in the table.

Continuous running			Burst of higher-intensity running	
Number of work periods	Time (seconds)	Intensity (% HR max.)	Time (seconds)	Intensity (% HR max.)
2	90	70	90	90
4	60	70	60	90
4	30	70	30	90
4	15	70	15	90

Using the training principles of specificity, intensity and duration, **evaluate** the effectiveness of this training method in improving the AFLW midfield player's aerobic power. Provide examples from the session outlined in the table to support your response.

10 **©VCAA** Exam 2019, Section B, Q6

Noah, an 18-year-old student, wants to improve his sprinting ability in track cycling (500–1000 m distance). Noah has designed a 12-week training program for himself and shown below is a snapshot of the program.

Week	Monday	Wednesday	Thursday	Saturday
1	seated accelerations on stationary bike reps: 10 RPE: 9 Recovery: 3 mins	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 10	gym session deadlifts: 4 sets of 3 repetitions @95% RM box jumps: 3 sets of 8 repetitions	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 10
4	seated accelerations on stationary bike reps: 11 RPE: 9 Recovery: 3 mins	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 11	gym session deadlifts: 4 sets of 3 repetitions @95% RM box jumps: 3 sets of 8 repetitions	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 11
7	seated accelerations on stationary bike reps: 12 RPE: 9 Recovery: 3 mins	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 12	gym session deadlifts: 4 sets of 4 repetitions @95% RM box jumps: 3 sets of 8 repetitions	sprint interval: 20 s and 40 s recovery RPE: 9 reps: 12





Week	Monday	Wednesday	Thursday	Saturday
10	seated accelerations on stationary bike reps: 13 RPE: 9 Recovery: 3 mins	sprint interval: 25 s and 45 s recovery RPE: 9 reps: 13	gym session deadlifts: 4 sets of 4 repetitions @95% RM box jumps: 3 sets of 8 repetitions	sprint interval: 25 s and 45 s recovery RPE: 9 reps: 13
12	seated accelerations on stationary bike reps: 13 RPE: 9 Recovery: 3 mins	sprint interval: 25 s and 45 s recovery RPE: 9 reps: 13	gym session deadlifts: 4 sets of 4 repetitions @95% RM box jumps: 3 sets of 8 repetitions	sprint interval: 25 s and 45 s recovery RPE: 9 reps: 13

**Key**

RM – repetition maximum

reps – repetitions

s – seconds

RPE – rate of perceived exertion

mins – minutes

- a i Suggest** one way for Noah to monitor his training.
- ii** Using examples, explain why Noah should keep a record of his training.
- b** Using data from the training program, **justify** whether progression has been correctly applied in Noah's training program.
- c** Using the FITT principles (frequency, intensity, time and type), **evaluate** the effectiveness of this training program to improve sprint performance for track cycling. Use specific examples from the training program to support your response.

# CHAPTER 12

## TRAINING PROGRAM PRINCIPLES

UNIT 4 - AREA OF STUDY 2



Brocreeative/Adobe Stock

**FIGURE 12.01** Training to enhance performance

### Quizzes

Chapter 12 Pulse check

**12.1** Check-in questions

**12.2** Check-in questions

**12.3** Check-in questions

Chapter 12 Review

### Videos

Masterclass: Chapter 12

**12.1** In focus: SAID

**12.3** In focus: Progression

**12.3** In focus: Tapering

### Resources

Chapter 12 Self-assessment checklist



 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)

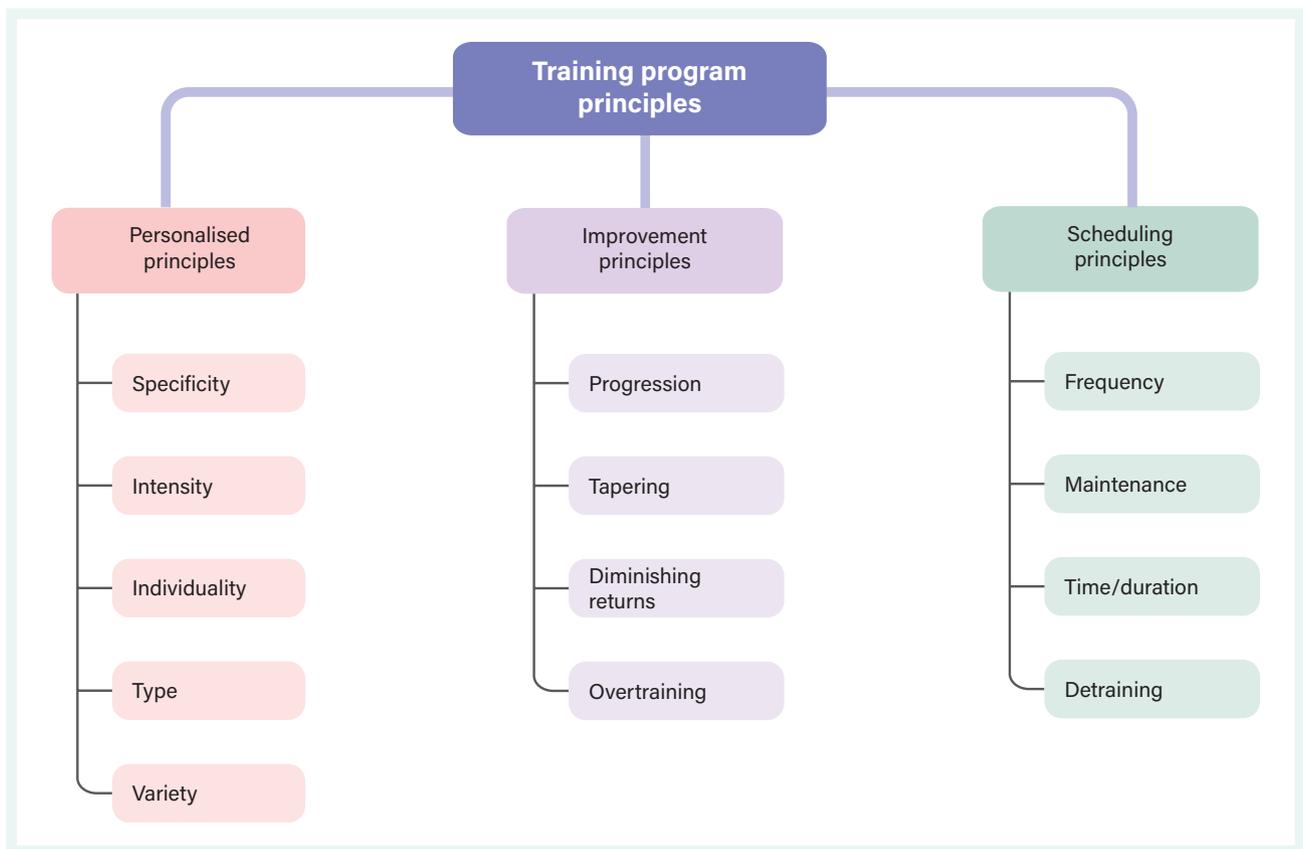
- » training program principles, including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining

## KEY KNOWLEDGE

- » design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 12

The correct application of training principles ensures that the benefits of undertaking a training program are maximised. Adherence to these training principles will lead to faster improvements, while decreasing the likelihood of injury.

To maximise fitness improvements, it is essential to apply the fundamental training principles listed below to a training program. This will ensure that physiological improvements or chronic adaptations occur as efficiently as possible (see Chapter 15). Applying the training principles will also help reduce the frustration of inadequate progress and the likelihood of injury and overtraining that can result from a poorly planned training program. The principles should also be applied to specific training methods.

The fundamental training principles are as follows:

- personalised principles:
  - » specificity
  - » intensity
  - » individuality
  - » type
  - » variety
- scheduling principles:
  - » frequency
  - » maintenance
  - » time/duration
  - » detraining
- improvement principles:
  - » progression
  - » tapering
  - » diminishing returns
  - » overtraining.

**Assessment**  
Pulse check**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of these concepts.

- 1 Why is specificity the most important training principle?
- 2 How is intensity related to specificity?
- 3 **Discuss** why it is important to constantly monitor training and apply progression (make it harder) when it becomes easier.
- 4 How are progression, overtraining and tapering connected?
- 5 Can you **identify** the minimum training frequency for improvement and identify why elite athletes exceed the minimum?
- 6 **Suggest** why the use of an activity analysis enhances the correct application of training principles.

## 12.1 PERSONALISED PRINCIPLES

In this module you will learn about:

- the importance of training principles and learn to:
- correctly apply these principles to a well-structured training program.

### Specificity

**Specificity** is the most important of all the training principles, providing the foundation on which a successful training program can be built. Specificity relates to tailoring a training program to meet the specific demands of an athlete's sport, position and other physiological requirements. This is why an activity analysis (see Chapter 9) is crucial in helping to identify energy system demands, key fitness components, major muscle groups and skills performed so that the intended training matches the physiological requirements of the sport.

**specificity**

The kind of precision achieved by fitness testing and training that mimics the skills, movements and actions observed during competition and performances, and that enhances the physiological requirements (major muscle groups, fitness components and energy systems) of the sport or physical activity

The 'SAID' principle is well known within the field of sports science. SAID is an acronym for 'specific adaptations to imposed demands'. Plyometric training will elicit specific adaptations such as increased motor unit recruitment and increased fibre size, which are important to events requiring muscular power. Fartlek training, on the other hand, will lead to adaptations such as increased mitochondrial density and increased oxidative enzyme activity, which are significant to events dominated by aerobic power. Data collection is again crucial. It ensures that the most significant physiological requirements of the sport are targeted through the correct application of appropriate training methods, producing the most appropriate chronic adaptations to improve performance.

## Energy system usage

The contribution of each of the three energy systems should be identified for the activity, and (if possible) for each individual position (or similar type of position) within a team activity. This enables the appropriate training method/s to be selected.

If the dominant energy system is aerobic, one of the aerobic training methods (continuous, fartlek, long-interval or HIIT) would be ideal. If one of the two anaerobic systems dominates, then one of the anaerobic training methods (short-interval, medium-interval, plyometric or resistance training) would be ideal. The activity analysis, achieved through data collection, may have revealed a significant contribution from two or three of the energy systems, and this requires greater selection and planning of training methods.

It is important to ensure that the work-to-rest ratios (W:R) and intensities used in interval training replicate those used in the game, and that the targeted energy system is not being compromised with a non-specific work-to-rest ratio that could change the intended emphasis of the training.

## Fitness components

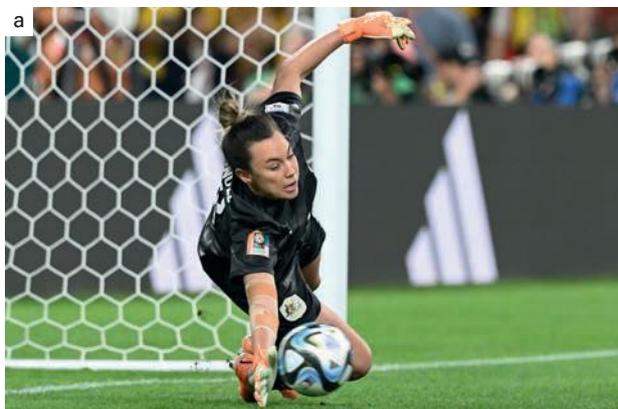
It is important to identify the most important fitness components necessary for successful performance in an individual or team activity. For example, a soccer goalkeeper, such as Mackenzie Arnold of the Matildas, would rely mostly on speed, agility and muscular power, whereas a midfielder or a striker, such as Sam Kerr, would rely more on aerobic power and local muscular endurance. Short-interval sprints and plyometrics incorporating agility might be appropriate for the goalkeeper, whereas the midfielder or striker might choose fartlek and long-interval training to enhance their dominant fitness components.

### LEARNING HACK

'SAID' – as in the SAID principle – is an acronym for 'specific adaptations to imposed demands'



Video  
In focus: SAID



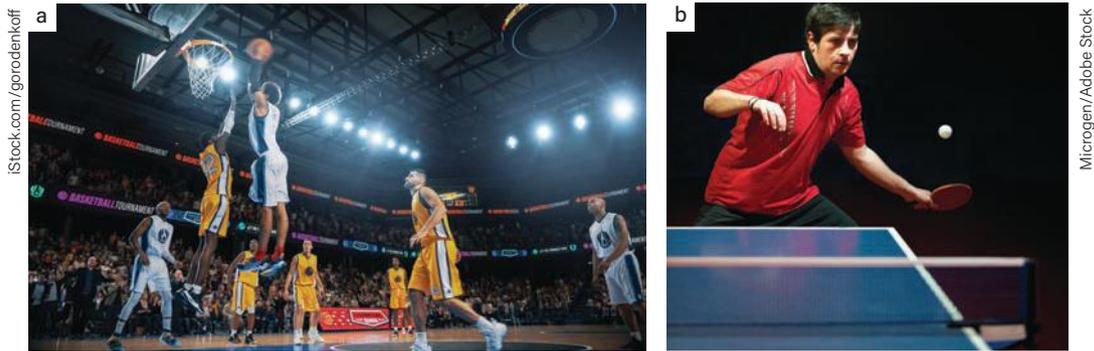
Bradley Kanaris/Getty Images Sport/Getty Images

Janelle St Pierre/Getty Images Sport/Getty Images

**FIGURE 12.02** a Mackenzie Arnold and b Sam Kerr in action

## Major muscle groups

Major muscle groups required for the activity need to be identified to ensure that they are a focus of training. Balanced training of muscle groups also needs to be maintained to ensure coordinated neuromuscular development. While a power forward in basketball may focus more on plyometrics training to develop leg power, a table tennis player may use plyometrics to focus on developing explosive upper body movements. The muscles involved with core strength should also be included in any training program, as they are integral to most sporting activities, helping with the transfer of power from the lower to upper body (or summation of momentum – see Chapter 3).



**FIGURE 12.03** Leg power for rebounding in basketball compared with upper body power for table tennis

## Skill frequency

The most common skills of an activity need to be identified. While our focus in this chapter is on the physiological requirements, it is becoming increasingly popular to blend skills sessions with physiological training to replicate the activity more closely while developing fitness components. This is not to say that training for team events should only consist of practice games to mimic absolute specificity. Rather, parts of an activity can be incorporated into a training program to enhance skills, teamwork, strategies and physiological development. For a basketball centre, for example, practising rebounding would lead to improvements in both the skill of rebounding and the fitness component of muscular power, which is vital to this skill. Manipulating rest and the number of repetitions would also enable the player to practise this skill while fatigued, which more closely resembles a game environment.

## Intensity

### intensity

The level of exertion applied during the work phase of a training session

**Intensity** refers to how hard you are working during physical activity; it is the level of exertion you are applying to the work phase of an activity, training session or competition. As discussed previously, specificity is the foundation principle on which all effective training programs are based. Intensity is the principle that ensures the right level of exertion is being applied to a training program; it is critical to ensuring that the targeted energy system/s and/or fitness component/s are being developed during training. Thus it critically underpins specificity.

The intended training intensity must be established before either frequency or duration can be effectively applied to a training program. Generally, higher training intensities will correspond to lower training durations.

It is essential to train at the correct intensity to maximise chronic adaptations. Table 12.01 demonstrates that training aimed at developing aerobic adaptations requires an **aerobic training zone** of 70–85% max HR, or RPE 3–7. Both % max HR and RPE are practical and reliable methods of establishing intensity. On the other hand, training either of the anaerobic energy systems, or most fitness components that rely on these energy systems, requires an intensity greater than 85% max HR or RPE 7. Training that is not performed at the correct intensity will diminish or nullify the potential for chronic adaptations.

Athletes can perform well above their  $\text{VO}_2$  max when there is a significant increase in anaerobic energy supply (in most cases, from the anaerobic glycolysis energy system).

**TABLE 12.01** Suggested training intensities

Training zone	Energy system trained	% max HR	% $\text{VO}_2$ max	RPE
Recovery	Negligible adaptations	< 70	< 50	0–2
Aerobic or continuous	Aerobic	70–85	55–75	3–6
At lactate inflection point (LIP)	Aerobic	85*	75*	7
Anaerobic	Anaerobic glycolysis	85–95	75–95	8–9
	ATP–CP	95+	100–200	10

\* LIP can be increased through aerobic training adaptations. Elite endurance athletes can have LIP occurring at up to 92% max HR.

#### **aerobic training zone**

Also known as the continuous training zone; between 70 and 85 per cent of maximum heart rate (70–85% max HR)

#### **LEARNING HACK**

The lactate inflection point (LIP) occurs at the last point of the aerobic training zone, generally at 85% max HR.

## Monitoring intensity

There are a range of methods available to ascertain and apply intensity to training, including the use of:

- percentage of maximum heart rate (% max HR), via heart-rate monitoring
- rate of perceived exertion (RPE), from performer self-evaluation
- global positioning system (GPS) tracking, with attached accelerometers to measure movement speed, and likely heart-rate monitoring capabilities
- percentage of  $\text{VO}_2$  maximum (%  $\text{VO}_2$  max), which requires a laboratory calculation. Based on this calculation, a corresponding heart rate will also be available to guide training
- percentage of one repetition maximum (1RM), which is commonly used to determine the intensity of weight training.

### Heart-rate monitoring

Heart rate is measured in beats per minute (bpm) and increases in a linear fashion with intensity until it reaches a maximum. From a practical viewpoint, percentage of maximum heart rate (% max HR) is an easy way to measure intensity, particularly with the abundance of heart-rate measuring devices available on the market. Heart-rate monitoring is very effective for training that relies heavily on the aerobic energy system.

A formula commonly used to calculate maximum heart rate is:

$$\text{maximum heart rate (bpm)} = 220 - \text{age (years)}$$

However, this may underestimate maximum heart rate in older adults (60 years of age and older) and overestimate it in young people (under 10 years of age). A more valid method of predicting maximum heart rate is to use the regression equation (see Table 12.02):

$$\text{maximum heart rate (bpm)} = 208 - 0.7 \times \text{age (years)}$$

**TABLE 12.02** Predicted maximum heart rate using  $208 - 0.7 \times \text{age (years)}$ 

Age (years)	Max HR (bpm)	Age (years)	Max HR (bpm)
16	197	40	180
17	196	50	173
18	195	60	166
20	194	70	159
30	187	80	152

### Rating of perceived exertion (RPE)

There is a lag associated with heart-rate monitoring – that is, your heart rate takes time to adjust to changes in intensity. This can make the use of heart-rate monitoring ineffective for anaerobic exercise, particularly short-interval training. For short-duration and high-intensity training, the rating (or rate) of perceived exertion (RPE) may be a more accurate indicator of intensity, particularly for performers who are in tune with their bodies (see Chapter 7 for a discussion of RPE and fatigue).

As a qualitative measure, RPE represents the performer's own perception of the training stress (both physical and psychological) they feel. It relies on the performer assigning a numeric rating to their perception of exertion (how heavy and strenuous the exercise feels), which is directly related to the intensity of the training stimulus. Factors such as sleep, nutrition, environmental conditions and energy levels would unconsciously form part of a performer's perception of their exertion, enabling the correct intensity to be established.

Importantly, RPE may also assist with the early detection of overtraining, particularly when a regular training session scores a higher RPE than previously assigned.

**TABLE 12.03** A description of RPE ratings

RPE scale	Training zone/goal	Description
0		No exertion at all
1		
2		Leisurely walk
3	Aerobic training	Light activity; feels as though you could exercise for hours!
4	Aerobic training	Moderate activity such as power walking or comfortable jogging
5	Aerobic training	Breathing heavily but can hold a conversation; feels as though you could exercise for an extended period
6	Aerobic training	
7	Aerobic training at LIP	On the verge of becoming uncomfortable; little interest in conversation
8	Anaerobic training – anaerobic glycolysis energy system	Vigorous activity; uncomfortable and short of breath
9	Anaerobic training – anaerobic glycolysis and/or ATP-CP energy system	Very hard activity; difficult to maintain exercise activity, can barely breathe or speak a single word
10	Anaerobic training – ATP-CP energy system	Maximum-effort activity; completely out of breath and unable to talk

### Global positioning system (GPS) watches

GPS watches continue to increase in popularity as a method of tracking and monitoring training. GPS watches track your speed and the distance covered in real time, and generally have a built-in heart-rate monitor, which obtains data from the radial pulse in your wrist. Some GPS watches have the ability to connect to a chest strap, providing more accurate heart-rate measuring.

Advantages of using a GPS watch include:

- real-time tracking – which lets you see how fast you are moving and how far you have travelled. This can also provide motivation for performers who like to monitor their training, particularly while the training is occurring
- tracking progress, particularly via distance. This enables the performer to keep accurate records of their training load. Higher-end watches have built-in functionality to suggest optimal recovery time
- greater accuracy, in general, than smartphone apps
- monitoring of speed in real time, which makes GPS watches very useful for interval work based on speed.



Wira SHIK/Shutterstock.com

**FIGURE 12.04** The obvious disadvantage of using a GPS watch is its reliance on obtaining a satellite connection.

## LOOKING BACK

### GPS watches

#### Chapter 9

Chapter 9 also discusses GPS watches.

## Percentage of one repetition maximum (1RM)

One repetition maximum (1RM) is the heaviest load (weight) a person can lift for a single repetition with good technique through a full range of movement. All forms of weight training – that is, strength, hypertrophy, power and endurance training – can base their intensity on a percentage of 1RM.

## LOOKING FORWARD

### Measuring intensity via percentage of 1RM

#### Chapter 13

A percentage of one repetition maximum (1RM) is a common method of applying load to weight training. As an example, to train muscular power, a load of 30–60 per cent of 1RM, lifted explosively, would be applied.

## Individuality

Individualisation, or **individuality**, is essential in any contemporary training program. This simply acknowledges that individuals will respond differently to a similar training stimulus. Reasons for this include:

- genetic predisposition
- initial fitness levels/training status
- preparedness
- adaptive response
- tailoring training to individual needs.

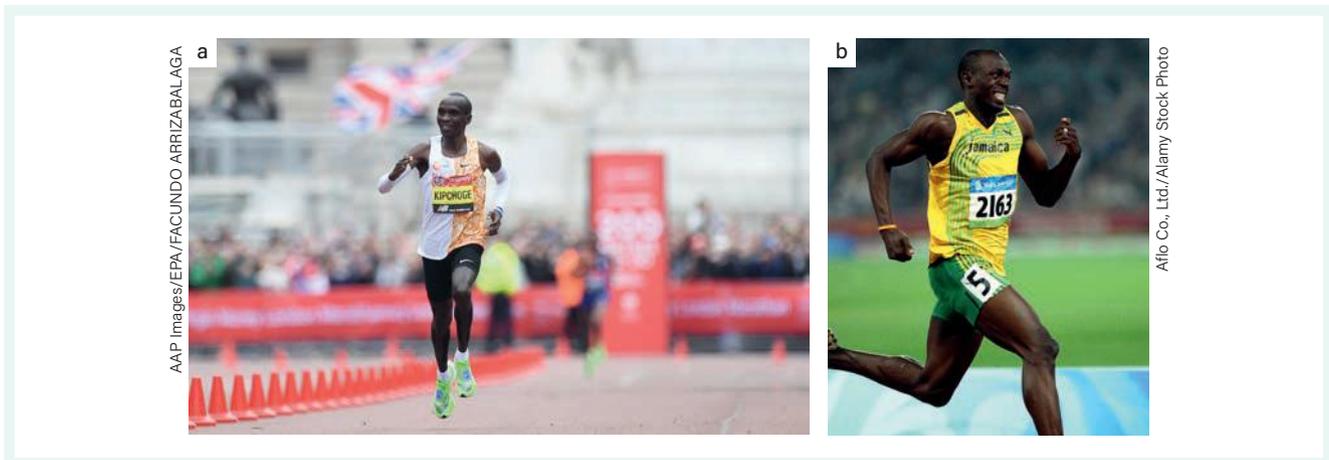
We will look at each of these reasons in more depth.

### **individuality**

The characteristics that distinguish one performer from another; in the case of exercise, ensuring that training specifically addresses or targets the needs of the performer

## Genetic predisposition

One of the most significant genetic predispositions is fibre-type composition. A performer with a higher percentage of fast-twitch fibres will respond more favourably to a training method that is closely linked to the anaerobic energy systems, such as plyometrics or short-interval training. Fast-twitch fibres can significantly increase in size compared to slow-twitch fibres, enabling them to generate more force. Conversely, a performer with a higher percentage of slow-twitch fibres will respond more favourably to aerobic-based training, such as continuous or long-interval training, and can expect to see significant gains in mitochondrial density compared to fast-twitch fibres.



**FIGURE 12.05** The difference in fibre type between these two elite athletes is obvious. Eliud Kipchoge (a) and Usain Bolt (b) are two of the greatest athletes of all time in their events – the marathon and the 100 metres sprint, respectively.

## Initial fitness levels/training status

Performers with little exposure to a training method may need to begin at a reduced volume to avoid excessive fatigue, which can lead to overtraining injuries.

## Preparedness

A performer returning from injury or illness may find that returning to a previous training stimulus causes excessive fatigue. It is generally accepted that, before increasing intensity, the participant should have completed some foundation work for that fitness component. An example would be a performer in a team sport participating in a continuous running program at an appropriate intensity before moving to more specific training, such as fartlek or long-interval training, at higher aerobic intensities.

## Adaptive response

Different people will have a different adaptive response to exercise due to individual identity and physiological and psychological factors such as hormonal, enzymatic, motivational and nutritional requirements. This is closely related to genetic predisposition.

## Tailoring training to individual needs

Considering the above factors, to optimise the potential for chronic adaptations, a training program must be tailored to suit the individual's needs and should take into consideration factors such as the performer's goals, motivation and cultural needs.

This can be exceptionally difficult to achieve in a team-sport environment, particularly at a local level, where there may be only one coach for the whole team, and especially in a sport that may have a variety of team positions with their own specific needs.

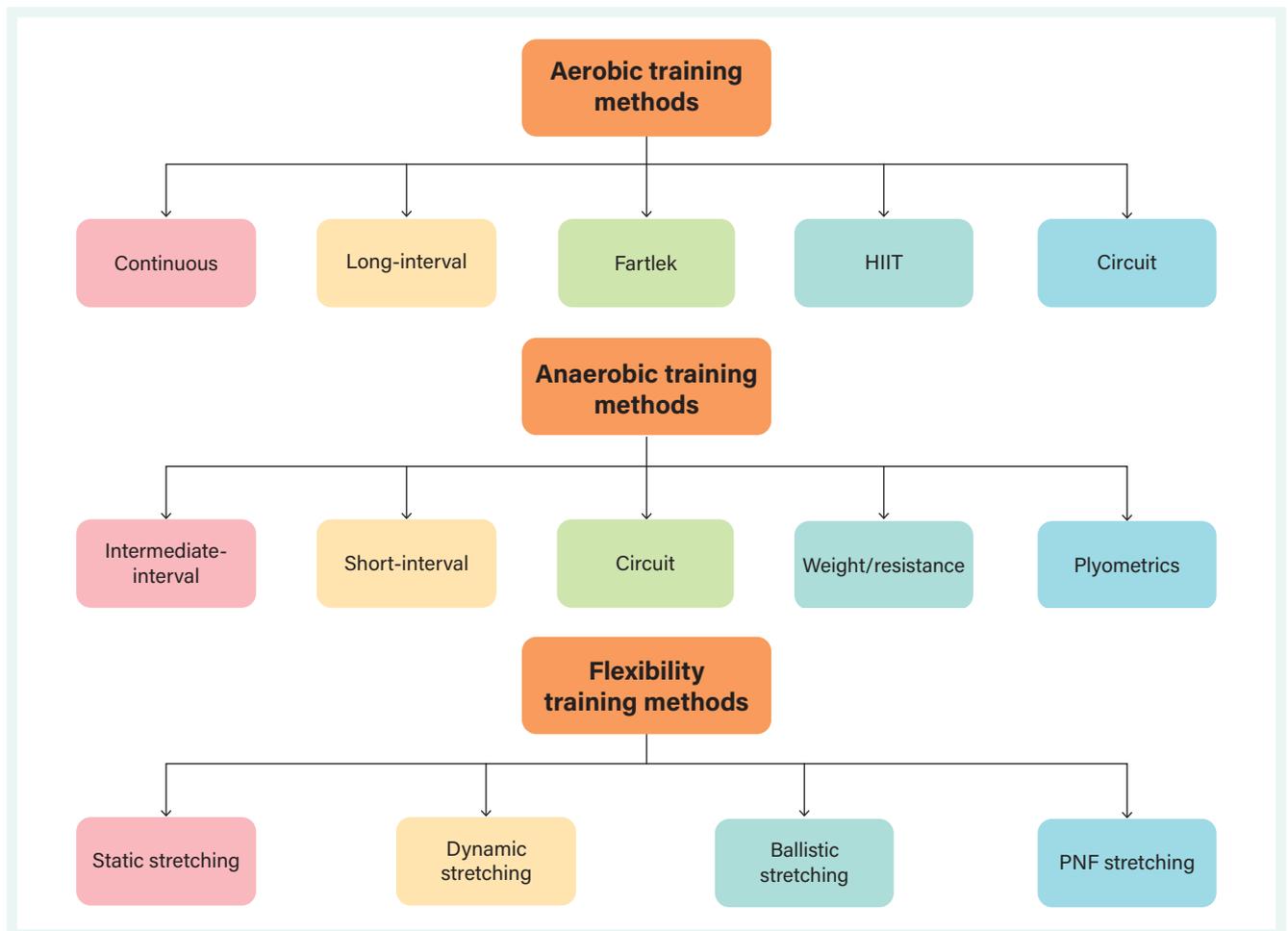
At a national level, particularly in well-funded sports, there is a growing trend towards a partially individualised program. Whole-team training is important to develop team cohesion, strategies and tactics, and to augment and strengthen the bond between team members. Areas where individualised supplementary training can be focused are identified through a needs assessment for each individual team member.

The transition, or off-season, phase of a training program is another important opportunity to address individual physiological weaknesses. It allows the individual to train specifically on these goals away from team-oriented training.

## Type

**Type** refers to the training method selected by the performer and/or their coach. Any training method should strongly align with specificity and the established physiological requirements of the sport – dominant energy system/s, fitness components and muscle groups – established via a games analysis. This will ensure the efficient development of the desired chronic adaptations.

**type**  
A class of training that shares certain characteristics; also the particular training method being undertaken



**FIGURE 12.06** Aerobic, anaerobic and flexibility training methods



**FIGURE 12.07** Australian Tia-Clair Toomey has won the CrossFit World Championships six times. She has represented Australia in weightlifting at the Olympic Games but must use a variety of training methods to prepare for the changing competition events in CrossFit.

### variety

A change – for example, to a regularly scheduled training session

include locations such as hills, forests or a beach for running or cycling, or ocean swimming instead of pool swimming. Performing a training program with a partner or group of friends may also add variety.



**FIGURE 12.08** A change of scenery can add variety to a training program while maintaining specificity.

Variety can also be advantageous by supplying a different stimulus while maintaining specificity. For example, changing a barbell bench press to a dumbbell bench press, while essentially still the same action, will provide the body with a new stimulus to help promote positive chronic adaptations. Similarly, fartlek sessions could replace continuous running, and the focus would still be on developing aerobic power via a changed training method.

In multidiscipline (or multidisciplinary) sports, such as CrossFit, performers will need to schedule multiple training methods and be mindful of choosing the correct modality, such as developing aerobic power for running, cycling or swimming, depending on the intended discipline. (CrossFit events regularly vary the activities that athletes must complete.)

## Variety

It cannot be emphasised enough that specificity is the foundation of any effective training program. Adding **variety** to a training program can, however, enhance, rather than compromise, a performer's development.

Variety can be extremely beneficial in mentally reinvigorating a performer who is becoming bored or stale with the same routine. This can be as simple as varying the environment for aerobic-based training to

However, when considering adding variation to a training program, it is essential to remember specificity. If variety takes the training focus off the intended muscle groups, energy systems and fitness components, then specificity (and more importantly, the intended aim of the training program) may be lost. An occasional change of training type for a one-off session, such as competitors in a running-based team sport completing a swimming session, may be appropriate to combat mental staleness, but the focus of the training program should return to specificity as soon as possible.

## 12.1 CHECK-IN QUESTIONS

- 1 **Discuss** how an activity analysis identifies specific elements that need to be considered when developing a training program.
- 2 Chronic adaptations may still occur if the principle of specificity is not applied. **Explain** the advantage of applying specificity to a training program.
- 3 How would you **define** 'training intensity' to a classmate?
- 4 **Describe** one problem associated with heart rate monitoring when used in training.
- 5 **Construct** a graph demonstrating the relationship between heart rate and exercise intensity.
- 6 The aerobic training zone is 70–85 per cent of maximum heart rate, though this may vary depending on the person's level of fitness.
  - a The highest point of the range is 85 per cent. **Suggest** what else this number represents.
  - b The upper and lower limits of the aerobic training zone would change for an elite endurance performer. **Predict** what you believe their aerobic training zone would be.
  - c **Predict** what you believe the aerobic training zone would be for an untrained performer who has participated in minimal aerobic activity over the previous few years.
- 7 **Outline** two reasons why individuals may respond differently to the same training stimulus.
- 8 Construct a 'T' diagram **identifying** two advantages and two disadvantages associated with the principle of variety.

Advantages	Disadvantages

- 9 **Discuss** how a chosen training method aligns with the training principle of specificity.



**Assessment**  
12.1 Check-in questions

### Command terms

**explain**  
Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

**describe**  
Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

## 12.2 SCHEDULING PRINCIPLES

In this module you will learn about:

- the correct frequency and duration in scheduling a training program and learn to:
- correctly apply these training principles to a well-structured training program.

## Frequency

It is generally accepted that, if a specific fitness component is to be improved, training for that component must occur at least three times per week, with a rest day between training sessions to allow recovery. However, this relies on the effective implementation of the other principles of training. Consideration must also be given to the amount of time the participant can commit to the training program, as well as their current level of training.

Rest and recovery are also important considerations that need to be built into the training program. Training will cause a **catabolic effect**, or muscle breakdown, in the body. It is during rest that the **anabolic effect** – the repair and, ultimately, the chronic adaptations – will occur. Without sufficient rest, these positive anabolic effects will be greatly reduced, and overtraining may result.

As performers become accustomed to their training program and are no longer novices (i.e. when they have been training consistently for over 6 months), **frequency** may be increased to further accelerate chronic adaptations. It is not uncommon for athletes who rely heavily on anaerobic fitness components (such as speed) to increase training to 5 days per week. This may involve a combination of different training methods (such as short-interval work and plyometrics) on different days. Although one method is trained only twice per week, this will still elicit improvements because of the cumulative effect of the two different methods.

Performers involved in resistance training may begin with a workout, suitable for novices, that involves the entire body, conducted three times per week. Later, they may split training into two different muscle-group sequences and train each of these twice per week, giving a total of four resistance training sessions per week. These are known as split routines.

### catabolic effect

The breakdown of muscle from training

### anabolic effect

The rebuilding of muscle after training

### frequency

How often training occurs; also the minimum number of weekly training sessions required to elicit chronic adaptations for a specific fitness component

**TABLE 12.04** Example of weight training split routines

Monday and Thursday	Tuesday and Friday
Chest	Back
Shoulder	Legs
Triceps	Biceps

Looking at Table 12.04, how else could split body routines be arranged?

Elite endurance athletes may train up to 6 or 7 days per week, and even twice a day. This is possible for two reasons. First, there is less of a catabolic effect from endurance training compared with training that is associated with anaerobic exercise, which requires the performer to be working at near-maximal intensities. Secondly, these elite athletes will build lower-intensity work, such as recovery runs, into their program.

## Maintenance

Fitness gains can be maintained by training twice per week, which is important in two scenarios. Firstly, it may have been identified that a performer needs to improve a particular fitness component(s). Once the desired performance level has been met, the performer can move to a **maintenance** program, which requires less training frequency, freeing up available time for other priorities.

Secondly, maintenance is very relevant for those involved in seasonal sport. Players often welcome the end of the season as a time to relax, recover from niggling injuries and freshen up mentally after weeks of competition. However, given the amount of work that went into achieving fitness gains during the season, and the fact that these gains are almost immediately reversed if all training ceases, it is worth continuing to train at least twice per week. This is often referred to as 'off-season maintenance'. By maintaining fitness improvements during the off-season, participants avoid detraining and can return to a new pre-season with no loss of fitness, ready to develop their fitness further.

### maintenance

The minimum number of weekly training sessions required to keep a specific fitness component at current levels

Finally, a coach may also decide that their players are at a sufficient physiological level that they can perform comfortably, and would prefer to maintain this fitness level so they can devote more training time to other parameters, such as tactics or set plays.

## Time/duration

In relation to exercise, **time/duration** can refer to:

- the length of a training program (e.g. 12 months)
- the length of an individual training session – for example, a minimum of 20 minutes is required to elicit aerobic adaptations when using continuous or fartlek training methods
- the length of a bout of exercise during a training session – for example, the length of the work phase in an interval training program
- the length of the rest break between sessions of any type of interval or resistance training. Changing the length of the rest break in interval training session must be considered carefully, as decreasing the rest time may alter the work-to-rest ratio and change the energy system the interval program targets
- the minimum time a training program needs to be performed before chronic adaptations will be evident (assuming the other training principles are being met).

### time/duration

How long training lasts or takes to complete; also the minimum length of time for which a training program needs to be performed before chronic adaptations become evident

## Detraining

**Detraining** is often referred to as reversibility. As the name suggests, this is the termination of training (or, more specifically, of a training method) and the corresponding and rapid return to pre-training levels. Detraining can occur for a variety of reasons, such as injury, illness, boredom or even a poorly planned training program. Regardless of the reason, the result is still the same – the reversal of previously achieved improvements.

The effects of aerobic detraining are almost immediate. Insufficient aerobic training has been shown to decrease  $\text{VO}_2$  max by 8 per cent in as little as 3 weeks, and by 18 per cent in 12 weeks. Some of the parameters associated with detraining are presented in Table 12.05. Similar decreases in performance are also evident in other fitness components when detraining occurs.

### detraining

What happens when training ceases or the training load is less than that required to maintain a certain level of fitness

**TABLE 12.05** The effects of detraining on aerobic parameters

Variable	Percentage change (%)	
	After less than 3 weeks of detraining	After 3–12 weeks of detraining
$\text{VO}_2$ max	-8	-18
Cardiac output	-8	-10
Stroke volume	-10	-13
a- $\text{vO}_2$ diff	-2	-7

Adapted from: McArdle, Katch & Katch, 2015

Detraining occurs more rapidly for those with immobilisation injuries – for example, with a leg in a cast. This helps to explain why some form of rehabilitation is often prescribed for a performer as soon as they are considered able to manage it.



**FIGURE 12.09** Why is it important, when recovering from an injury, to do as much training as possible without aggravating the injury?

Detraining also emphasises the importance of the transition or 'off-season' stage of a competition season. In most team sports, after a season ends, there is usually a period of between several weeks and a few months before the next pre-season training program commences. Higher-level sporting competitions such as the AFL will prescribe transition training programs for their players, with the expectation that they will meet certain fitness requirements, assessed through testing, upon their return.

The transition phase is an ideal time to add variety. For example, bicycle riding could be an effective training method for a running-based sport. Although it is not specific to running, it will nevertheless help to maintain aerobic power, avoiding the consequences of detraining while offering a low-impact alternative.



## ABOVE AND BEYOND THE STUDY DESIGN

Periodisation, page 494



### Assessment

12.2 Check-in questions

### Command terms

#### state

Give a specific name or value or other brief answer without explanation or calculation

#### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

## 12.2 CHECK-IN QUESTIONS

- State** the minimum number of training sessions required per week to see improvement when training a specific fitness component, and the number of sessions required to maintain a fitness component.
- Outline** the impact intensity has on the length of a training session.
- Outline** different ways in which the principle of time/duration can be applied to a training program.
- Explain** how players can avoid detraining in their off-season while also benefiting from physiological and psychological recovery from in-season competition.
- A marathon runner has broken their wrist and has been advised not to run for 6 weeks because of the risk of tripping and falling, and because of the vibration generated through their wrist from their foot striking the ground. **Discuss** how they could minimise the impact of not being able to run for this period.

## 12.3 IMPROVEMENT PRINCIPLES

In this module you will learn about:

- the training principles aimed at enhancing the outcomes of an effective training program and learn to:
- correctly apply these training principles to a well-structured training program.

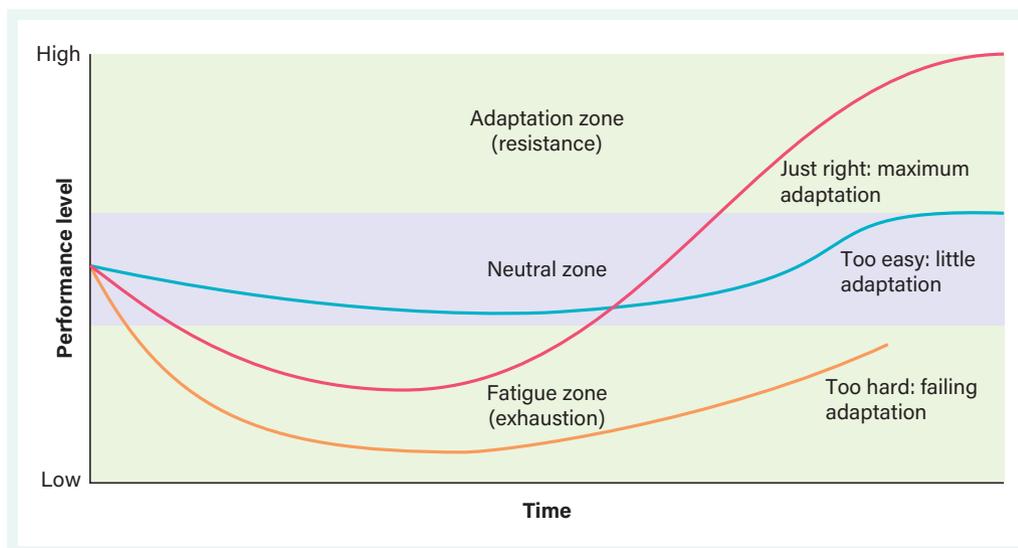
# Progression

The goal of any training program is to cause positive long-term, or chronic, adaptations to enhance performance from a physiological perspective, such as an increase in aerobic power, speed or muscular power.

**Progression** (also known as progressive overload, or overload) refers to the gradual structured increase of stress placed on the body during a training program, with the intended aim of causing further positive long-term, or chronic, adaptations. Provided some basic fundamentals are met, the body will adapt in a positive manner.

Without further increases in training stimulus, the body will become accustomed to the existing workload and will **plateau** – that is, no further positive chronic adaptations will be evident. This is why progression needs to be applied continually, in a structured manner, to ensure continuing positive adaptations.

The challenge in applying progression is to ensure the increased stimulus elicits maximal adaptations: a stimulus that is too difficult, or too easy, will not maximise chronic adaptations, and in fact may be counterproductive, as seen in Figure 12.10.



**FIGURE 12.10** Performances of three athletes under three different training loads

Adapted from: Pyke, 2001

The first consideration is how much progression to apply in your training program. It is generally accepted that only one variable (training parameter) should be manipulated at a time, and that this progression should fall within the range of between 2 and 10 per cent. Overload beyond 10 per cent may become too difficult and have the reverse effect, resulting in overtraining, increased risk of injury and performance setbacks. Conversely, an overload that is not challenging enough will cause minimal stress and therefore minimal, if any, adaptations. This is depicted in Figure 12.10.

Variables that can be manipulated to apply progression within a training program include:

- increasing the length of the training session
- increasing the distance of the training session
- increasing the resistance/load being lifted
- increasing either the number of repetitions or the number of sets being completed
- increasing the frequency of training sessions per week

## progression

A planned increase in training stimulus to cause a positive long-term (chronic) adaptation

## plateau

A level or period where no change is observed; also, to reach such a level



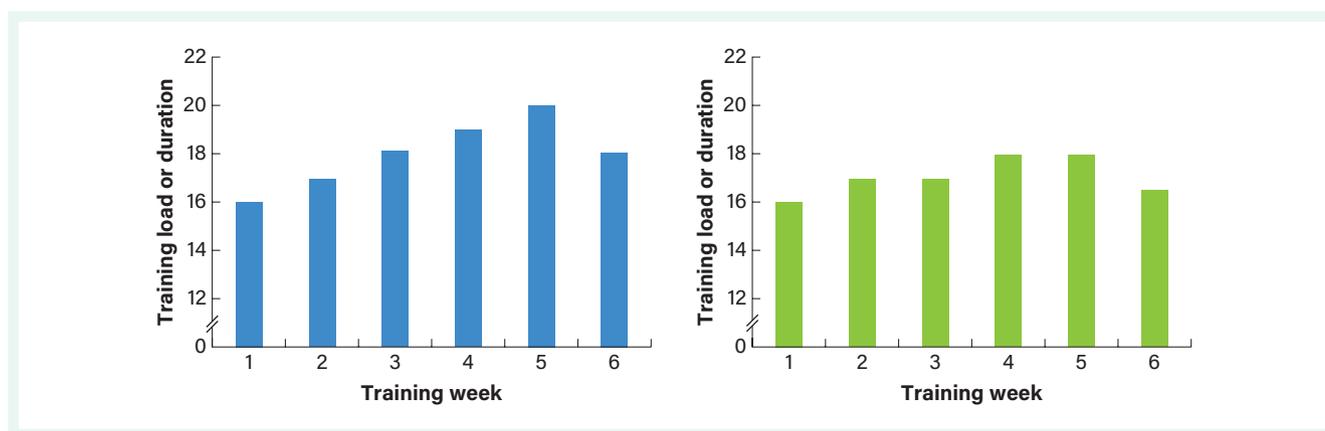
**Video**

In focus: Progression

- increasing the intensity of the training session
- increasing the range of motion
- decreasing the rest time between repetitions, bearing in mind that decreasing the rest period may change the work-to-rest ratio (W:R), which may in turn impact energy system contribution.

When designing a training program, it can be difficult to know when to initiate progression. In theory, it should occur when a performer has become accustomed to the existing workload, but this can be difficult to measure. This is why it is critical that participants keep records (a training diary) of both their training sessions and subsequent post-training wellbeing to provide qualitative insight into their response to the training program. This was covered in greater detail in Chapter 11.

Progression forms part of the overall program design. There are countless models that can be used to apply progression to training. One effective method is to apply a linear approach that focuses on training as a block of 6 weeks. In weeks 2 and 4, progression is applied to the training program, and in the sixth week training is reduced. This reduction is known as unloading or tapering and is important to counter the effects of cumulative fatigue, which may hinder adaptations and lead to overtraining. The assumption in this, and any, model is that the participant can cope with the progression.



**FIGURE 12.11** Two models of progressive overload for a 6-week training program. Which model has the greater potential to cause overtraining?

The temptation for some participants is to overload every week for the first 5 weeks before unloading in week 6. Effectively, this can amount to as much as a 50 per cent increase in the training load from week 1, and is more likely to lead to overtraining than it is to elicit the chronic adaptations the program is aiming to achieve.

Finally, it is worth noting that, during any period of progression, performance parameters, from a physiological perspective, will likely decrease.

### peaking

Demonstrating an optimal level of performance in competition as a result of successfully tapering before the event

### tapering

Reducing training with the aim of significantly decreasing physiological and psychological fatigue and achieving optimal preparedness for competition

## Tapering

Progression-increased stress on the body elicits positive chronic adaptations, leading to improved performance from a physiological perspective. However, while the body is under this stress, physiological, and possibly psychological, fatigue will be present, negatively impacting on any performance occurring at this time.

The goal for any athlete is **peaking**, or performing at their absolute best, during a competition. This is possible through carefully manipulating the performer's training schedule to ensure that both physiological and psychological fatigue are dramatically reduced leading up to the event – a process known as **tapering**. Tapering is widely used by athletes from a variety of sports to gain a performance edge over their competitors.



**Video**  
In focus: Tapering

Fundamentally, tapering involves reducing the performer's training load in the 1–4 weeks before competition; in most circumstances, tapering for between 8 and 14 days prior to competition is ideal. Training intensity within either anaerobic or aerobic training methods needs to be maintained (the specificity principle); medium-interval training, for example, aimed at developing anaerobic capacity, still needs to occur at an intensity above 85% max HR.

Tapering has been proven, through the reduction of cumulative fatigue, to improve performance by approximately 3 per cent, which is a significant benefit for elite performers. Importantly, tapering has also been demonstrated to help with psychological performance by improving mood and energy levels while decreasing the feeling of perceived effort and the sense of fatigue.

Finally, tapering is also an important consideration for athletes who may be carbohydrate loading. This is particularly relevant for aerobically dominated events of 90 minutes' duration or longer, such as a marathon. The decrease in training volume enables more carbohydrates to be stored as glycogen in the muscle and liver, as less is being used to fuel the reduced training.

## Overtraining

The goal of any training program is to elicit chronic adaptations, which improve physiological performance. A carefully constructed training program will challenge the athlete by applying appropriate overload. The purpose is to stress the body, challenging it to respond in a positive manner through adaptations. This will often result in some soreness, which is part of the adaptive process.

Problems can arise when the athlete does not recover from this continual stress over a longer period, resulting in what is termed **overtraining**. It is reported that between 10 and 20 per cent of athletes experience the syndrome of overtraining, or 'staleness' (McArdle et al., 2014). Overtraining is characterised by cumulative exhaustion that persists even after recovery periods. Overtraining causes long-term decreases in performance and an impaired ability to train – the exact opposite of training goals.

Preventing overtraining relies on a carefully constructed training program and appropriate recovery periods.

Applying the training program principles discussed in this chapter helps to minimise the likelihood of overtraining. This is why planning, or periodising, a training program is critical. Flexibility is also required so that the training program can be adjusted if a performer is not recovering sufficiently from training sessions.

The challenge for any performer is to build sufficient rest and recovery into the training program.

Positive chronic adaptations occur during rest, not during training. Insufficient rest means the performer will go into the next training session not fully recovered, compounding fatigue. Ultimately, if this imbalance between insufficient rest and excessive training without full recovery continues, performance will decline. The performer may even feel that they are not training hard enough and may attempt to increase training, compounding the problem further.

## Signs and symptoms of overtraining

There are more than 100 recognised signs and symptoms of overtraining, making a definitive diagnosis challenging. The American College of Sports Medicine has identified the following as the most common of those symptoms:

- persistent heavy, stiff and sore muscles
- persistent fatigue; a washed-out feeling

### overtraining

A result of insufficient recovery, which leads to a decrease in motivation and a decline in performance; can be exacerbated by excessive training volume

**tachycardia**

An abnormally fast heartbeat

**bradycardia**

An abnormally slow heartbeat

- a decrease in performance and ability to maintain the training regimen
- an increased susceptibility to infections, colds and headaches
- nagging and somewhat chronic injuries
- sleep disturbances
- decreased mental concentration and restlessness
- increased irritability
- depression
- **tachycardia** and, in some cases, **bradycardia**
- loss of appetite and weight loss
- changes to bowel movements
- amenorrhoea (absence of menstruation).

## Monitoring and preventing overtraining

Maintaining a training diary or log is valuable in helping to identify the signs of overtraining. The training diary should record how you feel each day (your mood and motivation towards training) as well as entries on resting heart rate, sleep and overall physiological state (soreness).

Performances should be monitored for trends. A downward trend may indicate insufficient recovery. Regular fitness testing could also be beneficial in providing this type of information.

There is also some evidence to suggest that an increase in resting heart rate could be an early warning sign of overtraining. Having established a base heart rate over a week, any future increase of 10 or more bpm above this should be seen as a warning that you have not fully recovered from a previous workout, are fatigued or stressed, and could be heading towards overtraining. In this instance, consideration should be given to reducing any scheduled training for that day or simply resting.



**FIGURE 12.12** A well-designed training program with recovery built into the schedule is the key to preventing overtraining.

# Diminishing returns

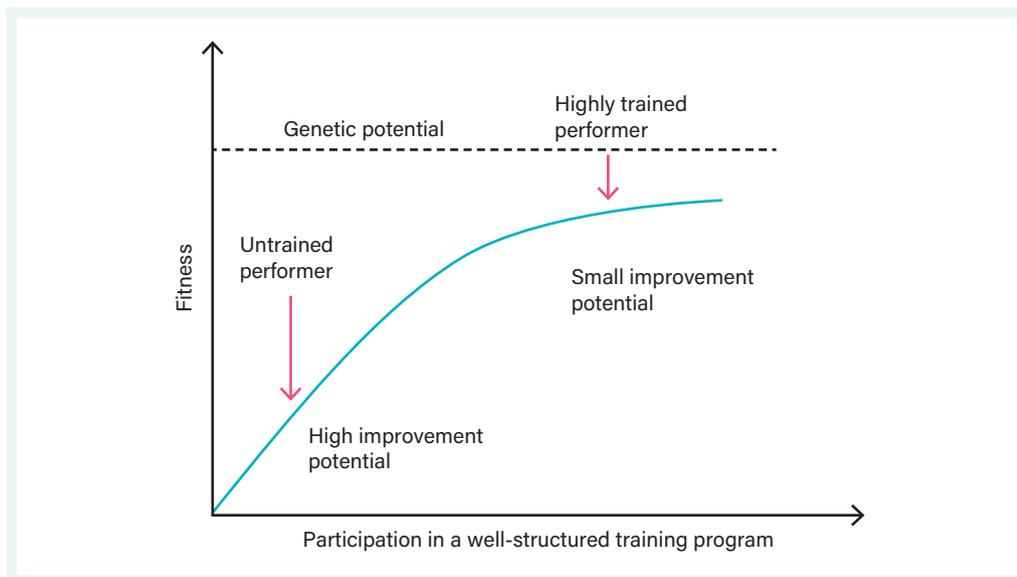
The principle of **diminishing returns** recognises that fitness improvements are more rapid early on in a training program. Improvements are also more rapid for people who begin a training program with a lower level of fitness.

Each individual has a genetic potential for fitness and, more specifically, for each fitness component. An untrained performer will show greater initial improvements than their trained counterparts. As a performer gets closer to their ultimate potential, the rate of improvement slows down significantly. This can be seen in Figure 12.13.

This is why, as they near their genetic potential, elite performers may participate in as many as 12 training sessions per week in the quest for even the slightest improvements. This sort of training volume would more than likely lead to immediate overtraining for a non-elite performer. Elite performers have accustomed their bodies to these volumes of training over a considerable period, but must also carefully monitor their training to ensure that they are not overtraining.

## diminishing returns

The slowing of improvement over time, even in response to an appropriate training program, after initial rapid improvements on commencing training



**FIGURE 12.13** The principle of diminishing returns

## 12.3 CHECK-IN QUESTIONS

- Progression is an important consideration in structuring a training program.
  - Outline** the purpose of progression.
  - Explain** when progression should be applied.
  - Discuss** the relationship between progression and overtraining.
- Overtraining can lead to a decrease in performance and injury.
  - Outline** the primary cause of overtraining.
  - Identify** two symptoms of overtraining.
  - Describe** one method of monitoring training to avoid overtraining.
- Referencing chronic adaptations, **distinguish** between the training principles of detraining and diminishing returns.



**Assessment**  
12.3 Check-in questions

## Command term

### distinguish

Make clear the differences between two or more arguments, concepts, opinions, narratives, artefacts, data points, trends and/or items



## ABOVE AND BEYOND THE STUDY DESIGN

### periodisation

The planned variation of training methods, volume and intensity, designed to bring about optimal performance at a specified time

### MODULE 12.2, PAGE 488

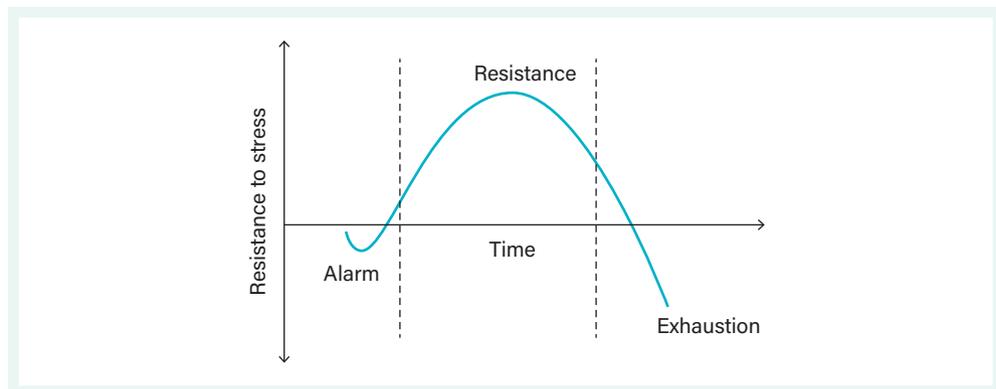
## Periodisation

There is clear evidence that a periodised, or structured, training program has a greater impact on both strength training and aerobic power development, producing superior adaptations, than a non-structured program. A properly periodised training program will also reduce the likelihood of overtraining.

**Periodisation** simply refers to organising training into manageable blocks, or periods, of time; it is the 'road map' ahead. While sports scientists have developed several different periodisation methods, there is overwhelming agreement that a structured approach to training will result in the greatest potential for improvement. Periodisation allows training goals to be set and offers the athlete an insight into their future training regime.

Scientist Hans Selye's widely accepted theory of the general adaptation syndrome (GAS) proposes that the body responds to stress in three stages:

- alarm reaction stage – the initial shock to the body from the training stimulus
- resistance stage – as the body repairs itself and adapts to the stimulus
- exhaustion stage – in which adaptations/repairs are inadequate, and the body will reach exhaustion, resulting in decreased functionality of body systems and decreased performance.



**FIGURE 12.14** A graph demonstrating the general adaptation syndrome

A clear aim of any properly constructed periodised training program is to ensure the performer spends most of their training in the resistance stage and avoids the exhaustion stage, which leads to overtraining.

Periodisation is further divided into three types of time blocks, or cycles:

- A macrocycle is a long training period, usually 12 months in duration.
- A mesocycle is a segment of the macrocycle, usually 4 to 6 weeks.
- A microcycle is a smaller segment of a mesocycle, usually 7 days.

Sports scientists and coaches, particularly those working with seasonal team sports, overlay the following training phases onto their plan to emphasise the type of training done in this time:

- preparation, or pre-season
- competition, or in-season
- off-season, or transition.

Mesocycles and microcycles will still form the basis of the planning for these phases.

Every sport, athlete or individual will have different training goals, which might be, for example, to complete a 5-kilometre fun run or a full ironman triathlon. Regardless of the intended goal, a carefully structured training program with the correct application of training principles will enable the athlete to meet these goals in a safe environment.

# CHAPTER SUMMARY

## 12.1 Personalised principles

- To optimise the positive physiological adaptations essential for optimal performance, an activity analysis should guide a training program via specificity.
- To maximise fitness improvements, it is important to apply sound training principles to any training program. This will capitalise on the training effect and reduce the likelihood of injury. Training principles guide the use of training methods to enhance positive outcomes.
- Training methods are the specific activities a performer engages in during a training session.
- Specificity must form the foundation of any training program to maximise the desired outcome. Training should be specific to the energy system(s), fitness components and major muscle groups identified for a particular activity.
- Intensity ensures the appropriate level of exertion is being applied to a training session. It is usually measured by heart rate for aerobic activities, using either a heart rate monitor or a GPS watch, and by rate of perceived exertion (RPE) for anaerobic activities.
- As a training principle, type simply refers to the training method being used – for example, long-interval or plyometrics.
- Variety can be used to reinvigorate a performer who is becoming bored with their training program. It is best achieved by changing the environment while maintaining the same muscle actions and energy system contributions. This ensures specificity is maintained.
- Each person will respond differently to a training stimulus due to factors such as their genetic disposition and preparedness for training. Therefore, where possible, a training program should be individualised for each performer.



**Resource**  
Self-assessment checklist

**Video**  
Masterclass: Chapter 12

## 12.2 Scheduling principles

- Frequency refers to the minimum number of weekly training sessions required to improve a fitness component. Three is the minimum number of sessions required for improvement, with a rest day between each session. Fitness gains can be maintained through two training sessions per week.
- Time/duration can refer to several different parameters:
  - length of the training program – for example 6 months
  - length of the training session
  - length of a work period within a training session
  - length of a rest period within a training session
  - the minimum time a training program needs to be engaged in before chronic adaptations will occur – for example 6 weeks.
- Detraining is easily remembered with the saying, 'Use it or lose it' Fitness gains quickly deteriorate without regular training.

### 12.3 Improvement principles

- For performance improvements to continue, progression – that is, making the training harder or more challenging – needs to be applied to a training program. This should occur when the performer has adapted to their current workload. Progression should only be applied to one parameter at a time and the change should not exceed 10 per cent of the current workload.
- It is also important to consider that training induces a catabolic (destructive) effect on muscle, followed by an anabolic (constructive) effect during the recovery period. It is during the recovery periods between training sessions that many of the physiological adaptations to training occur. Building sufficient recovery into a training program is vital.
- Tapering involves decreasing the volume of training, while maintaining intensity, 1–3 weeks before competition. The aim of tapering is to reduce residual fatigue and thus ensure the performer is at their peak for an important competition.
- Overtraining is the result of insufficient recovery and it causes a decrease in performance. The risk of overtraining can be minimised by following a carefully structured training program and allowing sufficient rest and recovery. Maintaining a training diary is important in monitoring training.
- Improvements occur more rapidly at the commencement of a training program, and they slow dramatically as performers become elite, approaching their genetic potential. This is the principle of diminishing returns.

# CHAPTER REVIEW

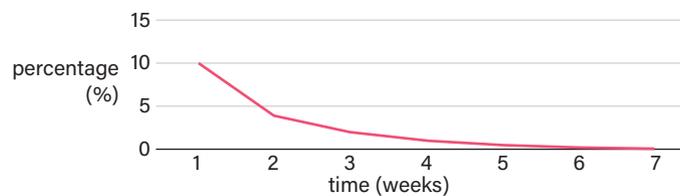


**Assessment**  
Chapter 12 Review

- A telltale sign of lack of specificity in training is:
  - muscle soreness.
  - tiredness.
  - dizziness.
  - moodiness.
- Which of the following training intensities will improve aerobic power?
  - 90% of maximum heart rate
  - 50% of maximum heart rate
  - 60% of  $VO_2$  maximum
  - RPE of 8
- The first consideration of any training program is:
  - variety.
  - specificity.
  - maintenance.
  - progression.

4 **©VCAA** Exam 2022, Section A, Q4

The graph below shows the percentage of improvement on an agility test over seven weeks.



Which training principle is shown in the graph above?

- progression
  - reversibility
  - diminishing returns
  - individuality
- 5 **©VCAA** Exam 2020, Section A, Q11
- 'The rate of fitness gains will decrease as an athlete gets closer to their genetic potential.'
- Which training principle does this statement refer to?
- detraining
  - progression
  - overtraining
  - diminishing returns

**Command terms****construct**

Make, build, create or put together by arranging ideas or items (e.g. an argument, artefact or solution); display information in a diagrammatic or logical form

**suggest**

Put forward for consideration a solution, hypothesis, idea or other possible answer

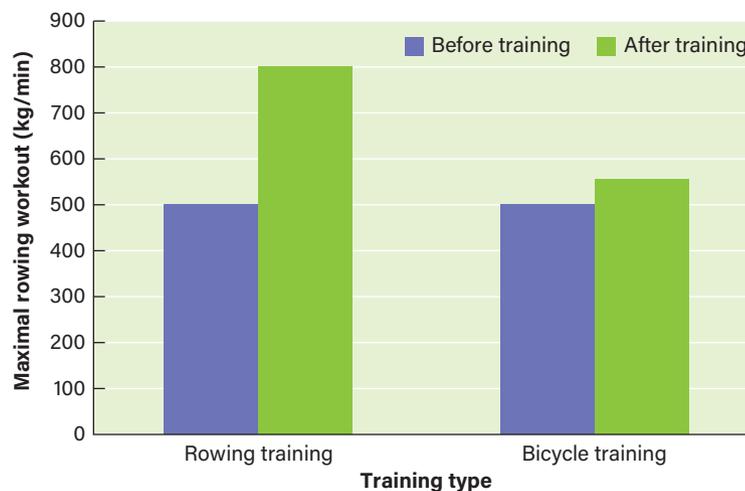
**identify**

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

**predict**

Give an expected result of an upcoming action or event; suggest what may happen based on available information

- 6 James, a 27-year-old sedentary male, decides to commence an aerobic training program with the aim of completing a 5-kilometre fun run in 6 months' time, in 25 minutes. He engages in a long-interval training program, 7 days per week, believing that this will increase his fitness in the shortest possible time.
- Outline** the most likely outcome of James participating in the above training program.
  - Construct** a more suitable 6-week continuous running-based training program for James. Include frequency, intensity, time and progression in the design of this program.
  - James follows your program for 4 months, then starts to feel a little stale. **Suggest** some alternative activities that he could complete without losing sight of the goal of the training program.
  - Two weeks before the event, James believes he will run 5 kilometres in 25 minutes. He seeks your advice on some new concepts he has heard about: tapering and carbohydrate loading. **Discuss** these two concepts, including the suitability of each for this event.
- 7 The graph below relates to two groups of athletes who were tested for aerobic power on a rowing ergometer. Both groups then completed aerobic power training on either a rowing ergometer or a bicycle ergometer.



Source: Pyke, F. (Ed.), 1980, *Towards Better Coaching*

- State** whether both types of training were successful in improving aerobic power.
- Identify** the two training principles evident in the above study.
- Explain** why training on one type of equipment produced significantly better results than training on the other type.
- Predict** what would happen if the bicycle ergometer was replaced with the same amount of sessions rowing on the Yarra River.

- 8 Construct** two simple graphs on the principle of diminishing returns. Time and rate of improvement will be the axes for both graphs. On one graph, show time on the horizontal ( $x$ ) axis and rate of improvement on the vertical ( $y$ ) axis. On the second graph, switch the axes – that is, make the  $x$ -axis show rate of improvement and the  $y$ -axis show time.
- 9** Variety can either complement or be in conflict with the goal of a training program.
- a Discuss** how variety can be used to complement a training program.
  - b Discuss** how variety could contradict the goal of a training program.
  - c Suggest** a reason for using variety if it contrasts with the goal of a training program.

# CHAPTER 13

## TRAINING METHODS

UNIT 4 - AREA OF STUDY 2



Flamingo Images/Adobe Stock

**FIGURE 13.01** Continuous training can involve rowing, running, cycling or swimming.

### Quizzes

Chapter 13 Pulse check

**13.1** Check-in questions

**13.2** Check-in questions

**13.3** Check-in questions

**13.4** Check-in questions

**13.5** Check-in questions

**13.6** Check-in questions

Chapter 13 Review

### Videos

Masterclass: Chapter 13

**13.2** In focus: High Intensity Interval Training

**13.4** In focus: Resistance training prescriptions

### Resources

Chapter 13 Self-Assessment Checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



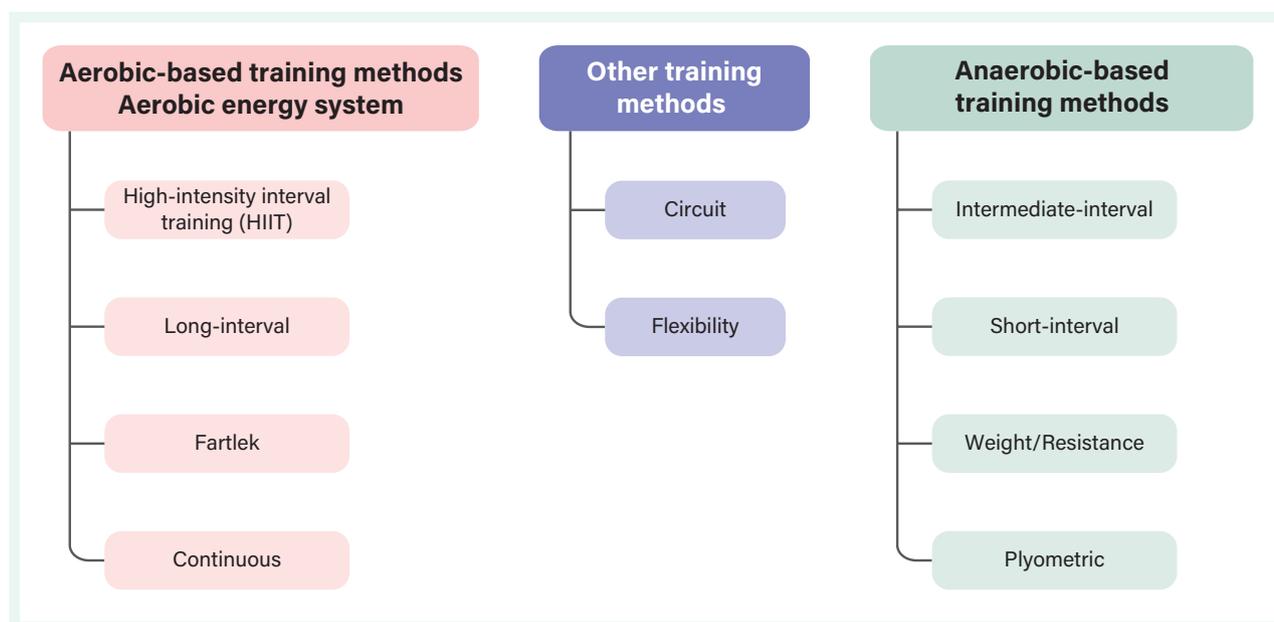
- » training methods including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics

## KEY KNOWLEDGE

- » participate in and conduct components of an exercise training session
- » design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components
- » evaluate and critique the effectiveness of different training programs

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 13

**Assessment**

Pulse check

Training methods are the various types of activities that can be chosen to target specific fitness components, energy systems and personal training objectives. A single method, or combination of multiple methods, can be included in a training program based on the following factors:

- games analysis findings
- fitness test results
- training goals and objectives
- training status and experience
- desired physiological adaptations.

**PULSE CHECK**

Take the pulse check quiz to check your knowledge and understanding of the concepts covered in this chapter.

- 1 What is the difference between continuous training and fartlek training that an endurance athlete might use?
- 2 Is it better to include flexibility training before a resistance training session or after its completion?
- 3 High-intensity interval training (HIIT) has become very popular in the last 10 years. **List** two advantages of HIIT compared with traditional long-interval training.
- 4 When performing a circuit program, the sequencing of body parts and exercises is vital to achieving the aims of the training session. Typically, this involves classifying exercises as 'upper-body' and 'lower-body.' Why would one program alternate between the two while another might have two or three consecutive stations use the same classification/type of exercise?
- 5 Plyometrics typically involves leg muscles.
  - a **Name** two different types of plyometric leg exercises.
  - b **List** two different types of plyometric upper-body exercises.

## 13.1 CONTINUOUS AND FARTLEK TRAINING

In this module you will learn about:

- similarities and differences between continuous and fartlek training
- aerobic training zone and FITT formula
- different types of continuous fartlek training specific to competition demands and learn to:
- apply continuous and fartlek training methods to your own and others' needs.

**VO<sub>2</sub> max**

The maximum amount of oxygen that can be taken up (at the lungs), transported (by the cardiovascular system) and used by muscles per minute; usually expressed in mL/kg/min when taking body weight into consideration

### Continuous training

Continuous training is a form of exercise that is performed at the same intensity, without a rest period, for an extended period of time. The main goal of continuous training is to improve the production of aerobic ATP by increasing aerobic power, **VO<sub>2</sub> max** and the lactate inflection point (LIP). Additionally, because of the repeated muscular contractions associated with continuous training, muscular endurance is also trained. Continuous training should be specifically used with the same muscle movements identified from an activity analysis and can involve different types of exercises, including running, swimming, cycling or rowing, and cross-country skiing, to name a few.

For adaptations to occur as a result of continuous training, the FITT formula needs to be applied to each session:

- **frequency** – a minimum of three sessions per week
- **intensity** – 70–85% max HR, or up to LIP, depending on training status; this is sometimes referred to as the aerobic training zone
- **time** – 20 minutes minimum, up to 1–2 hours, depending on the activity being trained for
- **type** – whole-body actions that replicate those obtained from the activity analysis (specificity). Two examples of continuous training are long slow distance (LSD) training and tempo training.



## ABOVE AND BEYOND THE STUDY DESIGN

Types of continuous training, page 543

## LOOKING BACK

### Training principles

#### Chapter 12

Intensity is an important principle that needs to be considered along with specificity of the major energy system being targeted.

## LOOKING FORWARD

### Chronic adaptations

#### Chapter 15

Correct selection of training methods and application of training principles provides a great recipe for targeted chronic adaptations to occur.

## Fartlek training

**Fartlek** is a form of continuous training with regular changes in speed and/or resistance, depending on where the training is undertaken. The increases in workload can be planned and can occur at set times or distances, or may simply occur when the subject feels they have sufficiently recovered and can 'surge' at a higher intensity.

Fartlek aims to activate the anaerobic glycolysis system when the athlete surges and must work above the lactate inflection point for short periods of time (this also occurs during high-intensity interval training). This helps develop lactate tolerance and trains  $\text{VO}_2$  max at the same time. Because there are no real opportunities for the ATP–CP system to be replenished during fartlek training, the aerobic energy system benefits the most, with additional benefits to the anaerobic glycolysis energy system.

Fartlek sessions are easily adapted to multiple movements in individual sports, including running, cycling, swimming and rowing. Many team sports also include fartlek in their training programs because it closely resembles the changing intensities experienced while participating in 'target', 'net' and 'invasion' games.

Mona fartlek workout, fartlek pyramid and Gerschler fartlek are three examples of fartlek sessions that all have in common the continuous base with varied intensity.

#### fartlek

From the Swedish word meaning 'speed play'; a training method that uses alternating low- and medium-intensity efforts, working the aerobic energy system, with high-intensity efforts, activating the anaerobic energy systems

## DID YOU KNOW?

Fartlek sessions have no 'rest' periods and should not contain any walking (if using running as the exercise mode).



## ABOVE AND BEYOND THE STUDY DESIGN

Examples of fartlek sessions, page 544



## COLLABORATIVE TASK

### Prac activity

#### Comparing continuous and fartlek training methods

##### AIM

To compare and contrast continuous and fartlek training methods

##### EQUIPMENT

Students outline any sporting equipment required – for example static cycle, rower or treadmill

##### METHOD

Plan a 10-minute continuous training session and a 10-minute fartlek session. Make sure you record where you are training, what intensities you intend to work at and for what duration, and which type of movement this is being applied to (e.g. running, cycling, swimming or rowing).

Participate in the continuous session first, take a 5-minute break and then participate in the fartlek session you have planned.

##### DISCUSSION

After completing both forms of continuous training, reflect on the following:

- Could you complete the session with ease? If not, how did you modify the session (intensity, duration of efforts etc.)?
- Which session did you enjoy more? Why do you believe this to be the case?
- Which session do you think placed greater stress on your aerobic energy system?
- If you were going to train a group of netball or football players, which type of training would you choose, and why?

Share your reflections with a classmate (face to face) or via a blog on your school's LMS.



##### Assessment

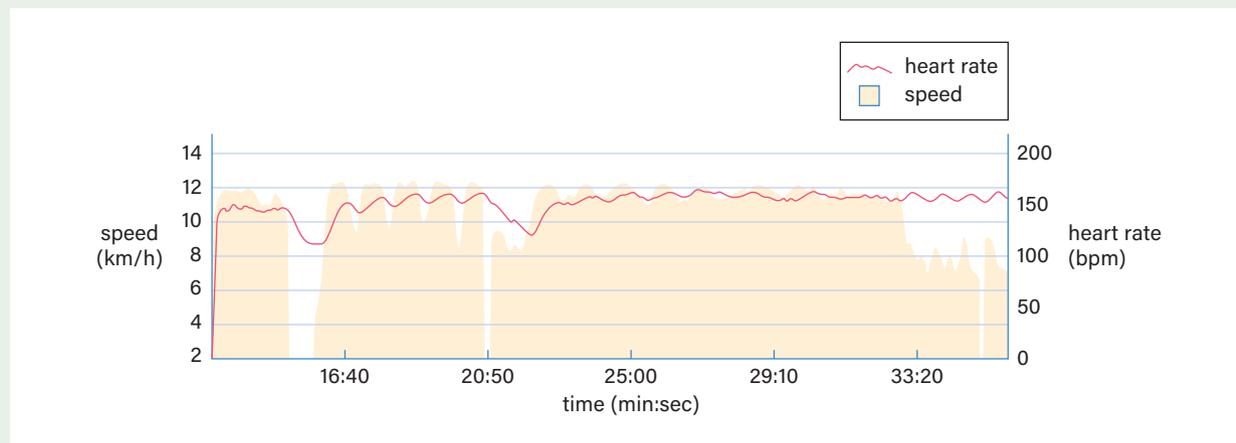
13.1 Check-in questions

## 13.1 CHECK-IN QUESTIONS

1 **Discuss** why the training intensities for continuous training of someone who is just starting to train for Parkrun activities and those of an experienced triathlete would be different.

2 **@VCAA** Exam 2017, Section B, Q3

The graph below shows heart rate data collected on a personal fitness tracker for a 31-year-old completing a run session. A warm-up was completed before the data collection started.



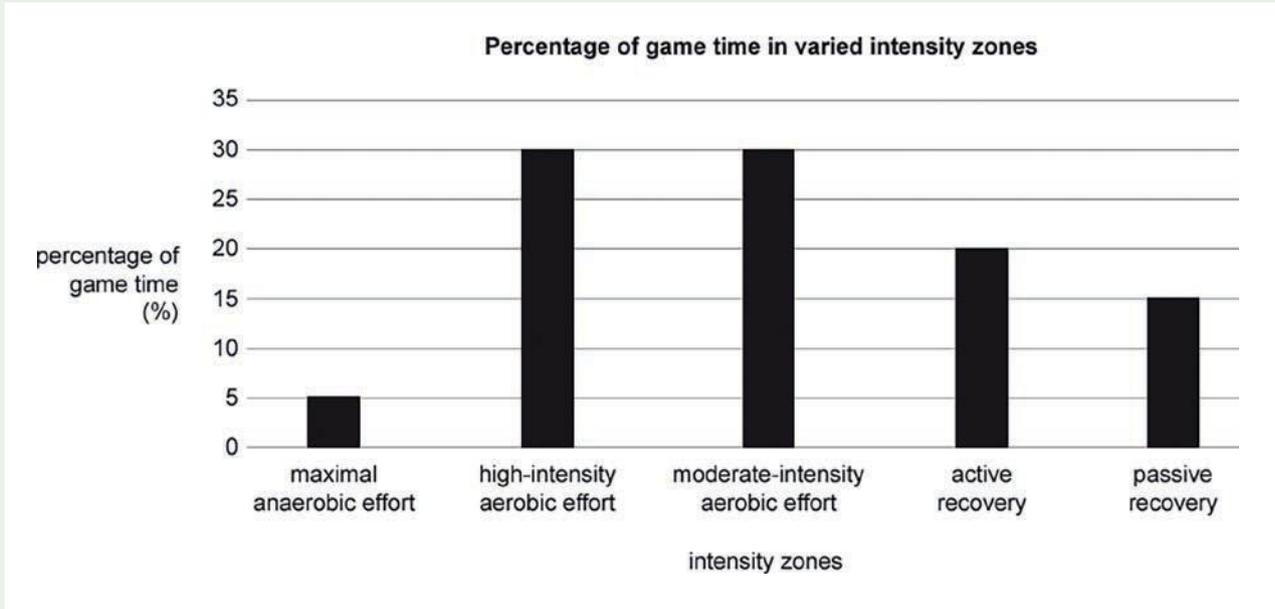
**Identify** two possible training methods undertaken in this session. **Justify** your response with reference to the data in the graph.





**3** ©VCAA Exam 2022, Section B, Q10 c

The graph and the table below show data resulting from an activity analysis of elite soccer referees. Based on the data provided in the graph and the table, design the conditioning phase of a fartlek training program for the soccer referees, focusing specifically on high-intensity and moderate-intensity aerobic efforts.



	Sprinting	Running	Jogging	Walking	Standing
Intensity of effort	Maximal anaerobic effort	High-intensity anaerobic effort	Moderate-intensity anaerobic effort	Active recovery	Passive recovery
Distance of average effort	10 m	65 m	40 m	20 m	0 m
Time of average effort	1.7 s	20 s	20 s	45 s	40 s

## 13.2 INTERVAL TRAINING

In this module you will learn about:

- matching the different types of interval training methods to each major energy system
- advantages associated with long-interval training vs continuous training
- many benefits associated with high-intensity interval training (HIIT) and learn to:
- manipulate duration, intensity and work-to-rest periods to achieve any of the four types of interval training methods covered.

**interval training**

Repeated periods of work that are followed by periods of rest/recovery

**Interval training** uses periods of work alternating with periods of rest to target specific fitness components and related energy systems. Essentially, interval training involves completing an exercise/activity (e.g. a run or some clap push-ups) then resting for a period of time before repeating this pattern for a number of repetitions. This incorporates several important training principles and variables. The comparison of the amount of time engaged in physical activity (work) with the time spent recovering (rest) is commonly referred to as the work-to-rest ratio (W:R).

Note that most forms of circuit training involve interval training. This will be addressed later in this chapter.

**TABLE 13.01** Key variables and terminology in interval training

Variable	What this means	Examples
Work interval	Distance or duration of work	<ul style="list-style-type: none"> <li>25 m</li> <li>20 s sprint</li> </ul>
Rest interval	Time between work intervals	<ul style="list-style-type: none"> <li>3 min (passive)</li> <li>40 s slow walk/jog (active)</li> </ul>
Work intensity	How much effort is being used	<ul style="list-style-type: none"> <li>RPE or GPS data – short and intermediate intervals</li> <li>% max HR – long intervals</li> </ul>
Set	Work and recovery intervals grouped together	<ul style="list-style-type: none"> <li>2 sets of 10 × 25 m sprints</li> </ul>
Repetition ('rep')	Each single period of work	<ul style="list-style-type: none"> <li>10 single reps of 25 m</li> </ul>
Work-to-rest ratio (W:R)	Expresses work in relation to rest – typically, 1:X, where X is rest	<ul style="list-style-type: none"> <li>1:1 = aerobic system focus</li> <li>1:3 = anaerobic glycolysis system focus</li> <li>1:6+ = ATP-CP system focus</li> </ul>

## Long-interval training

Long-interval training, also known as AIT (aerobic interval training), aims to improve the aerobic energy system as well as aerobic power and muscular endurance. Because its intensity is not as high, time spent working can be greater than time spent resting. Work intervals tend to be longer than 80 seconds. Note that 4:1 = greater work than rest, which means there is a focus on the aerobic energy system, and no  $H^+$  accumulation to worry about.

Long-interval training is common when training for sports and activities that require extended use of the whole body – from activities lasting a few minutes, such as the 1,500-metre run, all the way up to triathlons lasting 9 hours or more. Mobile team players who need to repeatedly call on aerobic power and who cover large distances during a game, such as soccer or hockey midfielders, would also use long-interval training.

Long-interval training allows performers to work closer to their lactate inflection point (LIP), without triggering  $H^+$  accumulation, for longer periods. This results in greater training adaptations, especially at the level of the cardiorespiratory system. As this occurs, athletes can work at higher intensities aerobically, and swim, run and cycle faster without experiencing fatigue.

### LEARNING HACK

Aerobic interval training (AIT) alternates between moderate- to high-intensity exercise (below 85% max HR) intervals and recovery intervals.

### Key points of long-interval training

Intensity	80–85% max HR (the aerobic/continuous training zone)
Energy system	Aerobic system development
Targets	Slow-twitch fibres or fast-twitch Type IIa
Main purpose	To improve aerobic capacity and muscular endurance

**TABLE 13.02** Examples of long-interval training

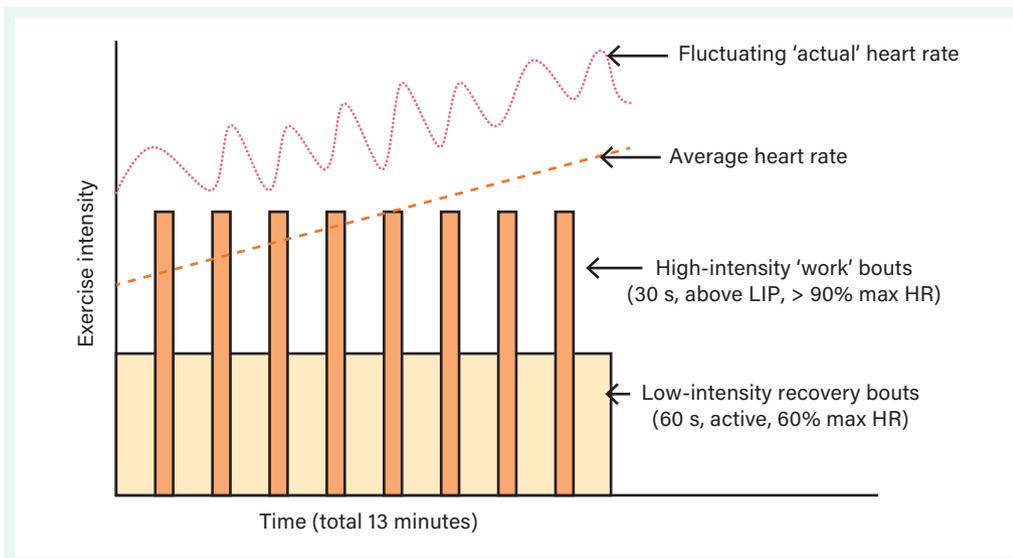
Athletics: 1,500 m (approximate duration 4 min)	Swimming: 1,500 m (approximate duration 15 min)
 <p style="writing-mode: vertical-rl; transform: rotate(180deg);">NurPhoto/Getty Images</p>	 <p style="writing-mode: vertical-rl; transform: rotate(180deg);">Maddie Meyer/Getty Images Sport/Getty Images</p>
<p>3 sets of 5 × 600 m (intensity = 85% max HR) W = 90 s R = 180 s W:R = 1:2</p>	<p>10 × 200 m with 30 s rest W = 120 s R = 30 s W:R = 4:1</p>

## High-intensity interval training

High-intensity interval training (HIIT) is increasingly being used as an alternative to traditional endurance training methods. It has been proven to produce higher levels of endurance performances, with reduced time commitment and increased training adherence as added benefits. What has made it so popular is its effectiveness in improving aerobic power and VO<sub>2</sub> max for a wide range of people, including athletes, healthy and overweight non-athletes and even cardiac patients returning to exercise and training.



**Video**  
In focus: High Intensity Interval Training



**FIGURE 13.02** A graph showing 8 × 30-second efforts above LIP with 60 seconds of active recovery between efforts. Note that the active recovery results in less oxygen deficit with each subsequent work bout, and a higher percentage of aerobic work during the 13-minute HIIT session, than had a passive recovery been undertaken.

HIIT sessions vary depending on the work period, intensity, number of repetitions and recovery time. It is generally accepted that optimal improvements occur when the following training protocols are followed.

## Intensity

- Reach and sustain an exercise intensity close to  $VO_2$  max (90–100%  $VO_2$  max or 90–100% max HR) per repetition.
- Accumulated duration of intensity spent at 90–100%  $VO_2$  max or 90–100% max HR should exceed several minutes across the training session.

## Time

- Commonly accepted work time per repetition is between 30 seconds and 4 minutes. A shorter work period is likely to require more repetitions than a session with longer work periods.
- Overall training session time, including work and recovery, could be less than the 20 minutes minimum for other aerobic training methods due to the increased intensity.

## Recovery

- No distinct differences are found when using passive or active recoveries in the ability to accumulate time spent working close to  $VO_2$  max within a session.
- Acceptable low-intensity active recovery between repetitions could be approximately 50%  $VO_2$  max or 60% max HR.
- The choice of recovery needs to be considered when determining work periods. For example, if a passive recovery is used, an individual would be expected to complete more repetitions than if an active recovery is used (for the same work period), to accumulate a similar time spent close to  $VO_2$  max or max HR.
- For the purposes of VCE Physical Education, a work-to-recovery ratio for HIIT sessions of between 1:1 and 2:1 is deemed suitable.

**TABLE 13.03** The different HIIT protocols

	Type	Repetitions	Work period	Recovery period	Recovery type and intensity	Work to recovery ratio
<b>Overview of accepted ranges</b>	Repetitive activity such as cycling or running	4–12	30 s – 4 min	30 s – 4 min	Passive (rest) or active recovery (~50% $VO_2$ max or 60% max HR)	1:1 or 2:1
<b>Example 1: Shorter work periods</b>	Cycling or running	10	45 s	45 s	Passive (rest) or active recovery (~50% $VO_2$ max or 60% max HR)	1:1
<b>Example 2: Longer work periods</b>	Cycling or running	4	2 min	60 s	Passive (rest) or active recovery (~50% $VO_2$ max or 60% max HR)	2:1
<b>Example 3: Active recovery</b>	Cycling or running	10	30 s	30 s	Active recovery (~50% $VO_2$ max or 60% max HR)	1:1
<b>Example 4: Passive recovery</b>	Cycling or running	12	30 s	30 s	Passive (rest)	1:1

Note: accepted frequency for all sessions is 3 x per week and accepted intensity for all sessions is 90–100%  $VO_2$  max or 90–100% max HR.

Many commercial gyms and sporting club trainers use the term HIIT to describe training sessions that include muscle-strengthening exercises (e.g. CrossFit or F45 training). These types of sessions include both aerobic and muscle-strengthening exercises performed at a high intensity, and they generally lead to improvements in aerobic parameters as well as strength and flexibility specific to sporting movements.

HIIT within VCE Physical Education focuses on achieving aerobic adaptations by using one type of activity, such as cycling or running, without a muscle-strengthening component.

Table 13.04 highlights the differences between the definition of HIIT used in VCE Physical Education and the definition of HIIT that is commonly used in a commercial gym.

**TABLE 13.04** Key differences between use of the term ‘HIIT’ in VCE Physical Education and in commercial gyms

	VCE Physical Education	Commercial gym
Mode	Unimodal exercises (running, cycling, swimming or rowing)	Multimodal exercises (whole-body, universal motor recruitment patterns in multiple planes of movement; e.g. squats, pull-ups, jumps)
Work format	Conducted in set intervals	Conducted in a circuit or interval format
Rest format	Defined rest period	Rest breaks taken ‘as needed’ (dependent on the individual)

Source: VCAA, ‘Clarification of content: High intensity interval training (HIIT)’



Microgen/Shutterstock.com

**FIGURE 13.03** Typically, periods of high-intensity work in high-intensity interval training are unimodal: they involve one type of training activity – for example, cycling, running, swimming or rowing – to address specificity.

**DID YOU KNOW?**

HIIT has been proven to result in faster aerobic power gains with shorter session duration than continuous, fartlek and long-interval training methods. It is thus deemed to be more time-efficient.

## REAL WORLD APPLICATIONS

### High-intensity interval training

#### DEFINING DIFFERENT TYPES OF INTERVAL TRAINING: DO WE NEED TO USE MORE SPECIFIC TERMINOLOGY?

JASON L. TALANIAN, FITCHBURG STATE UNIVERSITY

Interval training began gaining popularity in modern society throughout the mid 1900's when track and field athletes started to incorporate them regularly into training programs. Soon after, Christensen, et al. published a study with a sample size of two concluding that 'Research on intermittent work may open up a new field in work physiology' and in 1968 *The Science of Swimming* written by James Counsilman strongly advocated the use of sprints in training to optimize performance. This new found interest had peaked [sic] the curiosity of exercise physiologists and as a result a number of studies in the 1970's utilized higher intensity intervals as training protocols. The consensus was that training intensity was a powerful tool to induce significant positive adaptations.

Traditionally high-intensity interval training has been generalized as repeated bouts of exercise 20 sec or longer in duration at an intensity above anaerobic threshold, but more specific definitions have been used. For example, high-intensity interval training (HIIT) can be considered an exercise at an intensity between our anaerobic threshold and maximal aerobic capacity (~80–100% of  $VO_2$  max). However, sprint or supramaximal-intensity interval training (SIT) can be defined as an exercise >150%  $VO_2$  max power. A comparison of HIIT and SIT reveals distinct differences between the exercises and using specific terminology for different types of interval training can increase clarity among researchers and the general public.

A review on *Pubmed.gov* of the 20 most recent articles to include HIIT in the title have utilized protocols of varying exercise intensities (~80–250%  $VO_2$  max power) and duration (20–240 sec). Compounding the lack of clarity, the loose definition of HIIT can be commonly found in popular magazines that share training tips from published research. The conundrum is that two different types of training are being defined as the same.

HIIT programs that have resulted in positive adaptations utilized protocols that included 8–12 intervals that were 1–4 min in duration, while beneficial SIT protocols have typically included 4–10 intervals lasting 20–30 sec in duration. Acute responses to these protocols differ and each requires varying levels of aerobic and anaerobic contributions to energy production to complete the exercise. As a result, it is likely that unique levels of physiological stress result in some unique adaptations.

In general, similar chronic adaptations can be observed between HIIT and SIT programs lasting six weeks or greater. Both can improve aerobic, endurance and sprint capacity as well as markers of muscle metabolism and cardiovascular health in individuals of average fitness. However, training protocols that only last 2–3 weeks in duration have yielded different results. Following two weeks of training both HIIT and SIT appear to improve endurance capacity and markers of metabolism, but only HIIT has been observed to improve aerobic capacity. In addition, an investigation by Stepto, et al. observed trends that improvements in endurance and sprint capacity were greater with three weeks of HIIT compared to SIT.

Improvements in aerobic and endurance capacity following two weeks of HIIT suggest that it may be better suited for improving cardiorespiratory fitness over a short period of time. This would fit the theory of 'training specificity' since HIIT requires a significantly greater aerobic contribution compared to SIT. This same theory would suggest that SIT would be better at improving sprint ability compared to HIIT, but interestingly Stepto, et al. did not observe this trend. It is likely that their sample size was small and further research is warranted.

In addition to different physiological responses following HIIT and SIT, the time





commitment differs between the two programs. The average total exercise session (intervals and recovery between bouts) for HIIT lasts about 60 min and for SIT about 30 min. This can be a defining factor when deciding on the appropriate type of training. One could argue that SIT can be easier to complete because of the shorter training session, though the effort required to complete each interval may be greater.

An eloquent review of intense exercise training by Coyle concluded that 'SIT performed all-out and repeatedly requires a high level of motivation, and it causes a feeling of severe fatigue lasting for at least 10–20 min. That is the 'price' for its effectiveness and remarkable time efficiency.' Through personal anecdotal experience completing both HIIT and SIT training protocols, I concluded that both are taxing and requires a great deal of perceived and actual effort, however the perceived exertion during HIIT was less than SIT. The trade-off is that the intervals are longer for HIIT (~1–4 min) compared to SIT (~20–30 sec).

When determining the optimal training program we must consider a number of factors including: the goals of the program; the time required to complete training sessions; the effort of completing the training; and the health and fitness of the participant in relation to their ability and willingness to complete the exercise. Because there are distinct differences between HIIT and SIT, one protocol may be more appropriate than the other.

For practitioners to avoid confusion between these two unique training programs, we should use specific terminology to distinguish each type of training. These two logical terms would be HIIT and SIT; HIIT include intervals above anaerobic threshold up to  $VO_2$  max and last 1–4 min in duration and SIT include intervals above 150%  $VO_2$  max power and last 20–30 sec in duration. By offering a clear distinction between these two unique training protocols, we can ensure that athletes receive the specific workout that best fits their needs.

Talanian, J.L. (2015), 'Defining different types of interval training: Do we need to use more specific terminology?', in *Sports and Exercise Medicine – Open Journal* 1(5): 161–163. CC BY 4.0

## Questions

- 1 **Describe** two differences between HIIT and SIT.
- 2 Does HIIT or SIT result in quicker aerobic adaptations? **Propose** a reason why this may be the case.
- 3 **Discuss** how it is possible to work above 100%  $VO_2$  max.

## Intermediate-interval training

Intermediate-interval training aims to improve the anaerobic glycolysis system as well as anaerobic capacity and local muscular endurance. This involves activation of the anaerobic glycolysis system through efforts lasting 10–60 seconds above 85% max HR. Repeat shorter-duration efforts at this high intensity, with small rest periods, before additional repeat high-intensity efforts are called upon, will also activate this system significantly.

Sports and playing positions where repeat sprint efforts occur in quick succession over distances that activate the anaerobic glycolysis system typically use intermediate interval training. Mobile midfield players in sports such as hockey, soccer, Australian Rules football and netball, where they perform high-intensity (not necessarily maximal) efforts with little rest in between to replenish creatine phosphate (CP), are suited to this type of interval training.

### Key points of intermediate-interval training

Intensity	Above LIP (> 85% max HR)
Energy system	Anaerobic glycolysis system development
Targets	Fast-twitch fibres
Main purpose	To improve speed endurance and muscular endurance

### Command terms

#### describe

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

#### propose

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action

Examples of intermediate-interval training are shown in Table 13.05. At 1:2 and 1:3, neither example shown allows recovery for significant (> 90%) CP restoration, so activation of the anaerobic glycolysis system as the major energy supplier occurs between consecutive repetitions (reps).

**TABLE 13.05** Examples of intermediate-interval training

Swimming: 100 m butterfly (duration 50–60 s)	Athletics: 400 m (duration 45–55 s)
	
<p>6 × 50 m W = 60 s R = 120 s W:R = 1:2</p>	<p>3 sets of 6 × 300 m W = 40 s R = 120 s W:R = 1:3</p>

## Short-interval training

Short-interval training aims to improve the performance and recovery of the ATP-CP system. This involves the rapid activation of this energy system, via explosive and all-out actions (but recall that all three energy systems are contributing, even in short, high-intensity efforts). It can involve actions other than running – for example, cycling, rowing or climbing – all where short-duration, high-intensity efforts are required to succeed. Sports where repeat sprint efforts occur in quick succession typically use short-interval training.

Sprint interval training is a form of short-interval training where sprints are used as the training mode. Sometimes, short-distance **shuttle runs** make up short-interval sets, where the focus is on energy mainly coming from the CP system, and sufficient rest for this fuel to restore is a critical element. Examples of short-interval training are shown in Table 13.06.

### shuttle run

An exercise that consists of running back and forth between two points at a consistent pace

Key points of short-interval training	
Intensity	Maximal/explosive/'all-out'
Energy system	ATP-CP system development
Targets	Fast-twitch fibres
Main purpose	To improve speed, agility, and muscular power

**TABLE 13.06** Examples of short-interval training (need time to significantly replenish CP)

Athletics: 100 m	Swimming: 50 m (short course)	Speed climbing
 <p style="writing-mode: vertical-rl; transform: rotate(180deg); font-size: small;">Joe McNally/Sports Illustrated/Getty Images</p>	 <p style="writing-mode: vertical-rl; transform: rotate(180deg); font-size: small;">PCN Photography/Alamy Stock Photo</p>	 <p style="writing-mode: vertical-rl; transform: rotate(180deg); font-size: small;">alfaz77/A dobe Stock</p>
<p>4 sets of 6 × 30 m maximal sprints every 30 s                      W = 3–4 s                      R = 30 – (3 or 4 s)                      W:R = between 1:9 and 1:6</p>	<p>50 m best time = 28.5 s = 5.7 s/10 m (specificity)                      10 × 20 m at 50 m pace every 2 min                      W = 12 sec (approx.)                      R = 108 sec                      W:R = 1:9</p>	<p>3 sets of 5 × 10 s maximal arm-cranks with 3 min break                      W = 10 s                      R = 180 s                      W:R = 1:18</p>

## Advantages of interval training

Interval training is highly specific to intermittent team sports such as netball, soccer, hockey, badminton and tennis, where periods of work are followed by periods of rest.

This approach allows work of higher intensity to be performed without the same fatigue that would be experienced in a continuous session of equal intensity. For example, equal work can be achieved by completing one continuous 400-metre sprint in 70 seconds (resulting in high fatigue and low quality after 20+ seconds) or 10 repetitions of 50 metres in 7 seconds, with a 30-second passive recovery after each (lower fatigue but higher quality for each sprint/effort). Other advantages include that it:

- makes it possible to incorporate other methods of training (resistance, circuit, plyometrics) and add variety while targeting a wide range of skills, fitness components and energy systems
- allows all three energy systems to be developed during different training sessions by varying the work-to-rest ratio; and can train both aerobic and anaerobic components
- increases likelihood of completion due to variety.

### LOOKING BACK

#### Conducting an activity analysis

##### Chapter 9

An analysis of W:R with indication of work intensity is vital to gain a full understanding of key energy system involvement.

**TABLE 13.07** Major energy system being targeted by different forms of interval training

Major energy system	Possible interval training
ATP–CP	Short-interval
Anaerobic glycolysis	Intermediate-interval
Aerobic	Long-interval

Table 13.08 reveals different types of interval training that a national-level soccer player might complete during a training week.

**TABLE 13.08** Types of interval training in a training week

Type of interval training	Intensity	Work	Reps	Sets	W:R	Activities
Short-interval	Maximal	3–10 s	6–15	3	1:5+	6 × 40 m sprints with 1 min recovery or shuttle runs and obstacle sprints
Intermediate-interval	85–95% max HR	10–60 s	6–10	2	1:2 or 1:3	6 × 250 m (30 s) sprints with 90 s recovery
Long-interval	80–85% max HR	60–240 s*	2–4	2	1:1, 2:1, 3:1 etc.	3 × 1 km with 2 min recovery
HIIT	90–100% max HR	30–240 s	4–6	1+	1:1 or 2:1†	8 × 20 s sprints @ 95% max HR with 20 s active recovery @ 40% max HR

\* Work periods for long-interval must allow the aerobic energy system to take over as the major energy producer. In highly trained athletes, this can occur after about 60–70 seconds, but for those with lower levels of aerobic fitness this typically occurs at about 80 seconds.

† HIIT recovery periods can be passive (total rest) or active (same activity performed at or below 60% max HR).



## COLLABORATIVE TASK

### Prac activity

#### The effect of varying recovery periods on interval training

##### AIM

To investigate how the same work period with different rest periods alters energy system contribution to 28-metre sprints (Note: 28 metres has been chosen as this is the length of a standard basketball court.)

##### EQUIPMENT

- smart watch or stopwatch

##### METHOD

**Session 1:** 5 × 28-metre sprints (RPE 10) every 60 seconds (W:R = 1:11 approx.)

Pair up with a classmate and decide who is going to sprint the length of the basketball court first. The other person will act as the timekeeper and recorder. Practise using the 'lap' function on the smart/stopwatch, which keeps the timer going but records 'split' times within a time period. On 'Go!', the sprinter completes the first 28-metre sprint of the basketball court. When the runner crosses the end line, the partner presses 'Lap' on the timing device, which keeps recording elapsed time. The runner then stays at this end and awaits a 5-second warning before the first minute elapses and they are required to sprint back to where they started. Once again, the partner presses 'Lap'. Repeat another three times – that is, until the runner has completed five laps. Enter the lap times on the data sheet. Swap roles so the runner becomes the timekeeper and the original timekeeper now completes five sprints.

**Session 2:** 5 × 28-metre sprints (RPE 10) every 30 seconds (W:R = 1:5 approx.)

Swap back to the original roles and complete five sprints over the same distance, but this time with less rest – sprints are performed every 30 seconds. Record the data, swap roles and record another five lap times before considering the following questions.

### LEARNING HACK

It's easy to remember the major energy system being developed via any of the different interval training types:

- **short-interval**  
ATP–CP system = short duration  
**(0–10 seconds)**
- **intermediate-interval**  
anaerobic glycolysis system = medium/intermediate duration  
**(10–60 seconds)**
- **long-interval/HIIT**  
aerobic system = long duration  
**(60+ seconds).**





## RESULTS

Record each runner's times for each sprint in a table.

Session 1 (28 m sprints every 60 s)	Time	Session 2 (28 m sprints every 30 s)	Time
Sprint 1		Sprint 1	
Sprint 2		Sprint 2	
Sprint 3		Sprint 3	
Sprint 4		Sprint 4	
Sprint 5		Sprint 5	

## DISCUSSION

- 1 Which session produced the lowest decrease in sprint times? What contributed to the lowest performance decrement the most?
- 2 **Discuss** the major energy system being trained during each session and how the work-to-rest ration for repeat sprints in team sports is vital when choosing training methods.
- 3 'Quality is better than quantity' is something sports coaches often say. In relation to short- and intermediate-interval training, clearly **discuss** how this idea should be applied.

## 13.2 CHECK-IN QUESTIONS

- 1 Stevie is considering including a 3,000-metre run in a training program she is designing to improve aerobic power. **List** two advantages of breaking this up into three sets of 5 × 600-metre intervals rather than performing 3 × 1,000-metre repetitions. Both would have a W:R of 1:2.
- 2 In designing a short-interval training program for an indoor soccer player, **discuss** what needs to be considered in terms of the distances chosen, intensity of effort and rest between efforts.
- 3 **List** two advantages associated with performing an active recovery following each high-intensity effort as part of a HIIT training session.
- 4 Fartlek and HIIT both primarily train the aerobic energy system. **List** two main differences between these two types of continuous training.
- 5 **Discuss** how improving lactate tolerance via intermediate-interval training would benefit a netball centre player.



**Assessment**  
13.2 Check-in questions

### Command term

#### list

Provide a series of related words, names, numbers or items that are arranged consecutively

## 13.3 PLYOMETRIC TRAINING

In this module you will learn about:

- muscle actions that are involved in plyometric training
  - training stress/loads and associated recovery periods
  - safety considerations
- and learn to:
- design multiple plyometric activities specific to different muscle actions.

**plyometric training**

Using the stretch-shortening muscle cycle to produce more powerful contractions than had no stretch occurred beforehand

**eccentric contraction**

When muscle tension is developed while a muscle is lengthening

**concentric contraction**

When muscle tension is developed while a muscle is shortening

**potential energy**

Stored energy in any object or system because of its position or the arrangement of its parts

**kinetic energy**

Energy that is produced when an object is in motion

**myotatic reflex**

A regulating reflex that increases muscle contractility provided a stretch is within physiological limits, ensuring muscles don't stretch too far or too fast

**Plyometric training** consists of quick, powerful actions that involve rapid muscle lengthening (**eccentric contraction**) immediately followed by forceful/explosive shortening (**concentric contraction**) of the same muscle. Examples of plyometric exercises include explosive jumps, hops, bounds and skips. Plyometrics is designed to improve muscular power and force production and is commonly used in team sports where explosive and powerful movements occur, such as basketball, volleyball, netball and baseball/softball. Athletes involved in sprinting, jumping and throwing events would also benefit from plyometrics.

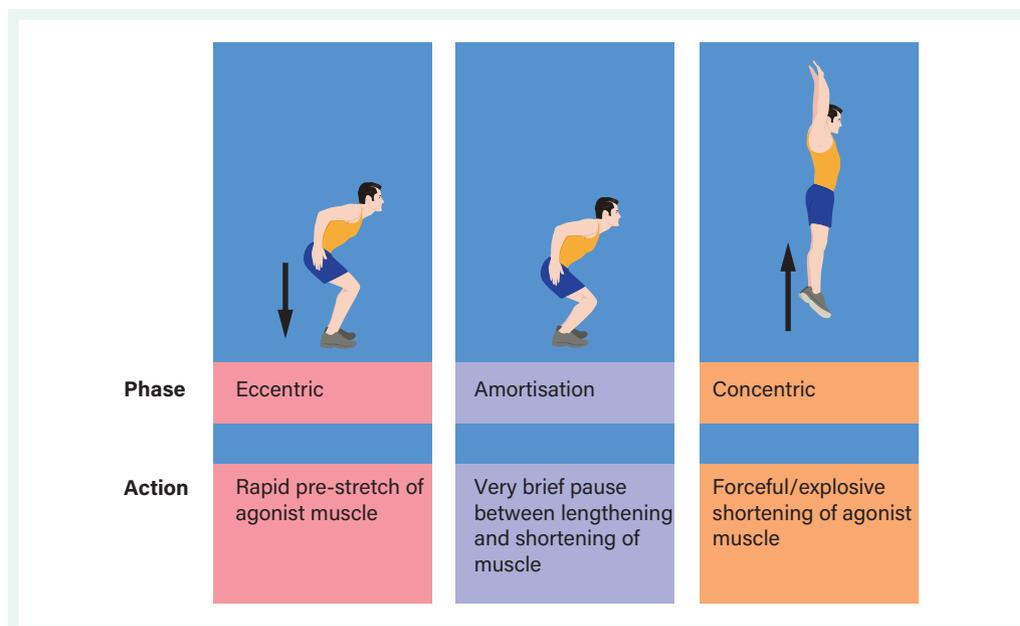
## Muscle actions used in plyometric training

The lengthening and eccentric stretching of a muscle before it is rapidly contracted produces a more powerful contraction. This pre-stretch (eccentric contraction) creates stored or **potential energy** that can be transferred immediately into **kinetic energy** (muscle contraction). Our muscles can store and transfer elastic energy. Think of an elastic band: the more you stretch it, the greater the speed with which it is going to retract. You probably do this automatically when you bend at the knees before you jump, or when you stretch backwards and create backswing before throwing an object.

A protective mechanism known as the **myotatic reflex** (stretch response) protects muscle and connective tendons from being overstretched and possibly injured. This stretch reflex stimulates a forceful opposing contraction to the stretched muscle. The greater the stretch put on a muscle (compared to its resting length) the greater the force the muscle can produce – because it recruits more motor units than when simply contracting without any prior muscle lengthening/stretching – and the greater the load the muscle can lift or overcome. The stretch reflex mechanism in muscles also produces an increase in the overall neural stimulation of the muscle, and therefore an increase in force output, via improved reaction time and neuromuscular coordination.

**LEARNING HACK**

There's no need to remember amortisation (see Figure 13.04) – just slow eccentric contraction, followed by rapid concentric contraction.



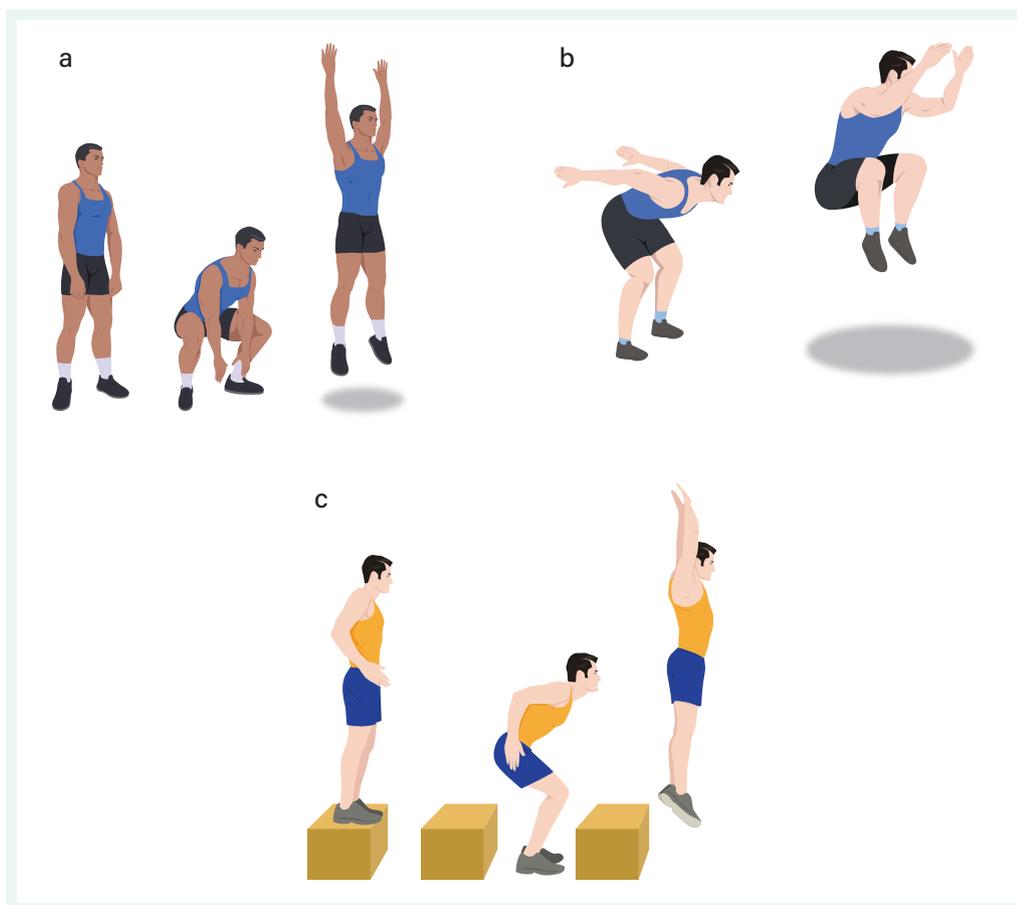
**FIGURE 13.04** The different phases of a plyometric contraction as applied to a vertical jump

Not all plyometric exercises are equal in the associated intensity and load placed on muscles. Skipping exercises, for example, are relatively low-stress, while single-leg bounds and depth jumps are high-stress. A program should progress gradually from lower-intensity drills to more advanced. If a plyometric activity has a high neuromuscular stress/load, it will require longer recovery before a repeat session can occur – for example, sessions with a rating of 4 will take twice as long to recover from as those rated 2.

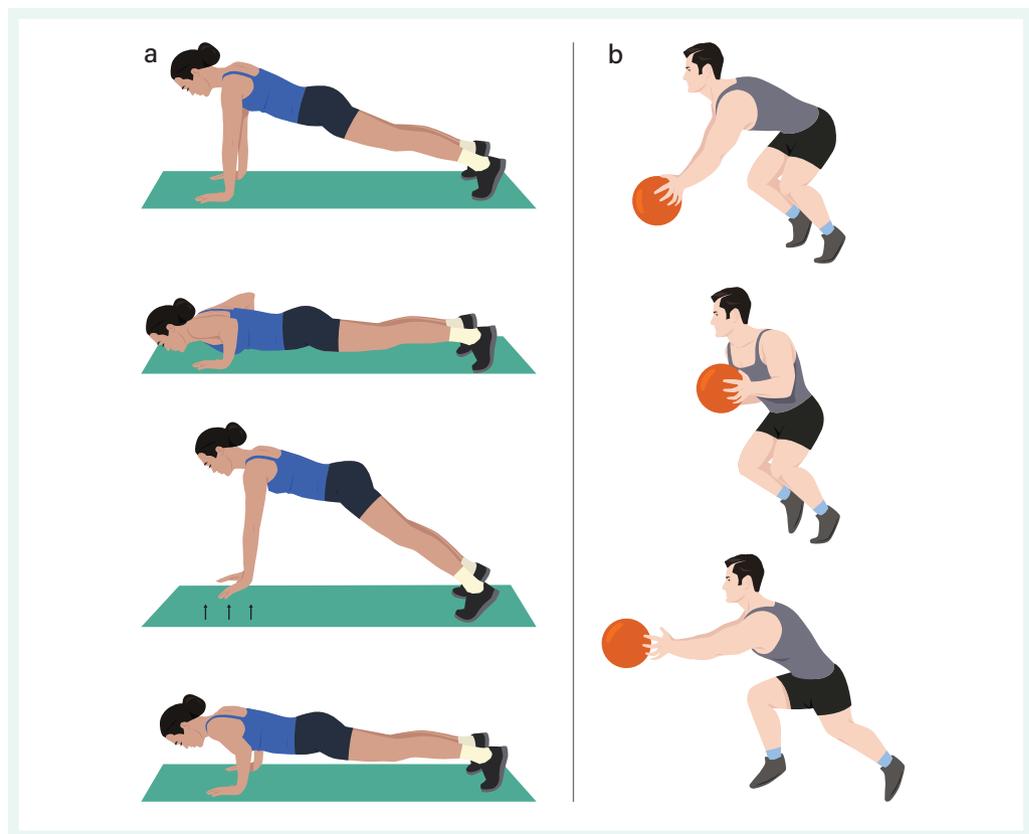
**TABLE 13.09** Plyometric demand rating scale and suggested recovery between plyometric sessions

Rating	Recovery time	Example
1 = very low stress	Recovery very rapid	Jump rope or ankle bounces or other similar low-amplitude jumps
2 = low stress	Recovery rapid (1 day required)	Tuck jump or other similar in place of jumps
3 = moderate stress	1 to 2 days for recovery	Stair jumps or similar short jumps
4 = high stress	Recovery slow (2 days required)	Hops or bounds for distance or other similar long jumps
5 = very high stress	Recovery very slow (3 days required); highest nervous-system demand	Depth jumps or other similar shock-type jumps

Source: Gambetta, V. (1998), 'Plyometrics: Myths and misconceptions'



**FIGURE 13.05** Some lower-body plyometrics that can make up specific exercises for different sporting activities such as volleyball, athletics, Australian Rules football and netball/basketball: **a** squat jumps (low intensity/load); **b** tuck jumps (moderate intensity/load); and **c** depth jumps (high intensity/load)



**FIGURE 13.06** Some upper body plyometrics that can make up specific exercises for different sporting activities such as volleyball, tennis, athletics, rugby union, etc: **a** plyo push-ups (low intensity/load); and **b** explosive-start throw/chest pass (moderate intensity/load)

## Safety considerations

Plyometrics is safe and can be used by people of all ages and ability levels provided the following guidelines are followed:

### dynamic stretching

Actively moving joints and muscles through a range of movement, usually with sports-specific motions

- Warm up using **dynamic stretches** and mobility exercises, and cool down appropriately.
- Ensure you have a strong core – this stabilises your body during plyometric movements, improves form and reduces likelihood of soft-tissue injuries.
- Adding external load (possible progression) will significantly raise the training demand. It should be noted that external loading will slow down the movement, thus negating some of the advantages of plyometric training.
- The greater the volume of training, the higher the training demand. Essentially, the volume of training can be high if the intensity of the plyometric activity is low. As a rule of thumb, the younger the athlete – in both age and stage of development – the lower the volume of plyometric activities.
- Focus on performing plyometrics with proper form and following correct technique. Fatigue can lead to poor form and increased risk of injury. Go for quality rather than quantity.
- Start with low-impact exercises and gradually progress to more challenging movements; for example, start with two-leg jumps and progress to single-leg variations.
- Wear athletic shoes with good support and cushioning to absorb the impact of jumps and landings.
- Perform plyometrics on a flat, even surface with some level of shock absorption, such as a gym floor or exercise mat.

- Allow sufficient time for recovery between plyometric workouts to prevent overuse injuries: 1–3 minutes between sets and 48 hours between sessions. Children under 12 years old should only do plyometrics twice per week, with 3–4 days recovery between sessions.
- Pay attention to any signs of pain or discomfort during plyometric exercises. If something doesn't feel right, stop the exercise immediately.
- If new to plyometrics, consult an appropriately qualified sports training/fitness professional and, if possible, ask for demonstrations and supervision/feedback during the first few sessions. Because plyometrics involves a degree of neuromuscular coordination, practise at lower intensity to develop this before attempting more complex and/or higher-intensity activities.
- Perform all plyometrics at the correct tempo – this usually means explosively and at maximal contraction speed.

## CASE STUDY

## PLYOMETRIC TRAINING

### 13 PLYOMETRIC DRILLS TO TAKE YOUR VOLLEYBALL GAME TO NEW HEIGHTS

Have you ever heard an athlete say, 'I jump too high for this game,' or 'I wish my vertical jump was a few inches shorter'? It doesn't happen, especially in volleyball – a sport where wins are determined by a team's aerial power. Those who jump the highest, hit the hardest and block the most, play the best. And, whether you're already jumping through the roof or still have countless inches to go, you can always improve your vertical jump.

To lend a coaching hand, we called in Chip Harrison, head strength and conditioning coach

for Penn State University. Harrison's plyometric-based routine – a component of his total training program – has helped the Nittany Lions women's volleyball team finish in the top three nationwide for two consecutive seasons.

Harrison provides 13 sample plyometric drills to help you maximise your leap. Each drill develops a different aspect of your jumping ability. For optimal results, perform jump training only one or two days a week in the off-season. More than twice a week can lead to injury from overtraining.

#### THE BREAKDOWN

Jump training rookies should begin with just 20–30 jumps in a single training session. Once your body adjusts to the training and you reach a point where your legs aren't sore after a workout, add more jumps per session. Advanced

training might include up to three drills and 100–150 jumps.

When you perform jump training two times a week, reduce the number of jumps in each session to avoid overtraining.

#### HARRISON'S KEY

'Your landing is always a key point in jump training. Not only do you need to land balanced, but you have to cushion the impact.'

#### CONSISTENCY AND FOUNDATION

'Be consistent with your training. Getting in a couple of days a week year round will go a long way toward making you a better athlete. A lot of athletes get to their junior or senior year and realise they should be – and should've been – training harder. At that point in your career, it's hard to catch up.'

'Being involved and working on your physical foundation is critical. You've got to be strong, you've got to be fit and you've got to be flexible to perform. When athletes develop a good foundation, they come in here way ahead of the curve.'



## VOLLEYBALL JUMP TRAINING

**1. Box jumps**

- Start with both feet together.
- Jump on top of box or other secure/elevated platform.
- Land softly and balanced.
- Step down from elevation to starting position.
- Repeat for 10–15 jumps.
- Repeat the set up to 3 more times.

**Coaching point:** Set the elevation height of the box or platform so that completing the prescribed number of jumps is challenging.

**2. Single-leg box jumps**

- Same as box jumps but off one leg.
- Adjust elevation height accordingly.
- Perform 5–10 jumps for each leg.

**Harrison's take:** 'We like box jumps because you land higher than where you take off, so there isn't a lot of impact. Reduced impact allows for more jumps per session with less recovery time.'

'With box jumps, we have each athlete jump as high as she can – regardless of her height, jumping ability or the height of the box. Jump like you're jumping over something, and then land softly.'

**3. Stadium/Stair hops**

- Find a series of stairs with about 50 steps.
- Hop two-footed up all stairs.
- Hop 1, 2 or 3 stairs at a time.
- Repeat up to 3 times.

**Coaching point:** When you're hopping with both feet, hop two steps the whole way, or one step the whole way. Don't mix it up in a single pass.

**4. Single-leg stadium/stair hops**

- Same as stadium/stair hops.
- Hop off one foot.
- Complete 10–20 hops each foot.

**Harrison's take:** 'This drill mixes it up a little bit, because you're dealing with locomotion instead of jumping in place or onto a box. You're actually travelling, so you need to maintain balance, land well and be in a specific place when you jump and land. The movements involve a kinaesthetic awareness and proprioception.'

**5. Lunge/Scissor jumps**

- Start in standard lunge position with hands on hips.
- Bend legs and lower hips until back knee almost touches floor.
- Jump as high as possible and scissor legs.

- Land with legs in opposite position: front leg switched to back.
- Repeat for 15–20 jumps.
- Repeat set up to 3 more times.

**6. Lunge/Scissor jumps (hands on head)**

- Same as lunge/scissor jumps, with hands placed on head.

**7. Lunge/Scissor jumps (swing arms)**

- Same as lunge/scissor jumps, swinging arms during jumps.

**Harrison's take:** 'There's a teaching process to this drill. Start with your hands on your hips and try to get as much as you can out of your lower body. Focus on getting deep – but not too deep – in the lunge and getting as high as you can during the jump. As you get more comfortable, progress to placing your hands on your head and then using your arms to propel yourself upward during the jump.'

**8. Broad jumps**

- Stand in gymnasium or long hallway.
- Broad jump off both feet.
- Repeat for 15–20 jumps.
- Cover as much distance as possible with each jump.
- Repeat set up to 3 more times.

**9. Broad jumps with single-leg landing**

- Same as broad jumps, but land on one foot.
- Repeat 5–6 times for each foot.

**10. Single-leg broad jump and landing**

- Same as broad jumps, but jump off and land on one foot.
- Repeat 5–6 times for each foot.

**Coaching point:** Initially, focus on a good broad jump, proper landing and then reloading for another jump. Once you master the jump and landing, eliminate the reload and jump immediately after you land: hit and go. Once you are at that point, cut down the number of jumps.

**Harrison's take:** 'The single-leg landing adds an eccentric component to the drill. You should be thinking about how well you're landing and whether you're balanced and controlled.'

**STACK says:** 'Eccentric' means that a muscle flexes and lengthens simultaneously. An example of eccentric movement is a jump landing. Your hips dip to cushion the landing, which causes your hamstrings and glutes to lengthen and flex so you don't crumble to the ground.

**11. Max jumps**

- Choose target on wall or backboard.
- Jump to target height 10–15 times.
- Repeat set up to 2 more times.

**Coaching point:** Mark your jump by putting chalk on your hand and touching the wall at the top of your jump. This provides a new target for each jump.

**Harrison's take:** 'Because you're not jumping onto or off something, this is a more natural kind of jump. You're just jumping straight up and doing the best you can. Showing a girl where her vertical used to be, and then giving her a new target, helps her jump to new heights.'

**12. Volleyball jumps**

- Choose one type of volleyball jump (approach, block, lateral block, etc.).
- Perform jump 15–20 times.
- Repeat set up to 3 more times.

**13. Volleyball combination jumps**

- Same as volleyball jumps, but perform combination of jumps in series.

**Harrison's take:** 'These jumps are most applicable to the game. You won't be successful at volleyball if you don't practise your volleyball jumps at least once a week. Your max vertical jump can go up two inches, but if you jump at the wrong time, in the wrong place or the wrong way, it doesn't do you any good – you're two inches higher in the wrong place.'

Source: 'Strength and plyometric drills with Penn State volleyball', World of Volley website, posted 22 February 2013

**QUESTIONS**

- 1 **Propose** why Harrison believes box jumps can be performed with greater frequency than depth jumps.
- 2 Harrison recommends that, once technique has been mastered for the single-leg broad jumps, subjects eliminate the 'reload' and jump again immediately on landing.
  - a Why is it important to master technique when performing plyometrics?
  - b What performance benefits may result from reducing or eliminating the 'reload' phase in plyometrics?
- 3 Why does Harrison **recommend** performing combination jumps as part of plyometric training for volleyball?

**13.3 CHECK-IN QUESTIONS**

- 1 **Propose** why upper-body plyometric exercises performed by a rugby player would be different from those selected for a volleyball player.
- 2 **©VCAA** Exam 2023, Section B, Q5 b  
A long jumper decides to complete plyometric training. **List** two safety protocols that must be adhered to when completing plyometric training.
- 3 **Justify** why sports physiologists recommend that 48 hours be the minimum recovery time between sessions when performing plyometric exercises involving the same muscle groups.
- 4 Some people might consider applying progression to plyometrics and increasing the resistance being worked against by using backpacks or ankle weights or by increasing the weight of medicine balls and other equipment being used. **Predict** why this might be counterproductive to the development of muscular power.
- 5 **©VCAA** Exam 2018, Section B, Q1 b  
**Describe** two possible plyometric exercises that the coach could use as part of the plyometric training program for European handball players.



**Assessment**  
13.3 Check-in questions

**Command term****predict**

Give an expected result of an upcoming action or event; suggest what may happen based on available information

## 13.4 RESISTANCE TRAINING

In this module you will learn about:

- types of contractions used with different types of resistance methods
- different training protocols for muscular strength, power, endurance and hypertrophy
- resistance training for health and fitness vs training adaptations and learn to:
  - apply key terms of resistance training to your own and others' programs
  - design resistance training methods to improve or maintain different fitness components.

### Command term

#### resistance training

Exercises that are performed against a resistance, including a person's own body weight, and that aim to develop muscular hypertrophy, power, strength or endurance



#### Video

In focus: Resistance training prescriptions

If you asked people what they think resistance training involves, most would say 'using weights'. **Resistance training** involves subjects working against something that resists the movement of their whole body, or of specific parts of their body (arms, legs etc.). Resistance can be provided by an external force or weight, including a person's own body weight. However, there are many different ways resistance can be applied to movements, and these include:

- free weights (dumbbells, barbells, medicine balls, kettle bells etc.) or machine weights (pin or plate loaded) – typically used in traditional weight-training activities
- hydraulic resistance machines – capable of providing maximal resistance throughout the full range of motion via isokinetic contractions
- resistance bands and tubes.

Resistance-training programs need to be individualised and to target specific goals in order to maximise the outcomes. Before starting any resistance training, it is important that a person undertake an assessment of 'readiness to train' and, in some cases, obtain medical clearance. This ensures that training is beneficial, rather than harmful, to those individuals with predisposing injuries or illnesses.

### LOOKING BACK

#### Assessment of fitness

#### Chapter 10

Pre-participation health screening is an important consideration before both fitness assessment and starting, or returning to, training.

Once an individual is deemed healthy to participate, the next step involves goal-setting through a needs analysis. Common questions that need to be addressed include:

- Are there any health or injury concerns that may limit the exercises performed or the exercise intensity?
- What type of equipment (e.g. free weights, machines, bands/tubing, medicine balls) is available?
- What is the targeted training frequency, and are there any time constraints that may affect workout duration?
- What muscle groups need to be trained? (In general, all major muscle groups are trained, but some may require prioritisation based on strengths or weaknesses or the demands of the sport or activity.)
- What are the targeted energy systems (aerobic or anaerobic)?

- What types of muscle actions (e.g. concentric [CON], eccentric [ECC], isometric [ISOM]) are needed?
- If the individual is training for a sport or activity, what are the most common body injuries?

The program goals must then be determined. Common goals of resistance training include increases in muscle size, strength, power and speed; improvements in local muscular endurance, balance, coordination and flexibility; reductions in body fat; improvements in general health (e.g. lower blood pressure, stronger connective tissue, reduced stress); and rehabilitation from injury. Most programs aim to collectively improve several of these components, in an integrated approach, as opposed to only focusing on one.

The amount of resistance and the associated speed of muscle contraction, along with the number of repetitions performed, can be varied to target the development of **muscular hypertrophy**, strength, power or endurance. There is an inverse relationship between the amount of weight lifted and the number of repetitions performed. As a rule of thumb, the resistance prescriptions in the tables on the following pages are used when trying to develop the three different fitness components, after having increased muscle size (hypertrophy) as a platform onto which to train.

It is useful to be familiar with key terms used in resistance training. These are summarised in Table 13.10.

Variable	What this means	Example
Repetition (rep)	Each single performance of an exercise	<ul style="list-style-type: none"> <li>• 1 squat = 1 rep</li> <li>• 10 squats = 10 reps</li> </ul>
Set	The number of consecutive reps performed without rest	<ul style="list-style-type: none"> <li>• 10 consecutive squats = 1 set of 10 squats</li> <li>• 10 squats + rest + 10 squats = 2 sets of 10 squats</li> </ul>
Repetition maximum (RM)	The maximum weight that can be used × the number of reps: <ul style="list-style-type: none"> <li>• 1RM = the heaviest weight that can be used once</li> <li>• 10RM = the heaviest weight that can be used 10 times</li> </ul>	If the heaviest load/weight that can be used in performing a squat once (1RM) = 100 kg and you wanted to do: <ul style="list-style-type: none"> <li>• 5 reps (5RM), then resistance = 85 kg</li> <li>• 10 reps (10RM), then resistance = 70 kg*</li> </ul>
Volume	The amount of work performed and the total weight lifted per training session: volume = weight × sets × repetitions	<ul style="list-style-type: none"> <li>• 10 repetitions of a 100 kg squat done as 3 sets:                              volume = 10 × 100 × 3 = 3,000 kg</li> <li>• 15 repetitions of a 20 kg biceps curl completed as 5 sets:                              volume = 15 × 20 × 5 = 1,500 kg</li> </ul>

\* Approximate values for RM relative to 1RM (100%) are: 2RM = 96%, 3RM = 92%, 4RM = 88%, 5RM = 85%, 6RM = 81%, 7RM = 78%, 8RM = 75%, 10RM = 70%

## DID YOU KNOW?

After building a strength base, muscular power can be targeted by performing contractions with rapid speed. Resistance needs to be light for this to occur and, if speed on contraction is reduced because of heavy loads, power will also be compromised.

### muscular hypertrophy

Increasing the thickness of muscle fibres

### LEARNING HACK

Hypertrophy is the technical term for increasing the thickness of muscle fibres. Hypertrophy training involves completing high volumes of work to cause micro-damage at muscles in order to stimulate the repair and growth required to increase muscle size. Increasing muscle fibre thickness allows muscles to generate more forceful contractions. This is a critical starting point for any resistance-training program as it provides the building blocks for developing strength and power.

**isolated exercise**

A movement that targets a specific muscle group and makes use of only one joint

**compound exercise**

A movement that uses several muscle groups collaboratively to perform movements of multiple joints

Resistance training can be varied or manipulated to target a single muscle group responsible for the movement of one joint. This is known as **isolated exercise**.

Alternatively, resistance training can target multiple muscle groups responsible for movement at more than one joint. This is known as **compound exercise**. These exercises have been shown to increase muscular strength, hypertrophy and power, so maximising performance of these exercises may be necessary for optimal gains.

**TABLE 13.11** Resistance training can focus on specific joints and associated muscles, or may involve kinetic chains, where multiple joints and muscles are trained together

Isolated resistance exercise	Compound resistance exercise
Commonly used when targeting specific joints and muscles to improve function for sports performance or rehabilitation	Commonly used when trying to replicate movement sequences from sport and using own body-weight resistance
<p><b>Examples:</b></p> <ul style="list-style-type: none"> <li>• calf raise × 65 kg pin-loaded machine</li> <li>• biceps curl × 22 kg barbell</li> <li>• lateral shoulder raise × 8 kg kettle bell</li> <li>• seated leg extension</li> </ul>	<p><b>Examples:</b></p> <ul style="list-style-type: none"> <li>• leg press × 180 kg plates on machine</li> <li>• TRX chest press</li> <li>• upright row × 45 kg dumbbells</li> <li>• medicine-ball floor slam</li> </ul>

**LOOKING BACK**

**Kinetic chains**

**Chapter 3**

**Kinetic chains** are discussed when considering biomechanical application to force summation.

**kinetic chain**

A classification system that refers to interrelated parts of the body (i.e. joints and muscles) and how they work together to perform movements. The upper kinetic chain basically consists of the spinal column, shoulder blades, shoulders, upper arms, elbows, forearms, wrists and fingers. The lower kinetic chain basically includes the spine, pelvis hips, upper legs, knees, lower legs, ankles, feet and toes.

**isometric**

A muscle action in which muscle length remains constant as force is developed; a static contraction, typically used to stabilise a joint

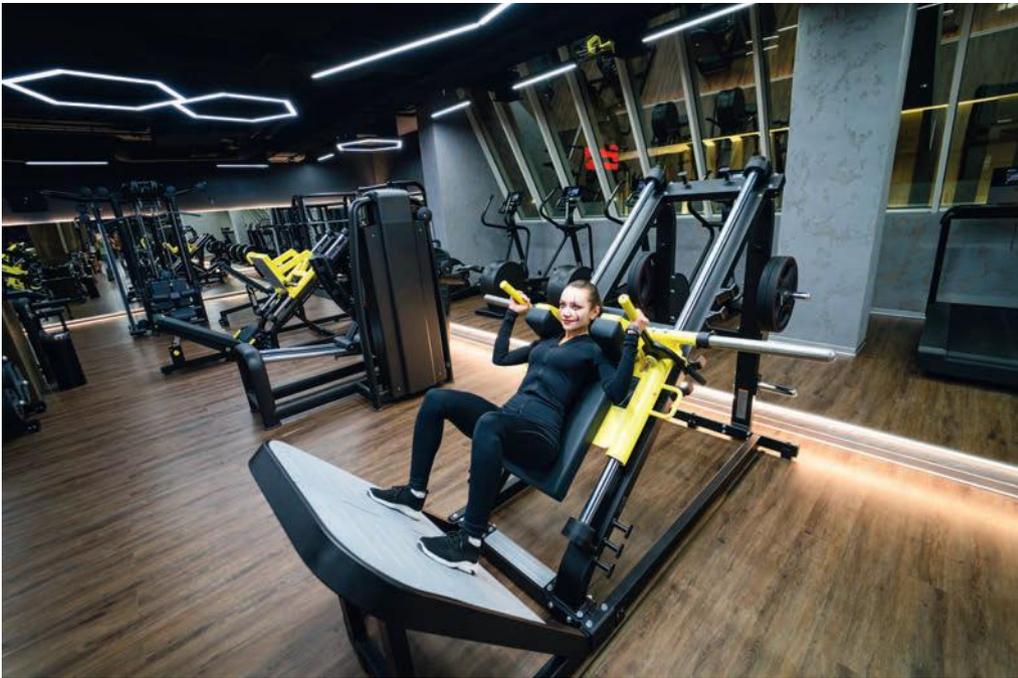
**isoinertial**

A muscle contraction that maintains a constant inertia/load throughout the range of motion

**Types of contractions**

While undertaking resistance training against one's own body weight or other forms of resistance, different types of muscle contractions can be used. These include:

- **isometric** (no movement)
  - » Tension is developed without any change in muscle length.
  - » Examples include performing wall sits and planks to develop muscular endurance.
  - » This does not mimic the actions involved in many sports settings and is used only minimally.
- **isotonic/isoinertial** (movement, which may be shortening or lengthening)
  - » Tension varies throughout the range of motion while using a constant resistance.
  - » This is the most common type of resistance training, as it more closely replicates sports movements and is relatively easy to organise.
- **eccentric** (developing tension while lengthening a muscle)
  - » Every muscle contraction is made up of two distinct phases: concentric and eccentric.
  - » The concentric phase is when you contract the target muscle (e.g. the quads in the squat and the biceps in the curl).
  - » The eccentric phase is when you lengthen that muscle (e.g. by lowering a weight).
  - » Emphasising the eccentric phase in most exercises can significantly enhance muscle growth, perhaps to an even greater degree than the concentric phase.



Tereyuk/Shutterstock.com

**FIGURE 13.07** An isoinertial machine for knee flexion (hamstrings) and extension (quadriceps)

### DID YOU KNOW?

Another type of contraction (not included in the VCE Physical Education Study Design) is isokinetic (controlled movement). It involves a muscle contraction where the velocity remains constant while the length of the muscle changes.

- Tension is maximal throughout the whole range of motion.
- This leads to the greatest improvements in power, strength and endurance, but is relatively difficult to organise because it relies on specialised hydraulic machines to keep contraction speeds constant.
- Another disadvantage is that the movements often do not replicate those seen in sporting situations.

Isokinetic exercises are better than other forms of muscle contractions used in resistance training because the resistance is maximal throughout the whole range of motion, rather than peaking for only a few degrees within the range, as is the case for other types of contraction.

## Different training protocols for muscles

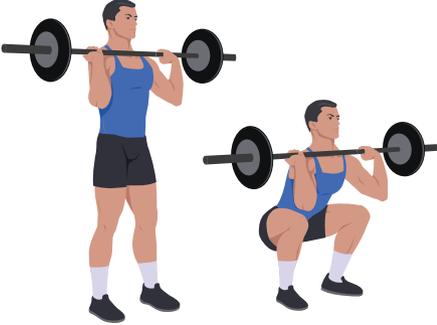
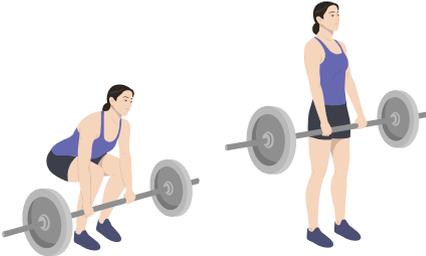
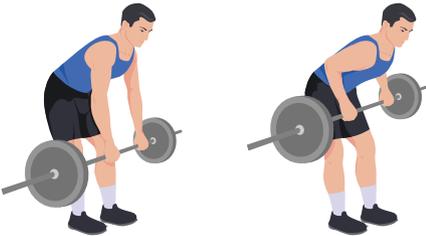
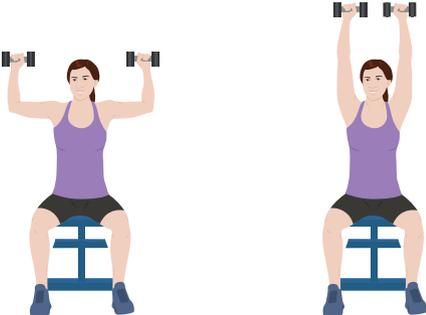
### Muscular hypertrophy

Muscular hypertrophy is the enhancement of muscle size before focusing on muscular strength, muscular power or muscular endurance.

When thinking about the most appropriate resistance protocols to use in resistance training programs, a person's training status is sometimes taken into consideration. A novice will most likely struggle with the training loads and volumes suggested for someone more experienced who is undertaking a more advanced program. These differences have been presented throughout this section on resistance training in an effort to provide strong links to the training principle of individualisation. Students undertaking VCE Physical Education will be required to learn and apply a set of resistance training protocols that appear in Table 13.16 on page 529.

Load	60–80% 1RM for novice to intermediate; 70–100% for advanced
Volume	1–3 sets of 8–12 repetitions for novice to intermediate; 3–6 sets of 1–12 repetitions for advanced
Rest period	2–3 min between higher-intensity exercises that use heavier loads; 1–2 min between lower-intensity exercises with light loads

**TABLE 13.12** Sample hypertrophy exercises

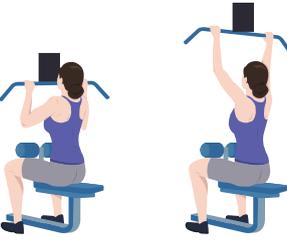
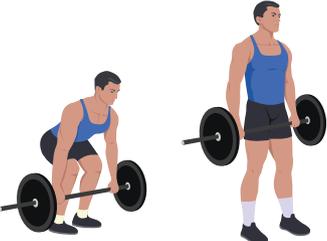
Exercise	Prescription
<b>Squat</b> 	3 × 10 × 80% 1RM
<b>Deadlift</b> 	3 × 8 × 85% 1RM
<b>Barbell row</b> 	3 × 10 × 75% 1RM
<b>Shoulder press</b> 	4 × 8 × 85% 1RM

## Muscular strength

Muscular strength is the ability of a muscle or muscle group to exert a maximal external force. This type of training is characterised by heavy loads with low repetitions. It is also important to provide muscles with sufficient time to fully recover in order to be able to exert maximal force for the next set.

Load	60–80% 1RM for novice to intermediate; 80–100% for advanced
Volume	1–3 sets of 8–12 repetitions for novice to intermediate; 2–6 sets of 1–8 repetitions for advanced
Rest period	2–3 min for higher-intensity exercises that use heavier loads; 1–2 min between lower-intensity exercises with light loads

**TABLE 13.13** Sample strength exercises

Exercise	Prescription
<b>Leg press</b> 	3 × 3 × 90% 1RM
<b>Lat pull-down</b> 	3 × 5 × 95% 1RM
<b>Bench press</b> 	3 × 5 × 85% 1RM
<b>Deadlift</b> 	3 × 5 × 90% 1RM

## Muscular power

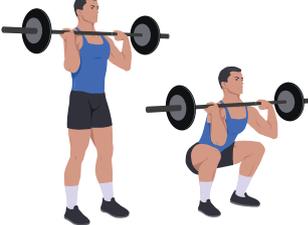
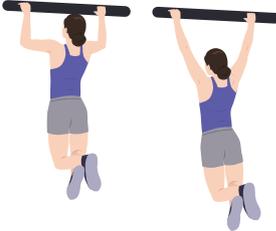
Muscular power is the highest power output attainable during a particular movement. There are many ways to train for power, including concentric and eccentric exercises, plyometrics and isokinetic exercises. Power development needs speed and is characterised by rapid and explosive muscular contractions. Simply put:

$$\text{power} = \text{force} \times \text{velocity}$$

For optimal improvements in muscular power, a light load of 30–60% of 1RM should be used for 3–6 repetitions over one to three sets per exercise.

Load	30–70% 1RM
Volume	1–3 sets of 3–6 repetitions per exercise for novice to intermediate; 3–6 sets of 1–6 repetitions for advanced
Rest period	2–3 min between higher-intensity exercises that use heavier loads; 1–2 min between lower-intensity exercises with light loads

**TABLE 13.14** Sample power exercises

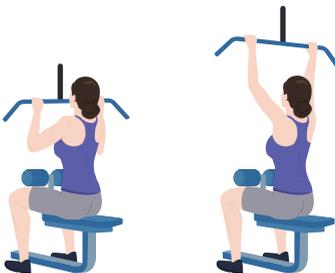
Exercise	Prescription
<b>Bent-over row</b> 	4 × 10 × 35% 1RM
<b>Squat</b> 	3 × 12 × 40% 1RM
<b>Wide grip pull-up</b> 	4 × 8 × own body weight
<b>Leg press</b> 	3 × 10 × 45% 1RM

## Muscular endurance

Muscular endurance is the ability of a muscle or a muscle group to repeatedly exert a submaximal force. Muscular endurance aims to make muscles more 'fatigue resistant' and is developed by using low–medium loads with high repetitions.

Load	40–70% of 1RM for novice to intermediate; 30–80% for advanced
Volume	2–4 sets of 10–15 repetitions for novice to intermediate; multiple sets of 10–25+ repetitions for advanced
Rest period	1–2 minutes between sets

**TABLE 13.15** Sample endurance exercises

Exercise	Prescription
<b>Modified push-up</b> 	3 × 20
<b>Bench press</b> 	4 × 15 × 45% 1RM
<b>Lat pull-down</b> 	4 × 30 × 30% 1RM
<b>Leg press</b> 	3 × 30 × 30% 1RM

**TABLE 13.16** Resistance training protocols

	Frequency	Intensity/load (% 1RM)	Repetition range	Set range	Tempo	Rest
Muscular strength	3 × per week	80–100	1–6	3–6	Slow	2–3 min
Muscular power	3 × per week	30–70	3–10	3–6	As fast as possible	2–3 min
Local muscular endurance	3 × per week	40–60	15–25	3–6	Moderate	1 min

Source: VCAA

# Health and fitness benefits of resistance training

## REAL WORLD APPLICATIONS

### Resistance training for health and fitness



ACSM Information On...

## Resistance Training for Health and Fitness

Resistance training is a form of physical activity that is designed to improve muscular fitness by exercising a muscle or a muscle group against external resistance. There are many positive health outcomes of resistance training.

#### A COMPLETE PHYSICAL ACTIVITY PROGRAM

A well-rounded physical activity program includes aerobic exercise and strength training exercise, but not necessarily in the same session. This blend helps maintain or improve cardiorespiratory and muscular fitness and overall health and function. Regular physical activity will provide more health benefits than sporadic, high intensity workouts, so choose exercises you are likely to enjoy and that you can incorporate into your schedule.

ACSM's physical activity recommendations for healthy adults, updated in 2011, recommend at least 30 minutes of moderate-intensity physical activity (working hard enough to break a sweat, but still able to carry on a conversation) five days per week, or 20 minutes of more vigorous activity three days per week. Combinations of moderate- and vigorous-intensity activity can be performed to meet this recommendation.

Examples of typical aerobic exercises are:

- Walking
- Running
- Stair climbing
- Cycling
- Rowing
- Cross-country skiing
- Swimming.

In addition, strength training should be performed a minimum of two days each week, with 8-12 repetitions of 8-10 different exercises that target all major muscle groups. This type of training can be accomplished using body weight, resistance bands, free weights, medicine balls or weight machines.

#### RESISTANCE TRAINING BENEFITS EVERYONE!

As we age we tend to lose lean muscle mass, which is a condition known as sarcopenia. Resistance training helps maintain and combat the loss of muscle mass by increasing muscular fitness. This form of training can also prevent osteoporosis by augmenting bone mineral density. What's more? Regular resistance training can decrease the risk of heart disease by lowering body fat, decreasing blood pressure, improving cholesterol, and lowering the stress placed on the heart while lifting a particular load. Improving muscular fitness is very important for enhancing quality of life.

#### VARIOUS TYPES OF RESISTANCES

Resistance training can be accomplished with traditional free weights and dumbbells, weight machines, body weight, elastic tubing, medicine balls, or even common household products like milk jugs filled with sand or soup cans. The choice to incorporate a certain type of resistance depends on level of physical fitness, how familiar a person is with specific exercise movements, and individual goals. For example, low fit individuals can focus primarily on machine-based exercises as they have been regarded as safer to use compared to more complex free weight

exercises. The incorporation of free weight movements can be performed as a person increases his or her muscular fitness. For example, advanced individuals can perform multiple sets and heavier resistances using multiple-joint exercises, such as squats and deadlifts. Whichever form of resistance is chosen, multiple-joint, large muscle group exercises should be performed before single-joint, smaller group exercises.

#### RESISTANCE TRAINING GUIDELINES AND EXERCISES

The American College of Sports Medicine (ACSM) recommends that a strength training program should be performed a minimum of two non-consecutive days each week, with one set of 8 to 12 repetitions for healthy adults or 10 to 15 repetitions for older and frail individuals. Eight to 10 exercises should be performed that target the major muscle groups.

Examples of typical resistance exercises that can be performed using free-weights, machines, or body weight for the major muscle groups are:

	Free-Weight	Machine-Based	Body Weight
Chest	Sapine Bench Press	Seated Chest Press	Push-ups
Back	Beit-over Barbell Rows	Lat Pulldown	Pull-ups
Shoulders	Dumbbell Lateral Raise	Shoulder Press	Arm Circles
Biceps	Barbell/Dumbbell Curls	Cable Curls	Reverse Grip Pull-ups
Triceps	Dumbbell Kickbacks	Pressdowns	Dips
Abdomen	Weighted Crunches	Seated "Abs" Machine	Crunches, Prone Planks
Quadriceps	Back Squats	Leg Extension	Body Weight Lunges
Hamstrings	Stiff-leg Deadlifts	Leg Curls	Hip-ups





ACSM stresses the importance of progressing resistance training programs to meet specific resistance training goals. Progression in resistance training is defined as “the act of moving forward or advancing toward a specific goal over time until the target goal has been achieved.” This can occur with specific trainable characteristics of muscular fitness, such as strength, power, hypertrophy, and local muscular endurance. These four factors will improve with almost any properly designed resistance training program, but will be fully enhanced by properly modifying the load, volume, rest period between sets, and the frequency of each workout. The load is the amount of weight lifted in a given set, which is based on a percentage of the 1-repetition maximum (1RM). The volume is the total number of exercises, repetitions, and sets that are performed in a given exercise session. Rest period is the time period between each set and exercise. Frequency refers to the number of exercise sessions per week. How to manipulate each of these for the optimal enhancement of strength, power, hypertrophy, or muscular endurance is described below.

**MUSCULAR STRENGTH**

Muscular strength is the ability of a muscle or muscle group to exert a maximal external force.

- Load: 60-70% 1RM for novice to intermediate; 80-100% for advanced
- Volume: 1-3 sets of 8-12 repetitions for novice to intermediate; 2-6 sets of 1-8 repetitions for advanced
- Rest period: 2-3 min for higher intense exercises that use heavier loads; 1-2 minutes between the lower intense exercises with light loads

**MUSCULAR POWER**

Power is defined as the optimal amount of work performed in a given time period. Muscular power is the highest power output attainable during a particular movement, and is required in activities of daily living, sport, and work. For optimal improvements in muscular power, a light load of 0 to 60% of 1RM should be used for 3-6 repetitions over one to three sets per exercise.

- Load: 30-60% 1RM for upper body exercises; 0-60% 1RM for lower body exercises
- Volume: 1-3 sets of 3-6 repetitions per exercise
- Rest period: 2-3 min for higher intense exercises that use heavier loads; 1-2 minutes between the lower intense exercises with light loads

**MUSCULAR HYPERTROPHY**

Muscular hypertrophy is the enhancement of muscle size.

- Load: 70-85% 1RM for novice to intermediate; 70-100% for advanced
- Volume: 1-3 sets of 8-12 repetitions for novice to intermediate; 3-6 sets of 1-12 repetitions for advanced
- Rest period: 2-3 min for higher intense exercises that use heavier loads; 1-2 minutes between the lower intense exercises with light loads

**MUSCULAR ENDURANCE**

Local muscular endurance is the ability of a muscle or a muscle group to repeatedly exert a submaximal resistance.

- Load: lower than 70% of 1RM
- Volume: 2-4 sets of 10-25 repetitions
- Rest period: 30 seconds to 1-minute between each set

**FREQUENCY**

For all the above, it is recommended that novice individuals train the entire body 2-3 days per week. Intermediate individuals should train 3 days if using a total-body workouts or 4 days if using an upper/lower body split routine, training each major muscle group twice per week. Advanced lifters can train 4-6 days per week, training each major muscle group once to twice per week. At this level, muscle group split routines of one to three muscle groups trained per workout are common since this would allow a higher volume per muscle group. Elite weightlifters and body-builders may benefit from using very high frequencies such as, two workouts per day for 4-5 days per week.

**OVERTRAINING**

To reduce the risk of overtraining, a dramatic increase in volume should be avoided. It is recommended that a 2-10% increase in the load be applied when the individual can comfortably perform the current workload for one to two repetitions over the desired number on two consecutive training sessions.

**STAYING ACTIVE PAYS OFF!**

Those who are physically active tend to live longer, healthier lives. Research shows that moderate physical activity – such as 30 minutes a day of brisk walking – significantly contributes to longevity. Even a person with risk factors like high blood pressure, diabetes or even a smoking habit can gain real benefits from incorporating regular physical activity into their daily life.

As many dieters have found, exercise can help you stay on a diet and lose weight. What's more – regular exercise can help lower blood pressure, control blood sugar, improve cholesterol levels and build stronger, denser bones.

**THE FIRST STEP**

Before you begin an exercise program, take a fitness test, or substantially increase your level of activity, make sure to answer the following questions. This physical activity readiness questionnaire (PAR-Q) will help determine if you're ready to begin an exercise routine or program.

- Has your doctor ever said that you have a heart condition or that you should participate in physical activity only as recommended by a doctor?
- Do you feel pain in your chest during physical activity?
- In the past month, have you had chest pain when you were not doing physical activity?
- Do you lose your balance from dizziness? Do you ever lose consciousness?
- Do you have a bone or joint problem that could be made worse by a change in your physical activity?
- Is your doctor currently prescribing drugs for your blood pressure or a heart condition?
- Do you know of any reason you should not participate in physical activity?

If you answered yes to one or more questions, if you are over 40 years of age and have recently been inactive, or if you are concerned about your health, consult a physician before taking a fitness test or substantially increasing your physical activity. If you answered no to each question, then it's likely that you can safely begin exercising.

**PRIOR TO EXERCISE**

Prior to beginning any exercise program, including the activities depicted in this brochure, individuals should seek medical evaluation and clearance to engage in activity. Not all exercise programs are suitable for everyone, and some programs may result in injury. Activities should be carried out at a pace that is comfortable for the user. Users should discontinue participation in any exercise activity that causes pain or discomfort. In such event, medical consultation should be immediately obtained.



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**TABLE 13.17** Resistance training summary: developing muscular power, strength or endurance requires the load and the repetitions to be varied, with different recommended rest periods.

Fitness component	Focus	Resistance prescription
Hypertrophy	Enhancement of muscle size to then target strength, power or endurance	<ul style="list-style-type: none"> <li>• Medium–high loads with medium reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, isometric, concentric</li> <li>• 1–2 min between sets and exercises</li> </ul>
Strength	Manoeuvring high loads	<ul style="list-style-type: none"> <li>• Heavy (close to maximal) loads with low reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, isometric, concentric</li> <li>• 3–5 min between sets and 1–3 min between exercises</li> </ul>
Power	Generating maximal force explosively	<ul style="list-style-type: none"> <li>• Medium loads with medium reps (at speed)</li> <li>• Multi-joint</li> <li>• Eccentric, concentric</li> <li>• 5 min between sets and 1–3 min between exercises</li> </ul>
Endurance	Sustained force over time	<ul style="list-style-type: none"> <li>• Low–medium loads with high reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, concentric</li> <li>• 1–2 min between sets and exercises</li> </ul>



## ABOVE AND BEYOND THE STUDY DESIGN

Resistance training recommendations for various levels, page 545



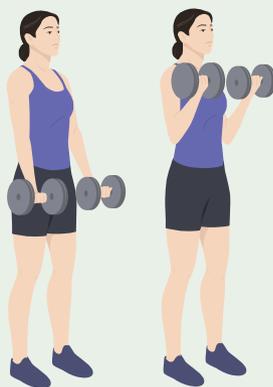
### Assessment

13.4 Check-in questions

## 13.4 CHECK-IN QUESTIONS

- 1 After considering the following resistance prescription, decide which component of fitness is being targeted: 4 × 15 chin-ups (own body weight) with 2 minutes rest between sets.
- 2 **a Justify** why isokinetic contractions used with hydraulic machines are associated with the largest increases in muscular strength, power and endurance.  
**b List** two limitations of using hydraulic machines as part of a resistance-training program.
- 3 The following are examples of resistance exercises performed to isolate the biceps muscle:

Standing biceps curl



'Preacher' biceps curl





While they both target the biceps, **discuss** why these exercises might not be as effective in developing muscular strength required in a sporting situation.

4 ©VCAA Exam 2020, Section B, Q7 c

An example of a training program designed to improve muscular strength is shown below:

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
weighted circuit	resistance training		weighted circuit	resistance training		cycling
85% of 1RM fixed reps = 6 4 rotations 40 s rest between each station 8 stations, all lower-body exercises	85% of 1RM maximum reps 4 sets 10 s rest between each set all lower-body exercises		85% of 1RM fixed reps = 6 4 rotations 40 s rest between each station 8 stations, all lower-body exercises	85% of 1RM maximum reps 4 sets 10 s rest between each set all lower-body exercises		65% HR max 20 min

**Key**

reps – repetitions                      RM – repetition maximum                      s – seconds

Using the FITT principles (frequency, intensity, time and type), **evaluate** the effectiveness of this training program in improving lower-body muscular strength. Use specific examples from the training program to support your response.

**Command terms**

**evaluate**

Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information

## 13.5 CIRCUIT TRAINING

In this module you will learn about:

- different types of circuit training methods
- advantages and disadvantages of circuit training and learn to:
- incorporate different work-to-rest periods and methods into circuit training in order to achieve specific outcomes.

**Circuit training** consists of a series of exercises (usually 10) designed to target specific fitness components identified in the games analysis. It can incorporate parts of other training methods and may include:

- plyometric activities
- resistance activities (own body weight and weights)
- flexibility exercises.

Circuit training is similar to interval training in that, once a particular exercise is completed at an exercise 'station', the subject moves on to the next station to complete another activity. The rest between stations, and hence the recovery from each activity, can be manipulated to mirror that collected from the games analysis. Similarly, it can be set to train the major energy

**circuit training**

Training that involves performing a variety of different exercises (between five and 15), with recovery/transition periods between each, that target different muscle groups and fitness components. The completion of all these exercises makes up a single circuit, which may be repeated one or more times.

system performers require. If it is important for creatine phosphate restoration to occur, thus enabling greater contribution from the ATP-CP system, rest and transition periods between stations should be employed. This might require 1–2 minutes of recovery, depending on the work period. However, if the anaerobic glycolysis system is the focus of the circuit session, the rest periods between stations might be as short as 15–20 seconds.

Typically, the exercise/activity stations are arranged so that body parts and major muscle groups have adequate recovery before being called upon again – for example, an upper-body exercise would be followed by a lower-body exercise or one involving core muscles. However, it is also possible to have consecutive stations call upon the same muscle group if the aim is to develop muscular endurance or anaerobic capacity.

Table 13.18 lists some sample circuit activities that might be included by a volleyball player targeting different muscles and actions, and Figure 13.09 sets out a circuit that might be used by netballers.

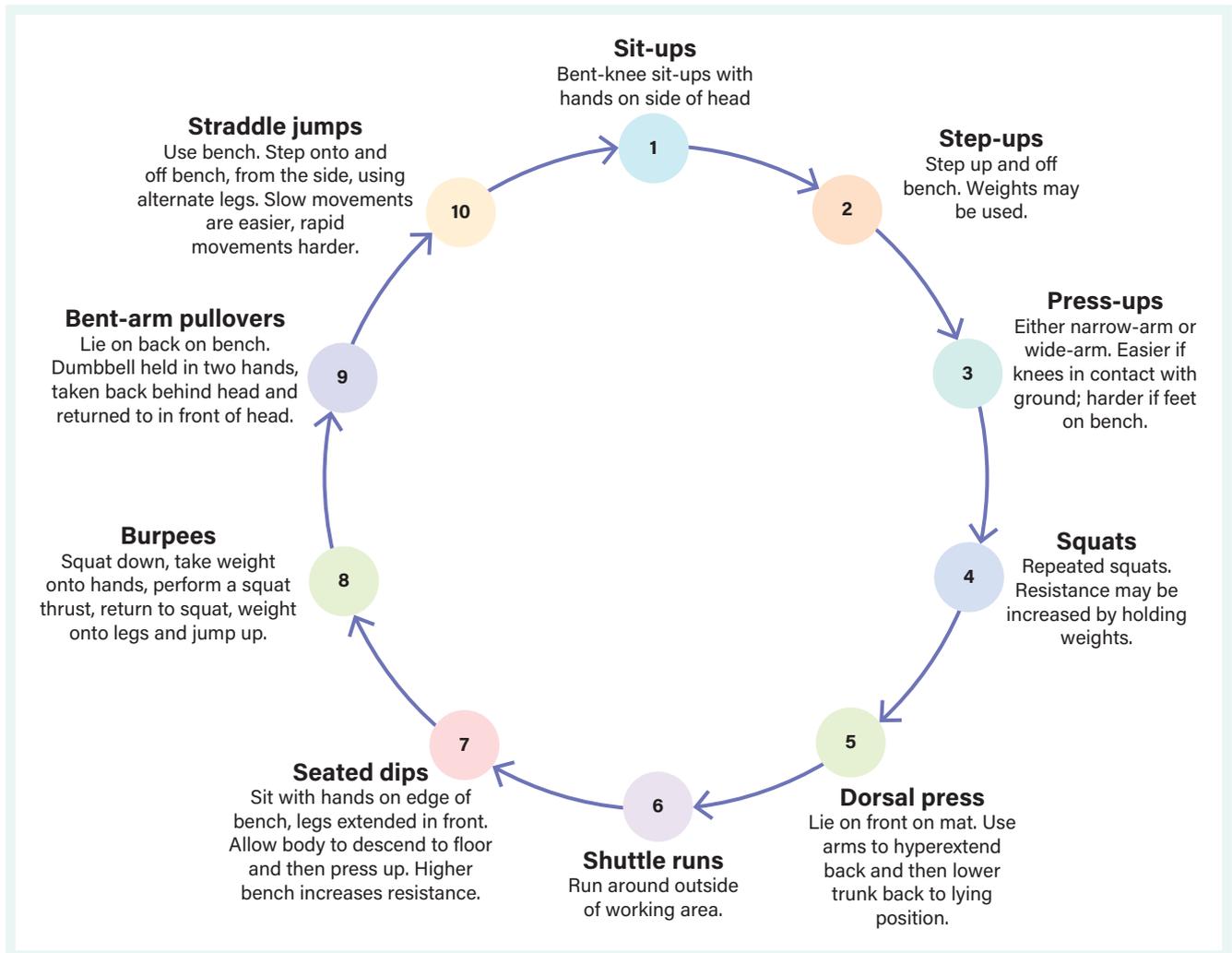
**TABLE 13.18** Circuit exercises focusing on different body parts and major muscle groups

Upper body	Lower body	Connected and coordinated	Locomotion	Core
<ul style="list-style-type: none"> <li>• push-ups</li> <li>• dips</li> <li>• modified chin-ups</li> </ul>	<ul style="list-style-type: none"> <li>• single-leg squats</li> <li>• step-ups</li> <li>• lunges</li> </ul>	<ul style="list-style-type: none"> <li>• box jumps</li> <li>• mountain climbers</li> <li>• single/double skipping</li> </ul>	<ul style="list-style-type: none"> <li>• front-to-back cone hops</li> <li>• half-court sprints</li> <li>• stair sprints</li> </ul>	<ul style="list-style-type: none"> <li>• front or side planking</li> <li>• V-sits</li> <li>• Russian twists</li> </ul>

Isaac Lawrence/AFP/Getty Images



**FIGURE 13.08** Volleyball players need to develop multiple fitness components to be successful. This can easily be achieved via circuit training.



**FIGURE 13.09** An example of a 10-station circuit for netball

Source: www.brianmac.co.uk

## Different types of circuit training

The three types of circuit training that are commonly used are:

- individual-load – which is highly specific and tailored to individual needs
- fixed-load – where resistance is provided by weights or the performer's own body
- fixed-time – in which as many exercises as possible are performed in a set time period.

For ease or convenience of set-up and participation in circuit training, fixed-load and fixed-time options are more commonly used for large group training, whereas individual-load circuits tend to involve one or two people working out together. Typically, the 'rest' period is used to adjust the load for the next person performing the activity, to cater for their training status and current fitness level.

### Individual-load circuits

Individual-load circuit training considers individual strengths and weaknesses, and different requirements/loads are set at each station. This typically takes place in a gym, and often the rest periods in between exercises are longer than in fixed-load or fixed-time circuits, while loads are being adjusted.

**TABLE 13.19** Examples of individual-load exercises – note the different focus on muscular power, strength and endurance achieved by changing the load and the repetitions.

Exercise station	Load and repetition	Focus
1 Triceps extension	10 kg × 10 (fast)	Muscular power
2 Squats	65 kg × 15	Muscular endurance
3 Lateral medicine-ball wall slams	8 kg × 12	Core/muscular strength
4 Seated dumbbell 'pec-flys'	27 kg × 6 (slow)	Muscular strength
5 Calf raises	82 kg × 15	Muscular endurance
6 Single arm cable pullover	14 kg × 10 (fast)	Muscular power

## Fixed-load circuits

In a fixed-load circuit, the subject completes a certain number of repetitions of an exercise within a set time. The load is 'fixed' by their own body weight; or, if using weights/machines, it is usually set so the person with the lowest fitness rating can perform a minimum of 10 repetitions. If subjects complete the number within the time limit, they have longer to rest before the next exercise/station. In some cases (e.g. push-ups, skipping, bench, depth jumps) their own body weight provides the resistance, whereas in other cases, weights are used.

**TABLE 13.20** Examples of fixed-load exercises, where everyone performs the same exercise and load for a given time

Exercise station	
1 Push-ups	<ul style="list-style-type: none"> <li>• 20 s work : 70 s rest</li> <li>• W:R = 1:3.5</li> <li>• Focus = muscular endurance</li> <li>• New exercise every 90 s</li> </ul>
2 Double skips	
3 Medicine ball sit-ups (5 kg)	
4 Lunges holding 20 kg dumbbells	
5 Kettle bell 'push press' (8 kg)	
6 Depth jumps	

## Fixed-time circuits

When completing a fixed-time circuit, subjects use their own body weight to provide the resistance/load to work against, for a set time, and do as many repetitions as they can.

**TABLE 13.21** Examples of fixed-time exercises

Exercise station	
1 Clap push-ups	<ul style="list-style-type: none"> <li>• 20 s work: 40 s rest</li> <li>• W:R = 1:2</li> <li>• Focus = muscular endurance</li> <li>• New exercise every minute</li> <li>• More likely to complete more lateral hops than other exercises – why?</li> <li>• Modified chin-ups chosen to ensure a certain number can be performed – otherwise no value including in circuit!</li> </ul>
2 Double leg bench blasts	
3 Dips	
4 Lunges	
5 Modified chin-ups	
6 Lateral hops	

### DID YOU KNOW?

A meta-analysis on resistance circuit-based training concluded that it results in a significant reduction in fat mass (by an average of 4.3%) and greatly increases muscle mass (by an average of 1.9%) and upper- and lower-body strength (on average, by 20.0% and 23.0%, respectively).

# Advantages and disadvantages of circuit training

Table 13.22 summarises the pros and cons associated with circuit training.

**TABLE 13.22** Advantages and disadvantages of circuit training

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>Targets multiple fitness components during single sessions</li> <li>Develops aerobic and anaerobic energy systems during the same session – note greater percentage anaerobic improvements</li> <li>Cost-effective, as minimal equipment and space is required – especially if using own body weight</li> <li>Time-effective – up to a third quicker than traditional resistance and continuous training programs</li> <li>High variability/variety promotes increased engagement and adherence to training</li> <li>Many can participate in a small area at the same time</li> </ul>	<ul style="list-style-type: none"> <li>Fixed-time and fixed-load are ‘generalised’ and not specific to individual levels of development</li> <li>ATP–CP system training requires longer rest periods – can extend duration of session</li> <li>Not effective at significantly improving muscular strength or aerobic capacity</li> </ul>

## COLLABORATIVE TASK

### Prac activity

#### Designing a sport-specific circuit program

##### METHOD

With a classmate, select a sport you are familiar with (you both know the major skills, movements and likely major energy system). Your aim is to design a 10-station fixed-time circuit to train the various components you have identified as being important to the sport and entered in the table below. Try to each come up with a different circuit exercise for each fitness component.

##### RESULTS

Sport: \_\_\_\_\_

Fitness component	Evidence of component from actions/skills performed	Possible circuit exercise(s)
Speed		
Agility		
Muscular power		
Muscular endurance		
Muscular strength		
Aerobic power		
Anaerobic capacity		
Flexibility		

##### DISCUSSION

- 1 Discuss the rationale behind the sequencing of body parts and stations.
- 2 Justify the inclusion of external weights for any of your chosen exercises.
- 3 What influenced your decision on how long each exercise was performed for and how much rest to have between exercises/stations?





- 4 List three different ways in which progression could be applied to the circuit you have designed.
- 5 Swap your program with another pair in your class and ask them to give feedback on:
  - specificity
  - duration
  - recovery.



#### Assessment

13.5 Check-in questions

### 13.5 CHECK-IN QUESTIONS

- 1 **Discuss** two reasons why players involved in team sports often perform circuit training.
- 2 If you were designing a circuit program for a person just starting training, what advantages would be gained by using an individual-load format based on their pre-test results rather than using a fixed load circuit?
- 3 'Cardio' circuits have become popular for people wanting to train multiple fitness components as well as develop aerobic fitness. Research and report back to a classmate on the typical intensity of exercise and recovery between stations – **list** any differences between this format and that which would be used if the focus was more on developing muscular power.
- 4 Fig 13.09 has stations 7, 8 and 9 all involving use of the upper arm muscles in performing the different exercises. **Discuss** why this might be the case.

## 13.6 FLEXIBILITY TRAINING

In this module you will learn about:

- benefits of flexibility training
- different types of flexibility training methods that can be used
- flexibility training before vs after the main training bout  
and learn to:
  - select flexibility methods and activities that are relevant and specific to game demands.

Flexibility training focuses on improving the range of motion at a joint or series of related joints, and involves exercises that stretch the muscles, tendons and ligaments in and around a joint. Flexibility training can occur before or after other forms of training, depending on what it is aiming to achieve. If conducted before any training or performance, a thorough warm-up needs to be performed to ensure increased blood flow and muscle temperature along with decreased joint viscosity and resistance.

### The benefits of flexibility training

Increased flexibility will lead to better performance by:

- increasing the range of motion with lower associated risk of injury
- improving mobility/agility and contributing to faster directional changes and lunges/ stretches to get to difficult positions
- reducing muscle tightness and correcting imbalances resulting from overuse of dominant muscle groups
- improving neuromuscular coordination and fluency/efficiency of movements.

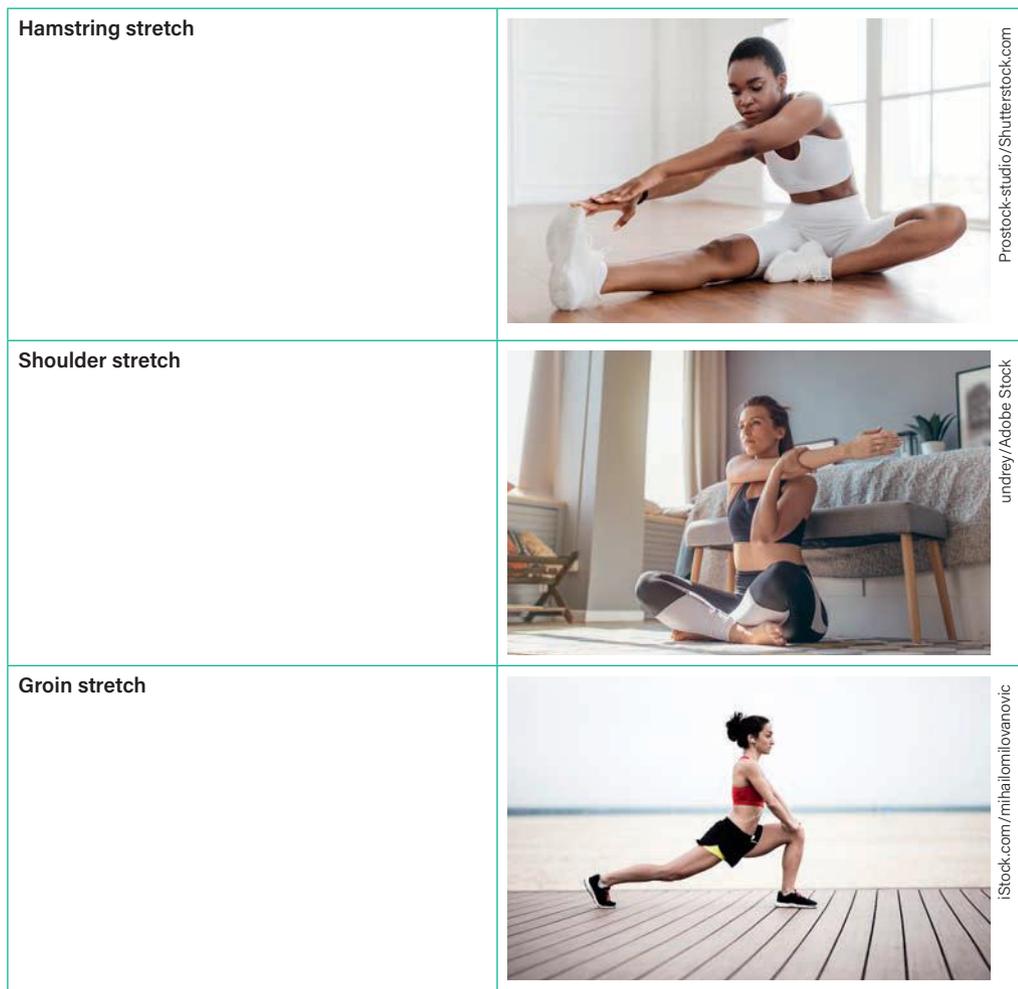
## Types of flexibility training

There are essentially four types of flexibility training:

- static (passive) flexibility training
- proprioceptive neuromuscular facilitation (PNF)
- dynamic stretching
- ballistic stretching.

### Static flexibility training

Static flexibility training involves stretching body parts and muscles through a full range of motion and then holding them in this position, typically for 10–20 seconds. This is probably the type of flexibility training most students are familiar with, and has traditionally been used during both warm-ups and cool-downs in PE classes, sports and training sessions. Examples include those shown in Figure 13.10.



**FIGURE 13.10** Examples of static stretches

Another form of static stretching is known as ‘passive’ stretching. This occurs when a partner takes a body part/limb through its full range of motion and holds it in this position for a period of time. Examples include partner-assisted chest and hamstring stretches.



**ABOVE AND BEYOND THE STUDY DESIGN**

PNF stretching, page 547

Klaus Vedfelt/DigitalVision/Getty Images



**FIGURE 13.11** PNF stretching is often carried out with a partner.

## Proprioceptive neuromuscular facilitation (PNF)

Proprioceptive neuromuscular facilitation is a form of flexibility training that involves stretching body parts and muscles through a full range of motion passively, and then contracting the muscle against an immovable resistance (isometric contraction) such as a partner or a resistance band or towel. The range of motion is increased, either by the subject (actively) or by a partner (passively), which increases the stretch slightly beyond the previous range of motion. This is again repeated until the limit

of the joint's range has been reached. Figure 13.12 shows a series of PNF exercises that can be performed on your own or with a partner.

### LEARNING HACK

'PNF' stands for proprioceptive neuromuscular facilitation. It sounds complicated, but when you break it down, it makes perfect sense:

- **proprioceptive** – using sensory receptors in muscles, tendons and joints
- **neuromuscular** – coordinating the nervous and muscular body systems
- **facilitation** – making something easier by some form of assistance.



**FIGURE 13.12** Stretching exercises demonstrating PNF methodology

- Performing PNF stretches safely requires certain precautions:
- Warm up thoroughly beforehand to prepare the body and mind for more strenuous activity ahead.
  - The isometric contraction should start with medium contraction force and gradually increase in effort in the first 2–3 seconds, building up to maximal effort for a total of 4–5 seconds.
  - Following the isometric contraction, the subject or their partner should not ‘force’ the joint beyond the limit of its range of motion. They should only apply low/light pressure to encourage slight increases in the range attained.
  - Exercises should be performed with submaximal effort until both the subject and any partner become familiar with the technique/practice.
- Static and PNF stretches have similar advantages and disadvantages. PNF has the added benefit of developing strength at the same time as flexibility.

**TABLE 13.23** Advantages and disadvantages of static and PNF stretching

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Low joint loading, therefore low risk of injury</li> <li>• Can be performed without prior experience or supervision</li> <li>• Low/no delayed soreness in the following day(s)</li> <li>• Low energy expenditure</li> <li>• PNF is 20% more effective at increasing flexibility than static stretching</li> </ul>	<ul style="list-style-type: none"> <li>• Not representative of actions about to be performed</li> <li>• Doesn’t contribute to neuromuscular coordination required for skills involving large muscle groups, such as jumping, throwing and changing direction</li> <li>• No conclusive evidence it reduces injury risk</li> <li>• Not a good way of ‘preparing’ for an activity/ game/competition in terms of increasing muscle/joint temperature along with cardiorespiratory systems</li> </ul>

## Dynamic flexibility training

Dynamic stretching involves different rates of movement, gradually increasing from slow to fast, with muscles and body parts being stretched in a very controlled way. The actions mimic those about to be performed in a game or activity, such as kicking or throwing a ball, lunging to make a catch or baulking to get around an opponent. Dynamic stretching almost always occurs before activities, sometimes after static and PNF stretches have been performed. Dynamic stretching is superior to static stretching because it engages the neuromuscular system and brings about acute body system responses that better prepare the body for actions about to be performed.

Some examples of dynamic stretches are:

- lunges
- high knees
- walking torso-twists
- arm/leg swings.

**TABLE 13.24** Advantages and disadvantages of dynamic stretching

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Replicates actions about to be performed, and leads to neuromuscular coordination required for skills involving large muscle groups</li> <li>• Contributes to greater increases in range of motion and flexibility compared to static and PNF stretching</li> <li>• Elevates heart rate and respiratory rate as well as muscle/joint temperature, and better prepares the body for upcoming movements</li> <li>• Conclusive evidence it reduces injury risk</li> </ul>	<ul style="list-style-type: none"> <li>• Higher potential for injury than static/PNF stretching (this can be reduced if guidelines are followed)</li> </ul>

## Ballistic flexibility training

### ballistic stretching

Using momentum of body parts to force a joint beyond its normal range of motion; characterised by 'bouncy' actions

**Ballistic stretching** involves rapid and repeated bouncing movements. It aims to push engaged muscles and joints beyond their normal range of motion by using momentum or gravity. The term is commonly used interchangeably with dynamic stretching in discussions of fitness, but the two are very different.

Dynamic stretching involves smooth and well-governed movements beneath, or close to, the range of motion limit. Ballistic stretching surpasses the usual range of motion and often, because of the large momentum involved, it is difficult to control directly. Ballistic stretching should only be used under strictly supervised training conditions, and only after thorough warm-up and practice. Ideally, only experienced athletes should consider using ballistic stretching.

Some examples of ballistic stretches are:

- bouncing toe touch
- seated forward bouncing reach.



**FIGURE 13.13** Ballistic/bouncing seated forward stretch, resulting in tightening of the lower back and hamstring muscles with reduced range of motion at the hip joint

This type of stretching does not allow the muscles to relax in the stretched position and, by repeatedly activating the myostatic stretch reflex, may actually cause joints and muscles to tighten and remain in a contracted state. The more rapid the bouncing movement performed, the more a stretched muscle will contract in an effort to avoid possible injury – which is counterproductive when stretching aims to work *with* the stretch reflex rather than *against* it.

**TABLE 13.25** Determining the most appropriate type of flexibility training needs consideration of several variables.

Type of Training	When	Why	How
Static	Post-training or post-performance	To increase ROM*	Without equipment or partner, a stretch is held at final ROM for 10–20 s
PNF	Post-training or post-performance and during dedicated training sessions	To increase ROM and strengthen joints when placed in stretched positions	Four parts: <ol style="list-style-type: none"> <li>1 Partner/equipment allows stretch to be held for 10–20 s</li> <li>2 Isometric contraction performed at ROM limit</li> <li>3 Contraction stops and muscle is relaxed</li> <li>4 ROM gently increased by partner/equipment and part 1 is repeated</li> </ol>
Dynamic	Pre-training or pre-performance During training or performance Sometimes post-training or post-performance	To increase ROM and promote blood flow before/after training or performance	Controlled (non-bouncy) active movements across entire ROM and multiple joints
Ballistic	Pre-training or pre-performance and during dedicated training sessions	To increase ROM and promote blood flow before performance	Rapid and repeated bouncing movements using momentum or gravity to push engaged muscles and joints beyond their normal ROM

\* ROM = range of movement

## 13.6 CHECK-IN QUESTIONS

- 1 **a** Clearly **discuss** how a warm-up is different from a flexibility training session.
- b** How do the acute responses achieved during a warm-up provide benefits during a flexibility session?
- 2 **List** two different ways to achieve PNF stretching without the assistance of a partner.
- 3 **Propose** why static stretching is more effective at the completion of a training session involving other methods, rather than at the start of a training session or competition.



**Assessment**  
13.6 Check-in questions

MODULE 13.1, PAGE 503

## Types of continuous training

### Long slow distance (LSD) training

Long slow distance is a type of continuous training often used by people who are commencing a training program or who have relatively low levels of aerobic fitness/power. It is also favoured by sportspeople during pre-season training in an effort to build a solid aerobic base. Generally, LSD training is performed at an intensity of 70–75% max HR over an extended period of time (duration) or distance. The focus is more on distance than it is on speed, and this allows sessions to run for 30 minutes or more with relative ease.

### Tempo training

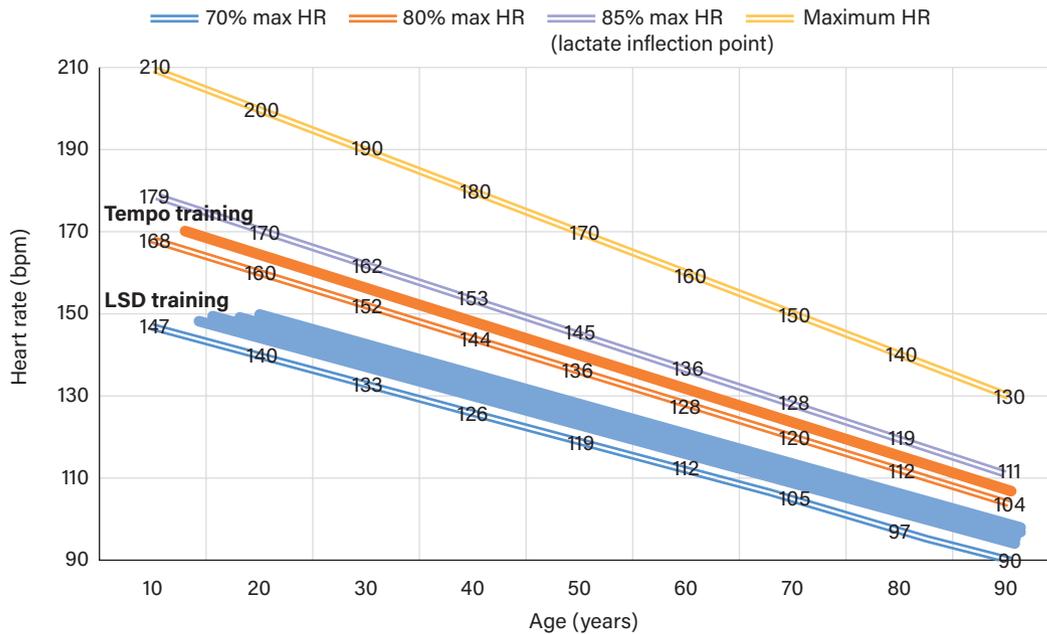
**Tempo training** is a type of continuous training that is performed at 'race pace' and occurs at or just below the lactate inflection point (LIP) – typically, 80–85% max HR. Because sessions are performed at higher intensities than in LSD training, performers should aim for a 20-minute minimum and gradually increase this as they improve both their aerobic power and LIP. Tempo training is most suitable for experienced athletes who can sustain the higher intensities for the required time, with the added bonus of simulating competition conditions.

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#### **tempo training**

Aerobic-based training performed at competition or race pace, which is highly individualised based on training status



**FIGURE 13.14** The aerobic training zone (70–85% max HR), showing long slow distance (LSD) and tempo training zones and changes associated with aging

MODULE 13.1, PAGE 503

## Examples of fartlek sessions

### Mona fartlek workout

The Mona fartlek workout was developed by elite Australian long-distance runner Steve 'Mona' Moneghetti (see Figure 13.15). Moneghetti won a Commonwealth gold medal in the marathon (1994) and finished fifth (1988) and seventh (1996) in the marathon at the Olympic Games. The workout is a variation on traditional fartlek running, alternating between periods of 'on' and 'off' running.

'On' means hard or fast-paced. 'Off' means you ease off the gas, to a low-moderate pace, which is sometimes referred to as 'float pace' or 'recovery'. The actual intensity is still self-selected in the traditional fartlek style.

Raise heart rate and body temperature with a 10-minute warm-up at low intensity:

- Run for 90 seconds on, followed by 90 seconds off; repeat × 2.
- Run for 60 seconds on, followed by 60 seconds off; repeat × 4.
- Run for 30 seconds on, followed by 30 seconds off; repeat × 4.
- Run for 15 seconds on, followed by 15 seconds off; repeat × 4.

Cool down with a 5-minute walk at low intensity.

Total workout time = 35 minutes.

## Fartlek pyramid

Warm up with 15 minutes of relaxed running, building to 6–7/10 RPE. Then 5 × 20–30-second pick-ups/accelerations to 9/10 RPE with 30 seconds recovery after each.

The pyramid set consists of:

1 minute on	8–9/10 RPE
1 minute off	4–5/10 RPE
2 minutes on	8–9/10 RPE
2 minutes off	4–5/10 RPE
3 minutes on	8–9/10 RPE
3 minutes off	4–5/10 RPE
2 minutes on	8–9/10 RPE
2 minutes off	4–5/10 RPE
1 minute on	8–9/10 RPE
1 minute off	4–5/10 RPE

Cool down with 5–10 minutes of relaxed, easy running.

Note: 4–5 RPE is 'easy' and equivalent to a jogging pace; 8 RPE is a fast run but can be sustained for extended periods at steady state; 9 RPE is sprinting above LIP; 10 RPE is a maximal/all-out effort.

## Gerschler fartlek

Gerschler fartlek is good for developing aerobic fitness rapidly when combined with steady running.

Warm up with 10 minutes of jogging.

Stride hard for 30 seconds, jog for 90 seconds, then repeat with a 15-second decrease in recovery jog each time:

- stride 30 seconds, jog 90 seconds
- stride 30 seconds, jog 75 seconds
- stride 30 seconds, jog 60 seconds
- stride 30 seconds, jog 45 seconds
- stride 30 seconds, jog 30 seconds
- stride 30 seconds, jog 15 seconds.

Repeat × 3.

Cool down with 10 minutes of jogging.



REUTERS/Bridgeman Images

**FIGURE 13.15** Australian long-distance runner Steve Moneghetti

MODULE 13.4, PAGE 532

## Resistance training recommendations for various levels

Table 13.26 considers resistance training recommendations for various levels of training experience: novice, intermediate and advanced.

**TABLE 13.26** Summary of resistance training recommendations: an overview of different program variables needed for progression with different fitness levels

	Muscle action	Selection	Order	Loading	Volume	Rest intervals	Velocity	Frequency
<b>Strength</b>			For Nov, Int, Adv: Large < small			For Nov, Int, Adv:		
Novice	ECC and CON	SJ and MJ exs	MJ < SJ HI < LI	60–70% of 1RM	1–3 sets, 8–12 reps	2–3 min for core	S, M	2–3 ×/wk
Intermediate	ECC and CON	SJ and MJ exs		70–80% of 1RM	Mult. sets, 6–12 reps	1–2 min for others	M	2–4 ×/wk
Advanced	ECC and CON	SJ and MJ exs – emphasis MJ		1RM – PER	Mult. sets, 1–12 reps – PER		US–F	4–6 ×/wk
<b>Hypertrophy</b>			For Nov, Int, Adv: Large < small					
Novice	ECC and con	SJ and MJ exs	MJ < SJ HI < LI	60–70% of 1RM	1–3 sets, 8–12 reps	1–2 min	S, M	2–3 ×/wk
Intermediate	ECC and con	SJ and MJ exs		70–80% of 1RM	Mult. sets, 6–12 reps	1–2 min	S, M	2–4 ×/wk
Advanced	ECC and CON	SJ and MJ exs		70–100% of 1RM with emphasis on 70–85% – PER	Mult. sets, 1–12 reps with emphasis on 6–12 reps – PER	2–3 min – VH 1–2 min – L–MH	S, M, F	4–6 ×/wk
<b>Power</b>			For Nov, Int, Adv: Large < small	For Nov, Int, Adv: Heavy loads (> 80%) – strength		For Nov, Int, Adv:		
Novice	ECC and CON	Mostly MJ	Most complex < least complex HI < LI	Light loads (30–60%) – velocity	Train for strength	2–3 min for core	M	2–3 ×/wk
Intermediate	ECC and CON	Mostly MJ		PER	1–3 sets, 3–6 reps	1–2 min for others	F	2–4 ×/wk
Advanced	ECC and CON	Mostly MJ			3–6 sets, 1–6 reps – PER		F	4–6 ×/wk
<b>Endurance</b>			For Nov, Int, Adv: Variety in sequencing recommended			For Nov, Int, Adv:	For Nov, Int, Adv:	
Novice	ECC and CON	SJ and MJ exs		50–70% of 1RM	1–3 sets, 10–15 reps	1–2 min for high-rep sets	S – MR M – HR	2–3 ×/wk
Intermediate	ECC and CON	SJ and MJ exs		50–70% of 1RM	Mult. sets, 10–15 reps or more	< 1 min for 10–15 reps		2–4 ×/wk
Advanced	ECC and CON	SJ and MJ exs		30–80% of 1RM – PER	Mult. sets, 10–25 reps or more – PER			4–6 ×/wk

**ECC** = eccentric; **CON** = concentric; **Nov** = novice; **Int** = intermediate; **Adv** = advanced; **SJ** = single-joint; **MJ** = multiple-joint; **exs** = exercises; **HI** = high intensity; **LI** = low intensity; **1RM** = 1-repetition maximum; **PER** = periodised; **VH** = very heavy; **L–MH** = light to moderately heavy; **S** = slow; **M** = moderate; **US** = unintentionally slow; **F** = fast; **MR** = moderate repetitions; **HR** = high repetitions

Source: American College of Sports Medicine (2002), 'Progression models in resistance training for healthy adults', in *Medicine and Science in Sports and Exercise*

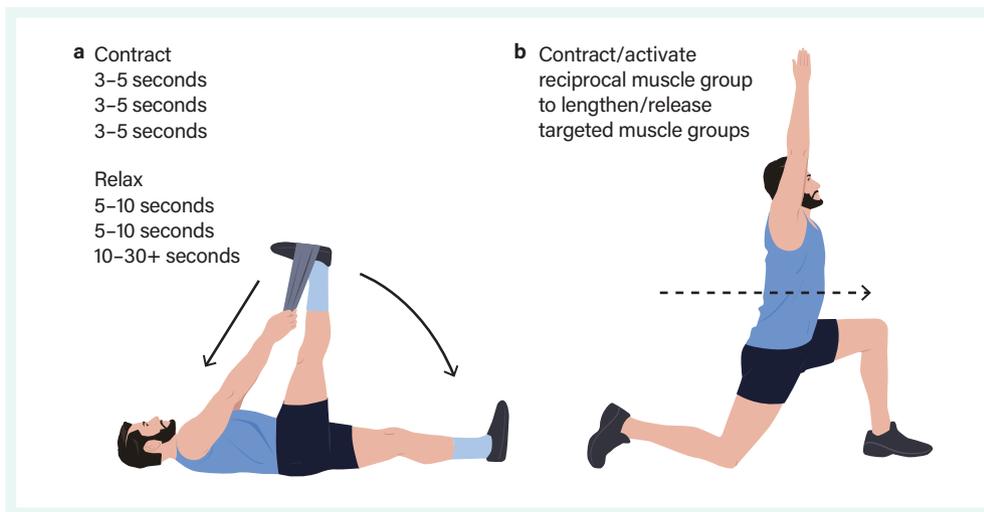
## PNF stretching

There are two main types of PNF stretching:

- the traditional contract–relax (CR) method
- the contract–relax–antagonist–contract (CRAC) method.

The CR method involves taking a muscle to its lengthened position and holding it there while isometrically contracting the same muscle maximally for an allotted amount of time. This is followed by lengthening the muscle further into range once the isometric contraction is released.

The CRAC method follows a similar method but instead involves contracting the target muscle you want to stretch as well as the opposing muscle (think, for example, of quadriceps and hamstrings, or biceps and triceps, doing the opposite movement to each other) for a period of time.



**FIGURE 13.16** Two main types of PNF stretching: **a** the contract–relax (CR) method; **b** the contract–relax–antagonist–contract (CRAC) method

# CHAPTER SUMMARY



## Resource

Self-assessment checklist

## Video

Masterclass: Chapter 13

### 13.1 Continuous and fartlek training

- Continuous training is performed at the same intensity within the aerobic training zone for at least 20 minutes.
- Continuous training can be further classified as long slow distance (LSD) training (performed at an intensity of 70–75% max HR) or tempo training (performed at 80–85% max HR), which tends to occur at performance/race pace, which is at or just below the lactate inflection point.
- Fartlek is a form of continuous training with regular changes in speed or resistance during a 20-minute (minimum) session.
- Fartlek aims to activate the anaerobic glycolysis system when surges see the athlete working above the lactate inflection point for short periods. This helps develop lactate tolerance and trains  $VO_2$  max at the same time.

### 13.2 Interval training

- Interval training involves completing an exercise/activity, then resting for a period of time, before repeating this pattern a number of times.
- Interval training enables better-quality work to be performed because of the rest periods.
- Interval training can target either aerobic power (long or HIIT) or anaerobic capacity (short or intermediate).
- The three energy systems can be targeted and trained via:
  - short-interval: ATP-CP system = short duration (0–10 seconds)
  - intermediate interval: anaerobic glycolysis system = medium/intermediate duration (10–60 seconds)
  - long interval/HIIT: aerobic system = long duration (60+ seconds)
- Interval training allows higher-intensity work to be performed without the same fatigue that would be experienced in a continuous session of equal intensity.
- HIIT has been shown to produce higher levels of endurance performances with reduced time commitment (under 20 minutes) and increased training adherence.

### 13.3 Plyometric training

- Plyometric training consists of quick, powerful actions that involve muscle lengthening (eccentric contraction) immediately followed by rapid shortening (concentric contraction) of muscles.
- Plyometrics improves the stretch reflex and is beneficial for power, speed and agility.
- The greater the stretch put on a muscle, the greater the force it can produce because the muscle recruits more motor units.
- Plyometrics should progress gradually from lower-intensity drills to more advanced.
- If a plyometric activity has a high neuromuscular stress/load, it will require a longer recovery before another repeat session can occur than one with lower muscle load.

### 13.4 Resistance training

- Resistance training involves subjects working against something that resists the movement of specific parts of their body.

- Resistance training can utilise different types of muscle contractions:
  - isometric (no movement)
  - isotonic/isoinertial (movement = shortening/lengthening)
  - isokinetic (controlled movement)
  - eccentric (developing tension while lengthening a muscle).

Fitness component	Resistance prescription
Hypertrophy	<ul style="list-style-type: none"> <li>• Medium–high loads with medium reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, isometric, concentric</li> <li>• 1–2 min between sets and exercises</li> </ul>
Strength	<ul style="list-style-type: none"> <li>• Heavy (close to maximal) loads with low reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, isometric, concentric</li> <li>• 3–5 min between sets and 1–3 min between exercises</li> </ul>
Power	<ul style="list-style-type: none"> <li>• Medium loads with medium reps (at speed)</li> <li>• Multi-joint</li> <li>• Eccentric, concentric</li> <li>• 5 min between sets and 1–3 min between exercises</li> </ul>
Endurance	<ul style="list-style-type: none"> <li>• Low–medium loads with high reps</li> <li>• Single and multi-joint</li> <li>• Eccentric, concentric</li> <li>• 30 s – 2 min between sets and exercises</li> </ul>

### 13.5 Circuit training

- Circuit training consists of a series of exercises (usually 10) designed to target specific fitness components.
- Circuit training is similar to interval training: once a particular exercise is completed at a 'station', rest is taken before the subject moves on to the next exercise 'station' to complete another activity.
- Three types of circuit training are commonly used:
  - Individual-load: highly specific and tailored to individual needs
  - fixed-load: resistance is provided by weights or own body
  - fixed-time: as many exercises as possible are performed in a set time period.

### 13.6 Flexibility training

- Flexibility training focuses on improving the range of motion (ROM) at a joint/series of related joints and involves exercises that stretch the muscles, tendons and ligaments.
- There are essentially four types of flexibility training:
  - static (passive)
  - proprioceptive neuromuscular facilitation (PNF)
  - dynamic stretching
  - ballistic.
- Dynamic stretching involves different rates of movement, gradually increasing from slow to fast, with muscles/body parts being stretched in a controlled way. The actions mimic those about to be performed in a game/activity, and it is the form of flexibility training most commonly used by professional athletes.

# CHAPTER REVIEW



**Assessment**  
Chapter 13 Review

**1** ©VCAA Exam 2018, Section A, Q1

Which one of the following training methods would be the best way to train for weightlifting?

- A fartlek
- B resistance
- C continuous
- D plyometrics

**2** ©VCAA Exam 2020, Section A, Q5

A short-interval training session at 90% HR max., with a work-to-rest ratio of 1:8, would train which energy system(s)?

- A aerobic system
- B ATP-CP system
- C anaerobic glycolysis system
- D ATP-CP, aerobic and anaerobic glycolysis systems

**3** ©VCAA Exam 2022, Section A, Q5

Which one of the following training methods is the most effective for improving muscular endurance?

- A plyometric training
- B resistance training
- C short-interval training
- D flexibility training

**4** ©VCAA Exam 2018, Section B, Q5 d

Jalena is a 17-year-old student who wants to design a training program for her upcoming lacrosse season. Design a long interval training session that would be suitable for Jalena.

- 5** Emma McKeon (AUS) won the 100 metres freestyle at the Tokyo Olympics (2021) in a time of 51.96 s and Katie Ledecky (USA) won the 1,500 metres freestyle at the same competition in a time of 15:37.34. The two women would use different training methods to prepare for these events.

**Outline** a training method likely to be chosen by Emma McKeon and one likely to be chosen by Katie Ledecky. Justify your selection of each.

- 6** Determine which type of interval training would be most appropriate for the following sportspeople. Provide a reason to support your selection.

Sporting situation	Most appropriate interval training	Justification
A hockey midfield player		
A 400 m swimmer (3:45)		
A volleyball outside hitter		

### Command term

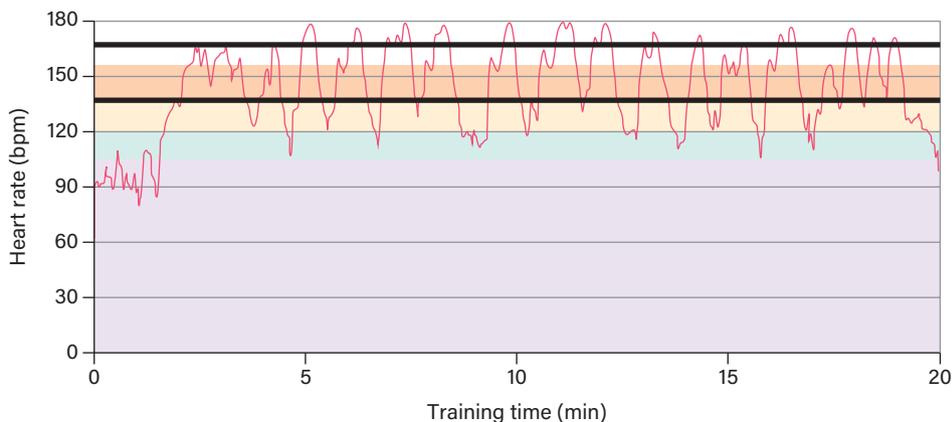
#### outline

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image

- 7 a Design a 20-minute fartlek training session for a Year 10 student who is starting to train for water polo. Provide information about the intensity and duration of effort throughout this session.
- b Comment on how the Year 10 student could best monitor intensity throughout the session.
- c **Suggest** why the intensity of effort would be different for a Year 10 student who had been training for 3 years and had previously made State selection.
- 8 **Compare** and **contrast** the two circuits below.

Circuit A RPE = 10 Rest between stations = 2 min 2 sets	Circuit B RPE = 8 Work = 1 min, rest = 1 min 2 sets
1 8 × box jumps	1 Half-court runs with walk recovery to start
2 6 × medicine-ball slams	2 Russian twists
3 8 × high cone hops forwards	3 5 m lateral shuffles
4 6 × clap push-ups	4 Modified push-ups (knees)
5 8 × tuck jumps	5 Jumping rope (rapid singles)
6 6 × medicine-ball side slams	6 Sit-ups
7 6 × burpees	7 Basketball chest pass (5 m)
8 6 × high knee ladders	8 Lying leg raises

- a What do you believe the training goal(s) might be for each circuit?
- b Propose a sport or sporting activity for which each circuit could be appropriate.
- 9 Plyometric training sees a rapid improvement in the amount of force a muscle can produce. **Explain** how this is possible without any increase in muscle fibre size, typically in the first couple of weeks after starting this type of training.
- 10 The graph below shows the heart rate of a 20-year-old subject during a fartlek training session.



- a The continuous training zone has been marked on the graph with two bold lines. How do you **calculate** the lower and upper limits?
- b The first 'surge' occurs just after the 5-minute stage of the session. What is the major energy system producing ATP at this stage?
- c Explain why each 'surge' tends to be immediately followed by lower-intensity efforts.

### Command terms

#### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer

#### compare

Recognise similarities and differences and the significance of these similarities and differences

#### contrast

Show how things are different or opposite

#### calculate

Determine from given facts, figures or information; obtain a numerical answer showing the relevant stages in the working; determine or find (e.g. a number, answer) by using mathematical processes

# CHAPTER 14

## COMPONENTS OF A TRAINING SESSION

UNIT 4 - AREA OF STUDY 2



Bojan Milinkov/Shutterstock.com

**FIGURE 14.01** All training sessions should include a warm-up, a conditioning phase and a cool-down.

### Quizzes

Chapter 14 Pulse check

**14.1** Check-in questions

**14.2** Check-in questions

**14.3** Check-in questions

Chapter 14 Review

### Videos

Masterclass: Chapter 14

**14.1** In focus: RAMP protocol

**14.2** In focus: Designing a training program

**14.2** In focus: Evaluating training programs

### Resources

**14.2** Full description of plyometric exercises

Chapter 14 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



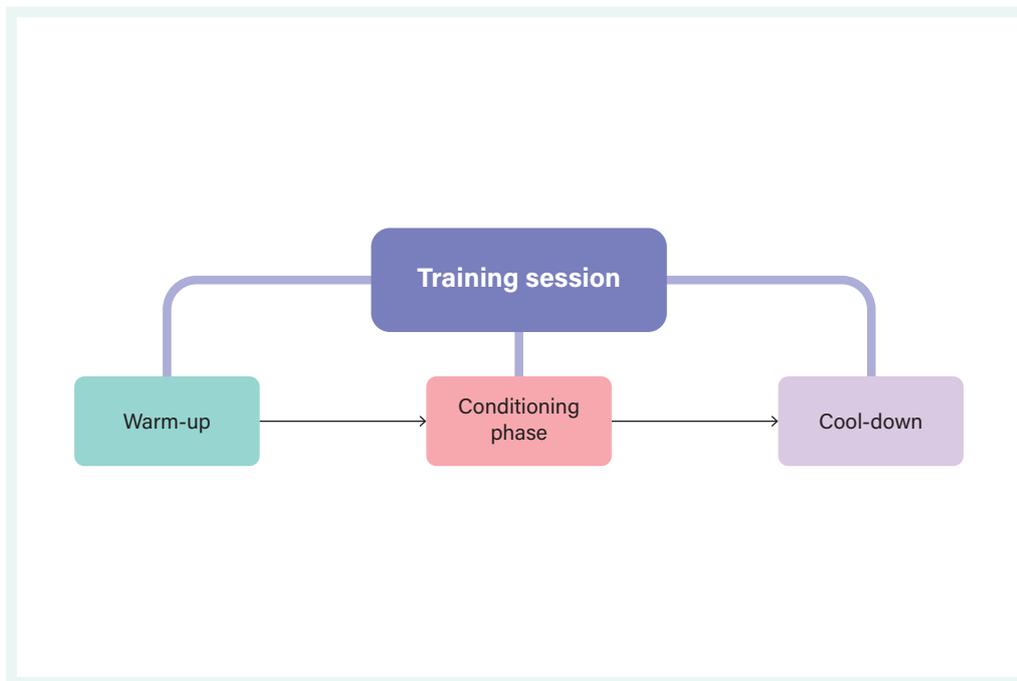
- » components of an exercise training session including warm-up, conditioning phase and cool down

## KEY KNOWLEDGE

- » participate in and conduct components of an exercise training session
- » analyse training data to identify and prescribe appropriate modifications to a training program
- » evaluate and critique the effectiveness of different training programs

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)





**Video**

Masterclass: Chapter 14

**Assessment**

Pulse check

Training programs are designed to achieve an intended outcome – for example, increased aerobic power, strength or anaerobic capacity – and will focus on the specific fitness components, energy systems, skills and movement patterns required for the physical activity, sport or exercise being undertaken. Individual training sessions will look different for different sports and different athletes, or at different times of the year. The volume, intensity and frequency of the training session, and the activities that make them up, may all vary, but there are three components of a training session that are common:

- warm-up
- conditioning phase
- cool-down.

In this chapter we will look at the purpose and characteristics of each component.

### PULSE CHECK

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 Outline** three reasons why an athlete should perform a warm-up.
- 2 Describe** the type of activity that should be included in the warm-up phase of the training session.
- 3** What is the purpose of the conditioning phase of the training session?
- 4 List** the four main training principles that should be applied to the conditioning phase of the training session.
- 5** Physiologically, why is it important for an athlete to cool down after training?

## 14.1 WARM-UP

In this module you will learn about:

- the warm-up component of an exercise training session and learn to:
- participate in and conduct a warm-up as part of an exercise training session.

The main purpose of a warm-up is 'to prepare the athlete mentally and physically for exercise or competition' (Jeffreys, 2007).

The warm-up is conducted before training or competition and aims to prepare the athlete or individual, physiologically and psychologically, for physical activity.

The warm-up serves multiple purposes. It contributes to:

- mental readiness
- physical readiness
- injury prevention
- performance enhancement.

### DID YOU KNOW?

It is well established that an effective warm-up increases performance, but whether or not a warm-up can reduce the risk of injury is a hotly debated topic. While the evidence around injury prevention is inconclusive, reducing the risk of injury is consistently viewed as a primary purpose of the warm-up.

## Psychological mechanisms

The warm-up can mentally prepare an athlete for their performance and provide an opportunity to focus and concentrate on the activity or task they are about to undertake. Many of the strategies that we looked at in Chapter 2 – such as mental imagery, positive self-talk, the use of cue words and arousal regulation techniques – can be used by athletes in the warm-up to help prepare them mentally for their performance. Elite athletes are more likely to use mental performance strategies as part of an effective warm-up routine than recreational athletes.

## Physiological mechanisms

As the name suggests, one of the key outcomes of a warm-up is an increase in body and muscle temperature. Increases in muscle temperature lead to increased oxygen delivery, force production, power output and movement velocity. Table 14.01 summarises the physiological and psychological benefits of a warm-up.

**TABLE 14.01** Physiological and psychological benefits of a warm-up

Physiological	Psychological
<ul style="list-style-type: none"> <li>• Increased core body temperature</li> <li>• Increased muscle temperature</li> <li>• Increased ATP turnover</li> <li>• Increased glycogen availability</li> <li>• Increased power output</li> <li>• Increased rate of force development</li> <li>• Increased blood flow to active muscles</li> <li>• Increased VO<sub>2</sub></li> <li>• Increased muscle contraction and relaxation</li> <li>• Increased respiratory rate</li> </ul>	<ul style="list-style-type: none"> <li>• Increased concentration on task</li> <li>• Increased focus</li> <li>• Increased self-confidence</li> </ul>

## Structure of the warm-up

A well-designed, effective warm-up can have a positive effect on an athlete's performance. The warm-up generally last between 10 and 30 minutes and its structure has traditionally included two phases:

- 1 general warm-up – consisting of low- to moderate-intensity aerobic exercise such as walking, jogging or cycling
- 2 specific warm-up – consisting of dynamic stretching and activity-specific movements that replicate the actions that will be undertaken in the activity.

## LOOKING BACK

## Dynamic stretching

## Chapter 13

In Chapter 13 we looked at different forms of stretching that are used to develop flexibility. You will recall that dynamic stretching engages the neuromuscular system and brings about acute body system responses that better prepare the body for actions about to be performed. This is a key reason that this type of stretching is used in the warm-up phase of the training session.

Balint Redu/  
Adobe Stock



**FIGURE 14.02** The warm-up should be specific to the activity to be undertaken.

- As with training, specificity is important when structuring a warm-up. An effective warm-up must be:
- sport-specific – the movements and exercises should mimic those performed in the activity/game
  - athlete-specific – the intensity and difficulty level should match the fitness and experience level of the athlete
  - done before every training session and competition/match/game.

Frode Arnesen/Alamy Stock Photo



Hoo-Me/Storms Media Group/Alamy Stock Photo

**FIGURE 14.03** The exercises performed in the warm-up need to be specific to the sport and the athlete.



Video

In focus: RAMP protocol

A more contemporary view of the warm-up is to view it as part of the training process. Ian Jeffreys (2007) developed what is known as the RAMP warm-up protocol. RAMP provides a framework to construct effective warm-ups through three key phases:

- 1 raise (R)
- 2 activate (A) and mobilise (M)
- 3 potentiate/prepare (P).

### Raise

In this phase the aim is to increase:

- body temperature
- heart rate
- respiratory rate
- blood flow
- joint viscosity.

This is achieved through activities such as running, line drills, change-of-direction drills (sport-specific movements), cycling and skipping.

## Activate and mobilise

Here the aim is to:

- activate key muscle groups
- mobilise key joints and ranges of motion used in the sport or activity.

This is done through a focus on specific movements used in the activity, rather than on individual muscle groups.

### DID YOU KNOW?

To activate a muscle, a neuron must fire a signal to the brain. The central nervous system (CNS) sends messages to activate the motor units (see Chapter 5 for more detail).

## Potentiate/Prepare

The **potentiate**/prepare phase aims to improve performance through sport-specific activities that increase in intensity.

### potentiate

To select activities that make the warm-up effective or will improve the effectiveness of the performance

# THE RAMP WARM-UP

Key to performing at your best in any sport or physical activity, a warm-up will also reduce your risk of injury.



### RAISE

3-5 minutes

Begin with light activities to get your heart rate and body temperature elevated, such as a gentle jog.

# 1



### Activate and mobilise

5-8 minutes

Start moving your body with greater intensity through a range of motions that you will use in your sport or activity.

# 2



### Potentiate

5 minutes

Use the final phase of the warm-up to focus on exercises that are specific to your sport or activity – for example, in football, drills that involve kicking, handpassing and marking the ball or tackling.

# 3



To reap the full benefits of your warm-up, time your warm-up to finish as close to the start of your game or activity as possible.

**FIGURE 14.04** The RAMP structure can be applied to a warm-up for any sport.

## LOOKING BACK

### Acute responses

#### Chapter 5

The Real World Applications box in Chapter 5 featured Football Victoria and acute responses. What is the relationship between acute responses and the purpose of a warm-up?



**Weblink**  
Dynamic Warm-up

### Command terms

#### list

Provide a series of related words, names, numbers or items that are arranged consecutively

#### describe

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way



## REAL WORLD APPLICATIONS

### Dynamic warm-up: AFL

Watch the *Dynamic Warm-up* clip on the Coaches AFL website to see AFL Victoria's Head of Athlete Management, Matthew Glossop, explain the range of exercises and activities that can be used as part of a warm-up for Australian Rules football players and then answer the questions.

- 1 Provide two reasons why static stretching is not used in the AFL warm-up.
- 2 What movement patterns should be included in the warm-up?
- 3 **List** three reasons why the players perform dynamic movements in the warm-up.
- 4 Using a specific example from the video, **describe** how a player can tailor the warm-up to their individual needs.

## COLLABORATIVE TASK

### Prac activity

#### Warm-up

##### AIM

To participate in, and reflect on, two different warm-up activities

##### EQUIPMENT

- soccer pitch
- cones
- soccer balls

##### METHOD

- 1 Participate in the two warm-up sessions outlined below.
  - a Traditional warm-up
    - Jog two laps of the soccer pitch
    - Perform static stretches for the following muscle groups:
      - neck
      - shoulders/back/chest
      - knees/thighs
      - calves/ankles.
  - b RAMP warm-up (adapted from the FIFA 11+ warm-up)
    - Raise – running exercises:
      - straight line running: 2 × jog to cone (30 metres), increase intensity on the way back
      - running – hip out: 2 × jog to the first cone. Stop and lift knee to the side. Rotate knee forwards and put your foot down. Jog to the next cone and do the exercise on the other leg. When you have finished the course, jog back to the start.
      - quick forwards and backwards sprints: 2 × run quickly to the second cone, then run backwards quickly to the first cone, keeping your hips and knees slightly bent. Repeat, running two cones forwards and one cone backwards. When you have finished the course, jog back.





2 Activate and mobilise – sport-specific movements.

Complete the activities shown in Figure 14.05.



**1 THE BENCH  
ALTERNATE LEGS** 3 sets

**Starting position:** Lie on your front, supporting yourself on your forearms and feet. Your elbows should be directly under your shoulders.

**Exercise:** Lift your body up, supported on your forearms, and pull your stomach in. Lift each leg in turn, holding for a count of 2 seconds. Continue for 40–60 seconds. Your body should be in a straight line. Try not to sway or arch your back.



**2 SIDEWAYS BENCH  
RAISE AND LOWER HIP** 3 sets on each side

**Starting position:** Lie on your side with both legs straight. Lean on your forearm and the side of your foot so that your body is in a straight line from shoulder to foot. The elbow of your supporting arm should be directly beneath your shoulder.

**Exercise:** Lower your hip to the ground and raise it back up again. Repeat for 20–30 seconds. Take a short break, change sides and repeat.



**3 HAMSTRINGS  
INTERMEDIATE** 1 set

**Starting position:** Kneel on a soft surface. Ask your partner to hold your ankles down firmly.

**Exercise:** Your body should be completely straight from the shoulder to the knee throughout the exercise. Lean forward as far as you can, controlling the movement with your hamstrings and your gluteal muscles. When you can no longer hold the position, gently take your weight on your hands, falling into a push-up position. Complete a minimum of 7–10 repetitions and/or 60 seconds.



**4 SINGLE-LEG STANCE  
THROWING BALL WITH PARTNER** 2 sets

**Starting position:** Stand 2–3 metres apart from your partner, with each of you standing on one leg.

**Exercise:** Keeping your balance, and with your stomach held in, throw the ball to one another. Keep your weight on the ball of your foot. Remember: keep your knee just slightly flexed and try not to let it buckle inwards. Keep going for 30 seconds. Change legs and repeat.



**5 SQUATS  
WALKING LUNGES** 2 sets

**Starting position:** Stand with your feet hip-width apart. Place your hands on your hips if you like.

**Exercise:** Lunge forward slowly at an even pace. As you lunge, bend your leading leg until your hip and knee are flexed to 90 degrees. Do not let your knee buckle inwards. Try to keep your upper body and hips steady. Lunge your way across the pitch (approximately 10 times on each leg) and then jog back.



**6 JUMPING  
LATERAL JUMPS** 2 sets

**Starting position:** Stand on one leg with your upper body bent slightly forwards from the waist, with knees and hips slightly bent.

**Exercise:** Jump approximately 1 metre sideways from the supporting leg onto the free leg. Land gently on the ball of your foot. Bend your hips and knees slightly as you land and do not let your knee buckle inward. Maintain your balance with each jump. Repeat the exercise for 30 seconds.

**FIGURE 14.05** Exercises for the ‘activate’ and ‘mobilise’ aspects of the warm-up



**3** Potentiate/prepare – sport-specific movements

- Running exercises:
  - 2 × sprint across the pitch (75–80% of maximum pace)
  - 2 × bounding across the pitch
  - 2 × plant and cut
- Soccer skills activities
  - 5v5 keepings-off with ball

If there is enough time in the lesson, participate in a game of soccer (modified, small-sided or full-pitch).

**OBSERVATIONS**

Reflect on which session/s increased heart rate, respiratory rate and body/muscle temperature, and which was more enjoyable.

**DISCUSSION**

**Compare** and **contrast** the two warm-up sessions in terms of the purpose of the warm-up in preparing the body for the activity.

**Command terms****compare**

Recognise similarities and differences and the significance of these similarities and differences

**contrast**

Show how things are different or opposite

**ABOVE AND BEYOND THE STUDY DESIGN**

To stretch or not to stretch, that is the question!, page 577

**Assessment**

14.1 Check-in questions

**14.1 CHECK-IN QUESTIONS**

- 1 What is the main purpose of the warm-up?
- 2 Other than increased body and muscle temperature, **list** three physiological benefits of warming up.
- 3 **©VCAA** Exam 2021, Section B, Q6 e  
Michelle is a lacrosse player. Michelle's pre-game warm-up routine is shown in the table below. Critique the effectiveness of Michelle's warm-up routine.

<b>Cardio component</b>	walking at a moderate pace for two minutes
<b>Stretching component</b>	<ul style="list-style-type: none"> <li>▪ three lunges</li> <li>▪ three leg swings on each leg</li> <li>▪ three torso twists in each direction</li> <li>▪ three arm swings in each direction</li> <li>▪ three neck circles in each direction</li> <li>▪ three squats</li> </ul>
<b>Sport-specific component</b>	using a lacrosse stick to throw and catch from various distances with a teammate

- 4 Using the RAMP structure, design a warm-up for a sport or activity that you have played or that you play.

**Weblinks**

FIFA 11+ manual  
FIFA 11+ poster

**🚩 SIGNPOST**

Links to the FIFA 11+ program can be found on Nelson MindTap.

## 14.2 CONDITIONING PHASE

In this module you will learn about:

- the conditioning phase of an exercise training session and learn to:
- design and conduct the conditioning phase of an exercise training session
- analyse training data to identify and prescribe appropriate modifications to the conditioning phase of a training program
- evaluate and critique the effectiveness of different training programs.

The **conditioning** phase of the training session is where the work is done to improve the relevant energy systems and fitness components. The conditioning phase involves one of the training methods that we looked at in Chapter 13:

- continuous
- fartlek
- circuit
- interval
- weight/resistance
- plyometrics
- flexibility.

In the conditioning phase, an athlete may target areas of weakness (determined through fitness testing – see Chapter 10) to improve, for example, specific fitness components; or the focus might be to maintain the physiological requirements for the activity.

### conditioning

Increasing the capacity of the body to produce energy and do work through training

## Conditioning phase: for a half marathon



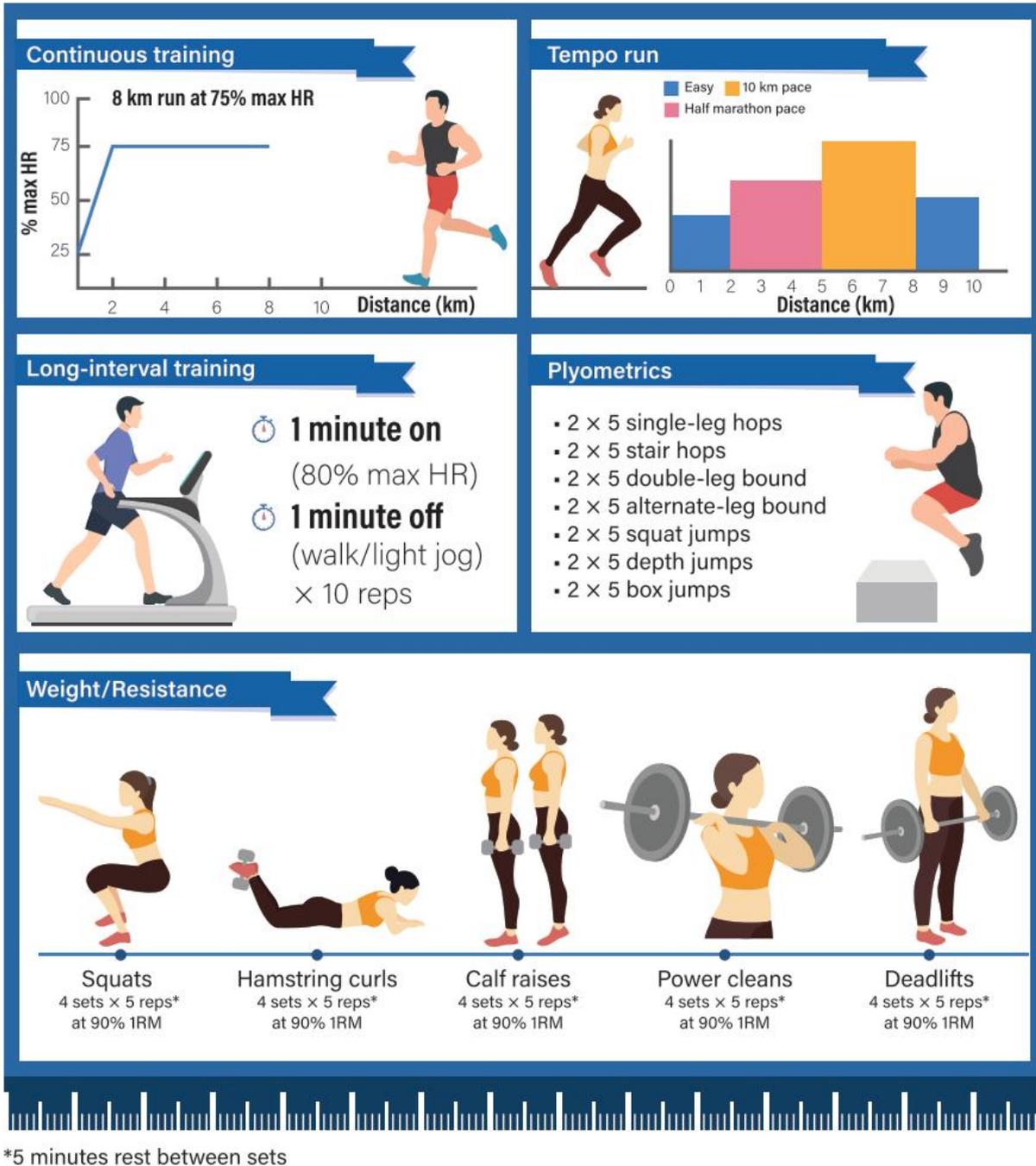
Bryan Bedder/New York Road Runners/Getty Images

**FIGURE 14.06** Training for a half marathon may involve a range of training methods in the conditioning phase.

The conditioning phase of a training session for a half marathon can be structured to:

- develop aerobic power
- increase speed
- build power and strength
- increase the range of motion of the joints.

Remember that a warm-up is always performed before the conditioning phase!



**FIGURE 14.07** Examples of training methods that could be used in the conditioning phase of a training session for a half marathon

## 🚩 SIGNPOST

For a full description of each of the plyometric exercises shown in Figure 14.07, go to Nelson MindTap.



**Resource**  
Full description of  
plyometric exercises

## Flexibility

**TABLE 14.02** Stretches for flexibility

Body part	Static stretching	Dynamic stretching
	Hold position for 20–60 s without rocking or bouncing	10–15 repetitions of each exercise
Shoulder	<ul style="list-style-type: none"> <li>flexor stretch</li> </ul>	<ul style="list-style-type: none"> <li>flexion and extension stretch</li> <li>abduction and adduction stretch</li> </ul>
Trunk	<ul style="list-style-type: none"> <li>standing lower-trunk flexor stretch</li> </ul>	<ul style="list-style-type: none"> <li>lateral flexion stretch</li> <li>rotation stretch</li> </ul>
Hip	<ul style="list-style-type: none"> <li>standing hip external rotator stretch</li> <li>lying-down external rotator and extensor stretch</li> <li>external rotator and back extensor stretch</li> <li>lying-down hip and back extensor stretch</li> </ul>	<ul style="list-style-type: none"> <li>adduction and abduction stretch</li> <li>flexor and extensor stretch</li> </ul>
Knee/thigh	<ul style="list-style-type: none"> <li>seated knee flexor stretch</li> <li>kneeling knee flexor stretch</li> </ul>	<ul style="list-style-type: none"> <li>standing knee flexor stretch</li> </ul>
Feet/calves	<ul style="list-style-type: none"> <li>standing toe extensor stretch</li> <li>plantar flexor stretch</li> <li>toe extensor and flexor stretch</li> </ul>	<ul style="list-style-type: none"> <li>plantar flexor stretch</li> </ul>

## LOOKING BACK

### Joint actions

#### Unit 1, Chapter 1

Unit 1 of VCE Physical Education covers the musculoskeletal system and looks at joints and joint actions. You can review the terminology of joint actions that is used when describing different stretches in Chapter 1 of the Units 1 and 2 textbook.

**Video**

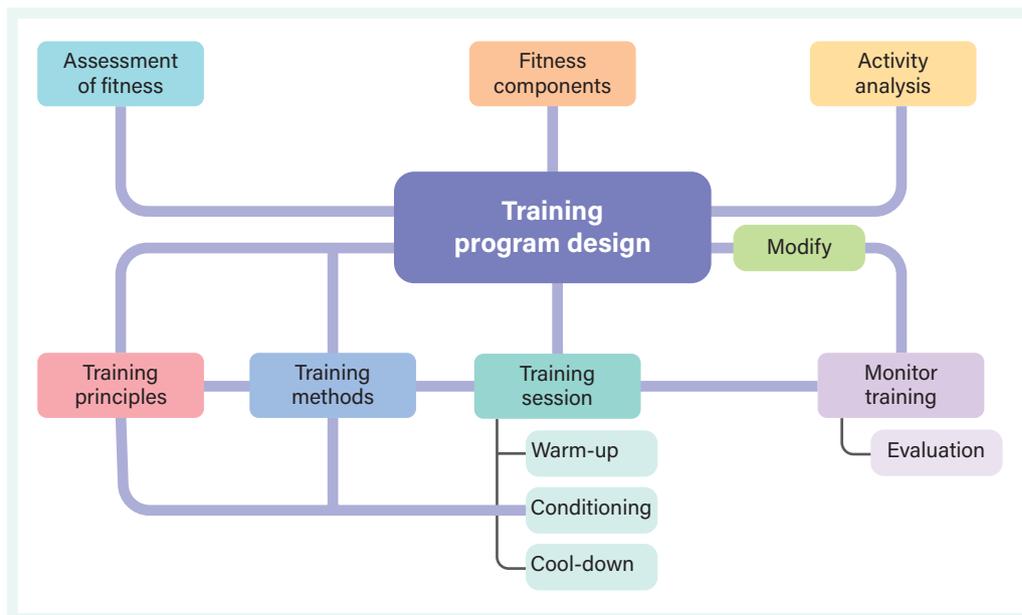
In focus: Designing a training program

**LEARNING HACK**

The content that you have been studying in Unit 4 is all interrelated, and you should now be starting to understand how everything fits together! Figure 14.08 shows how each of the key concepts informs the development of the training program.

## Designing a training program

The aim of the training program determines the selection of methods used in the training session, and the appropriate application of the training principles within the session (specifically, the intensity, time, type and progression) will ensure that the training is effective in achieving the athlete's goals.



**FIGURE 14.08** There are many things to consider when designing a training program.

## Designing the conditioning phase

The design of a training program will be informed by the:

- aim/goal/objective – what is the athlete/coach/team trying to achieve through training?
- requirements of the activity/sport – from the activity analysis, what are the movement pattern and physiological requirements of the activity/sport (energy systems, fitness components, muscle groups)?
- strengths and weaknesses of the athlete – from the fitness assessment, which fitness components need to be improved and which need to be maintained?

There are other considerations that are secondary to the design:

- availability of resources (equipment, facilities)
- time commitment (work/school).

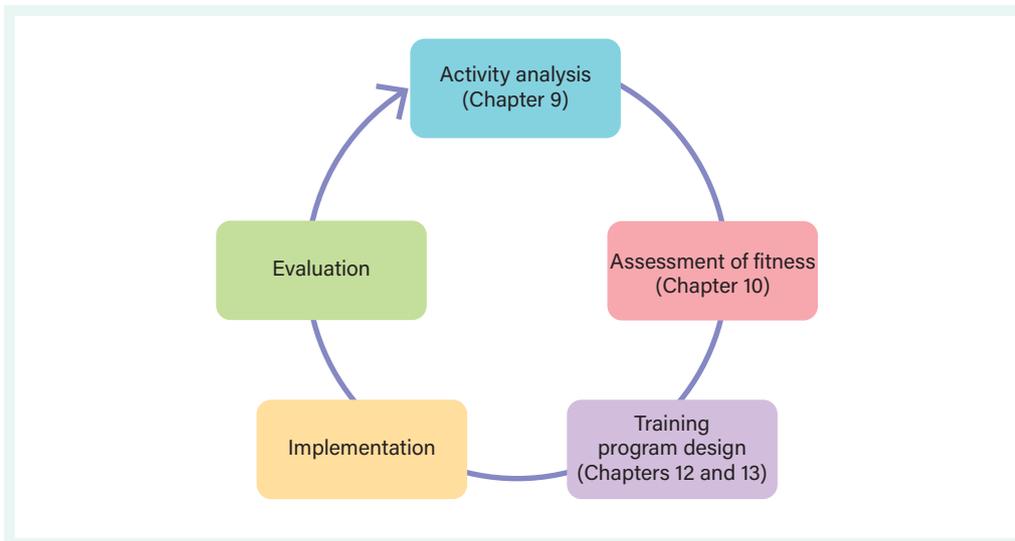
All these factors need to be taken into consideration when designing a training program. This information will determine the selection of training methods and the application of the training principles, resulting in a training program that is specific to the demands of the activity, meets the needs of the athlete and elicits the desired chronic adaptations.

### LOOKING FORWARD

#### Chronic adaptations

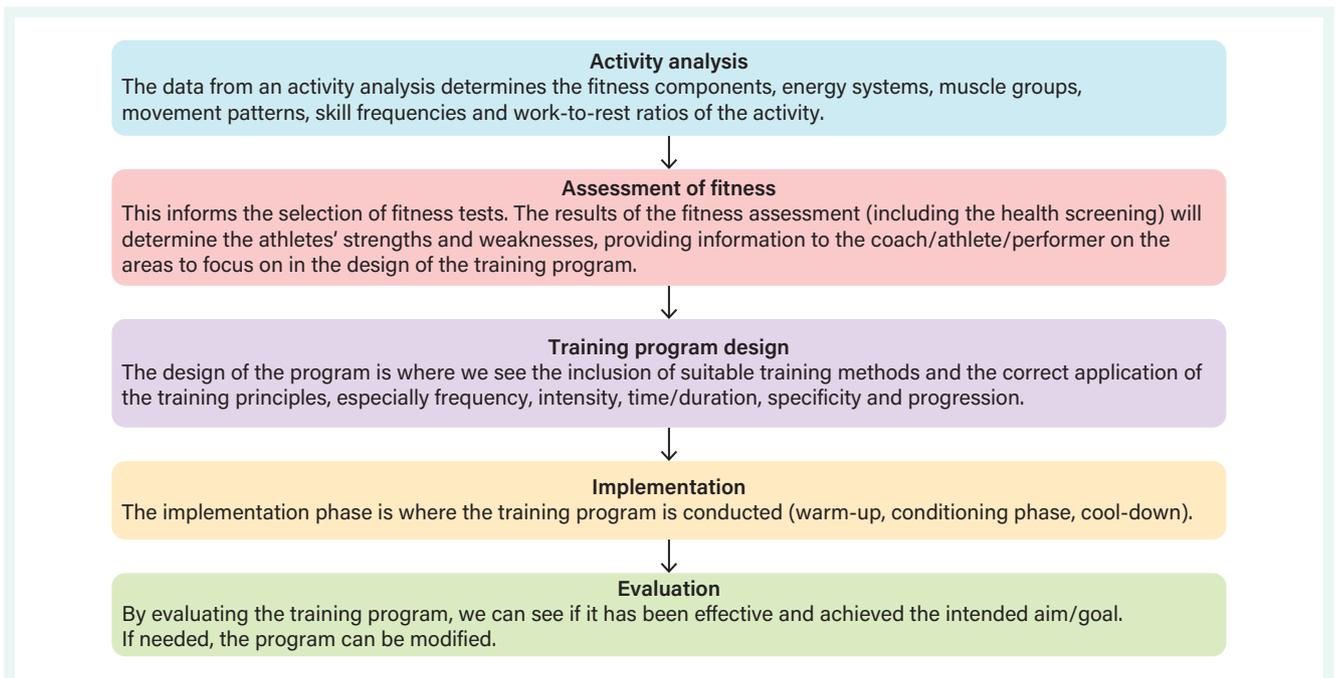
#### Chapter 15

Chronic adaptations are long-term physiological changes that occur as a result of training. We will look at these in detail in Chapter 15.



**FIGURE 14.09** Training program design, implementation and evaluation is a cyclic process.

Each step in the cycle informs the next step.



**FIGURE 14.10** Designing a training program involves multiple, interrelated steps.

## LOOKING BACK

### Goal setting

#### Chapter 2

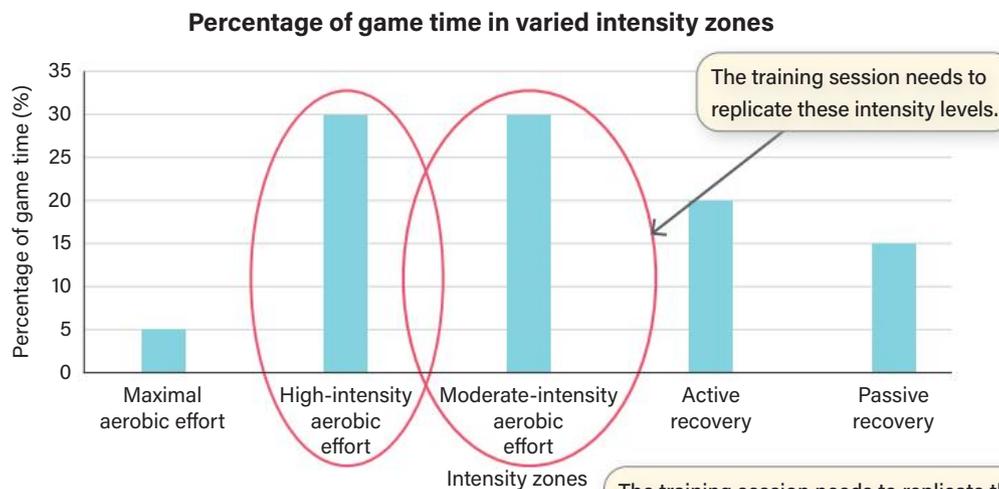
SMART goals (see Chapter 2) can be applied to training. Setting a specific goal to increase aerobic power means setting one that is measurable and achievable with training. The key is to set a measurable, achievable and realistic goal within a suitable time period. For example, 'I want to improve my result in the 20-metre multistage fitness test from 10.2 to 12.2 with 3 months of training.'

## WORKED EXAMPLE

The following question is from the 2022 VCAA VCE Physical Education exam. The question provides two different data sets and asks students to design the conditioning phase of a fartlek training program.

©VCAA Exam 2022, Section B, Q10 c

The graph and the table below show data resulting from an activity analysis of elite soccer referees.



### Time and distance spent in different intensity zones for soccer

	Sprinting	Running	Jogging	Walking	Standing
Intensity of effort	maximal anaerobic effort	high-intensity aerobic effort	moderate-intensity aerobic effort	active recovery	passive recovery
Distance of average effort	10 m	65 m	40 m	20 m	0 m
Time of average effort	1.7 s	20 s	20 s	45 s	40 s

Based on the data provided in the graph and the table above, **design** the **conditioning phase** of a **fartlek training program** for the soccer referees, focusing specifically on **high-intensity and moderate-intensity aerobic efforts**.

#### TIPS:

- The **purple** highlights the command term – that is, what you need to do to answer the question.
- The **green** highlights the component of the training session you need to focus on.
- The **orange** highlights the relevant information to inform the design of the training session.

#### Steps to answer the question

- 1 Identify the relevant data from the graph and the table. What percentage of time is spent in high- and moderate-intensity efforts? What movement patterns do referees cover? What is the length of the work period? What distances do they cover?
- 2 Apply the relevant training principles to the data and fartlek training:
  - intensity – high-intensity efforts should be between 80% and 90% max HR; medium-intensity efforts should be between 65% and 85% max HR.
  - time – aerobic training, so duration of conditioning phase should be at least 20 minutes.
  - type – activities should be specific to the soccer referee, therefore running or jogging.



&gt;

- 3 Characteristics of fartlek training: state the duration of each effort (e.g. high-intensity effort for 20 seconds, recovery jog at medium intensity for 60 seconds). There are no rest periods in fartlek training, only floating recoveries.
- 4 Combine the information into a response.

**Sample response**

*Conditioning phase: 20 minutes of continuous running alternating between high-intensity (85% max HR) efforts for 20 seconds and medium-intensity (65% max HR) efforts for 60 seconds.*

## Evaluation

Data used to evaluate the effectiveness of a training program can include:

- training diaries/journals/logs
- digital tools
- wearable activity trackers
- fitness test results (post-test)
- other physiological measures (e.g. changes in resting heart rate).

The following checklist can be useful for determining whether a training program is going to be effective:

- Is the goal of the training program clearly identified?
  - Are the training methods appropriate to develop the identified fitness components and/or energy system?
- Have the training principles been applied correctly?
- frequency (including appropriate rest days)
  - intensity
  - time/duration
  - activity type/exercise
- And, if appropriate:
- Is there sufficient variety within the program?
  - Is the progression applied correctly?
  - Does the data show an increase/improvement?

It is also important to make sure that the training program is not having a detrimental effect on the athlete, either physically or psychologically. Training diaries can record motivation and energy levels, and can help monitor an athlete's physiological and psychological responses to the training program, and thus help to avoid overtraining (Chapter 12).

Table 14.03 shows a beginner running program. The aim of the program is to run 5 kilometres in 6 weeks' time.

**LEARNING HACK**

This style of exam question is quite common. To see more examples of exam questions that specifically look at the conditioning phase of a training session, go to the Physical Education page on the VCAA website, search for 'Past examinations and examination reports' and see 2023, Question 9 d; 2021, Question 2 c; 2020, Question 2 c; and 2018, Question 7 c.



**Weblink**  
VCAA Physical Education

**Video**  
In focus: Evaluating training programs

**TABLE 14.03** A beginner running training program

Week	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
1	Rest	<ul style="list-style-type: none"> <li>Run 1 min</li> <li>Walk 1 min</li> <li>Repeat × 10</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 2 min</li> <li>Walk 4 min</li> <li>Repeat × 5</li> </ul>	Rest	Rest	<ul style="list-style-type: none"> <li>Run 2 min</li> <li>Walk 4 min</li> <li>Repeat × 5</li> </ul>
2	Rest	<ul style="list-style-type: none"> <li>Run 3 min</li> <li>Walk 3 min</li> <li>Repeat × 4</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 3 min</li> <li>Walk 3 min</li> <li>Repeat × 4</li> </ul>	Rest	Rest	<ul style="list-style-type: none"> <li>Run 5 min</li> <li>Walk 3 min</li> <li>Repeat × 3</li> </ul>
3	Rest	<ul style="list-style-type: none"> <li>Run 7 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>	Rest	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>
4	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 10 min</li> <li>Walk 2 min</li> <li>Repeat × 2</li> <li>Run 5 min</li> </ul>	Rest	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>
5	Rest	<ul style="list-style-type: none"> <li>Run 9 min</li> <li>Walk 1 min</li> <li>Repeat × 3</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 12 min</li> <li>Walk 2 min</li> <li>Repeat × 2</li> <li>Run 5 min</li> </ul>	Rest	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>
6	Rest	<ul style="list-style-type: none"> <li>Run 15 min</li> <li>Walk 1 min</li> <li>Repeat × 2</li> </ul>	Rest	<ul style="list-style-type: none"> <li>Run 8 min</li> <li>Walk 2 min</li> <li>Repeat × 3</li> </ul>	Rest	Rest	5 km race!

- Is the goal of the training program clearly identified?  
Yes, the aim is to run 5 km in 6 weeks.
  - Are the training method/s appropriate to develop the identified fitness components and/or energy system?  
Yes, continuous training is appropriate to build aerobic power, the main fitness component required to complete a 5 km run.
- Have the training principles been applied correctly?
- frequency (including appropriate rest days)  
Yes, 3 per week to improve aerobic power
  - intensity  
Yes, the intensity level is embedded in the activity (run or walk).
  - time/duration  
Yes, each session is at least 20 minutes in duration, specific to developing the aerobic energy system.
  - activity type/exercise  
Yes, running and walking are specific to the aim of the program (to run 5 km).
  - Is the progression applied correctly?  
Yes, the run minutes increase as the walk minutes decrease, but the total volume does not increase by more than 10% each week.

**FIGURE 14.11** The checklist can be used to make sure the program has been designed correctly.

## WORKED EXAMPLE

©VCAA Exam 2021, Section B, Q6 c

Dry land muscular endurance resistance training is recommended for elite water polo players. A suggested program is outlined in the table below.

Monday	Tuesday	Wednesday	Thursday	Friday
front squats 5 sets × 5 reps	seated row 2 sets × 20 reps	heavy weight walk 1–2 reps × 400 m	sumo squats 1 set × 20–30 reps	push-ups 5 sets × 5 reps
	triceps dips 2 sets × 10 reps		triceps dips 1 set × 20 reps	chin-ups 5 sets × 5 reps

Note: 'reps' stands for 'repetitions'

Critique the effectiveness of this program for improving a water polo player's performance through the development of muscular endurance. (4 marks)

**TIP:**

To critique the effectiveness of a program you will need to be able to provide a:

- strength of the program
- weakness of the program
- judgment of the effectiveness of the program.

Use data to support your response.

**Sample response**

*The program shows the correct application of reps and sets on Tuesday and Thursday (10–30 reps with only one or two sets, which is appropriate to develop muscular endurance).*

*A weakness of the program is the incorrect application of reps on Monday and Friday (low reps – only five reps of front squats, push-ups and chin-ups – which is more suited to the development of strength than endurance).*

*The program would be somewhat effective in developing muscular endurance, but could be improved by modifying the number of repetitions for exercises on Monday and Friday.*



## ABOVE AND BEYOND THE STUDY DESIGN

Training phases (periodisation), page 578

## 14.2 CHECK-IN QUESTIONS

- 1 An appropriate intensity for the conditioning phase of a continuous training session designed to improve aerobic power is:
  - A less than 50% max HR.
  - B 60–70% max HR.
  - C 70–80% max HR.
  - D greater than 85% max HR.
- 2 How is the duration of the conditioning phase determined? Provide examples of at least two different durations and give an explanation for your answer.
- 3 ©VCAA Exam 2022, Section B, Q4 c

To improve their maximum jump height while serving and to improve their blocking and spiking skills, a team of volleyball players were prescribed a training program,



**Assessment**  
14.2 Check-in questions





including the following effective conditioning phase to improve muscular power. The training program is completed three times a week for 12 weeks, with a rest day in between each session.

Exercise	Load (% of 1RM)	Repetitions	Sets	Speed of contraction	Rest time
weighted squats	50% of 1RM	3 reps	5 sets	as fast as possible	3 min rest between sets
dead lift	40% of 1RM	6 reps	3 sets	as fast as possible	2 min rest between sets
kettle bell swings	30% of 1RM	12 reps	3 sets	as fast as possible	1 min rest between sets

Note: 'reps' stands for 'repetitions'.

### Command term

#### discuss

Present a clear, considered and balanced argument or prose that identifies issues and shows the strengths and weaknesses of, or points for and against, one or more arguments, concepts, factors, hypotheses, narratives and/or opinions

**Discuss** three correct applications of training principles in the conditioning phase to improve muscular power. Make one recommendation to fix any errors in this conditioning phase.

## 14.3 COOL-DOWN

In this module you will learn about:

- the cool-down component of an exercise training session and learn to:
- participate in and conduct a cool-down as part of an exercise training session.

The cool-down is performed at the conclusion of the conditioning phase of the training session and aims to aid recovery and return the body to its pre-exercise state.

The cool-down usually lasts 5–15 minutes and consists of low- to moderate-intensity exercises that use the same muscle groups and movement patterns as were used during the conditioning phase of the training session.



**FIGURE 14.12** An appropriate cool-down activity following a spin class would be low-intensity cycling.

The intensity of the cool-down needs to be high enough to ensure that heart rate remains elevated so there is increased blood flow to facilitate the removal of metabolic by-products. However, it cannot be at an intensity level that may cause muscle damage or increased levels of fatigue.

While it is widely accepted that a cool-down aids recovery, there is little empirical evidence to support the claim. The infographic in Figure 14.13 shows the wide range of beneficial effects a cool-down is thought to have (Van Hooren & Peake, 2018). Recent research (Afonso et al., 2021) has also concluded that post-exercise stretching does not aid recovery. However, when compared to no cool-down or a passive recovery method, a cool-down has been shown to benefit:

- rate of recovery from exercise
- recovery of the cardiovascular and respiratory system (decreasing heart rate and respiratory rates to resting levels)
- lowering of core body temperature
- removal of blood lactate
- lowering pH levels to resting levels
- reduction in delayed onset muscle soreness (DOMS).



**FIGURE 14.13** There are many possible psychological and physiological effects of a cool-down.

Source: Van Hooren, B. & Peake, J. (2018), 'Do we need a cool-down after exercise? A narrative review of the psychophysiological effects and the effects on performance, injuries and the long-term adaptive response', in *Sports Med* 48, 1575–1595. CC BY 4.0

## DID YOU KNOW?

Delayed onset muscle soreness, or DOMS, is usually felt 12–24 hours after unaccustomed strenuous exercise. Typically, DOMS will be felt in multiple limbs and is often associated with eccentric muscle contractions. The severity of the soreness will depend on the intensity and duration of the activity, and, while it might seem counterintuitive, exercise is the most effective strategy for relieving the pain. The good news is that, while the soreness may increase and peak somewhere between 24 and 72 hours, it will usually have gone within 7 days.

## LOOKING BACK

### Active and passive recoveries

#### Chapter 6

In Chapter 6 we looked at the replenishment of the three energy systems through active and passive recovery strategies. An active recovery is no different from a cool-down: both include low-intensity activity that aims to maintain an elevated heart rate, thus increasing the rate of removal of waste products, and to prevent blood pooling by activating the muscle pump.

## Stretching

Static stretching is part of the cool-down routine for many athletes (Driller & Leabeater, 2023). While it may not produce any additional reduction in delayed onset muscle soreness, it is an appropriate time, while the muscles are warm, to perform stretching exercises with the aim of improving range of motion.

## Foam rollers

Foam rolling is a form of self-massage that is commonly used in cool-down routines. It has been shown to reduce delayed onset muscle soreness, increase range of motion and enhance sports performance when used in this way. The recommendation is to roll each muscle group for 90–120 seconds.



iStock.com/PeopleImages

**FIGURE 14.14** The use of foam rollers has become popular as a form of self-massage.

## DID YOU KNOW?

An active cool-down may also benefit an athlete's psychological recovery after exercise. Most people perceive an active cool-down as more beneficial than a passive one. Research has found that doing an active cool-down aided relaxation and socialising and provided time to reflect on the training or the match (Van Hooren & Peake, 2018).

## COLLABORATIVE TASK

### Prac activity



### Foam roller session

#### AIM

To participate in a foam roller session

#### EQUIPMENT

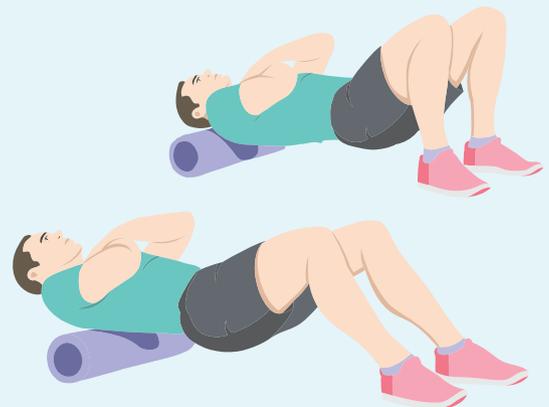
- foam rollers

#### METHOD

Perform each movement for 1 minute. For movements that require work on both sides of the body, do 30 seconds on each side.

#### 1 Upper back

Lie down with a roller under your upper back, with hands crossed over your chest, your feet flat and knees bent. Push away, rolling down your torso from your upper back to your mid-back, straightening your legs. Then pull back, rolling on your spine from your mid- to upper back.



#### 2 Lower back

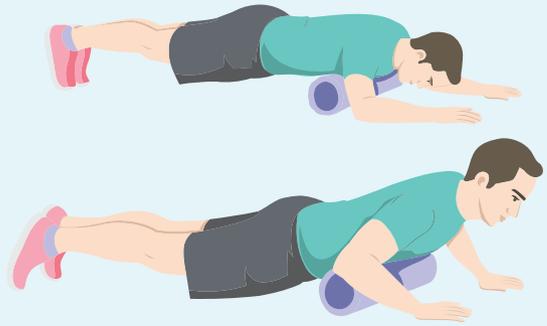
Lie with a roller on your mid-back, with hands on the ground behind, your feet flat and knees bent. Push away, rolling down from your mid-back to your buttocks, straightening your legs. Then pull back, rolling up from your buttocks to your mid-back.





### 3 Chest

For your starting position, lie face-down with a roller under your upper chest and your arms stretched overhead, but still touching the ground. Balance on your toes, and keep your head and neck lifted. Pull your body toward your forearms using your biceps, rolling down from your upper chest to your mid-abdomen (stopping before your stomach), supporting your weight on your toes, forearms and wrists. Push away, rolling back from your mid-abdomen to your upper chest.



### 4 Latissimus dorsi

Sit on the ground, leaning to your right side, with the side of your rib cage on top of the roller, resting on your right forearm with your elbow bent. Keep your right knee on the ground and your left foot wherever it's comfortable. Roll upward towards your armpit, straightening your arm. Stop at the armpit, before you reach your biceps. Roll back down from your armpit to your rib cage, bending your elbow.



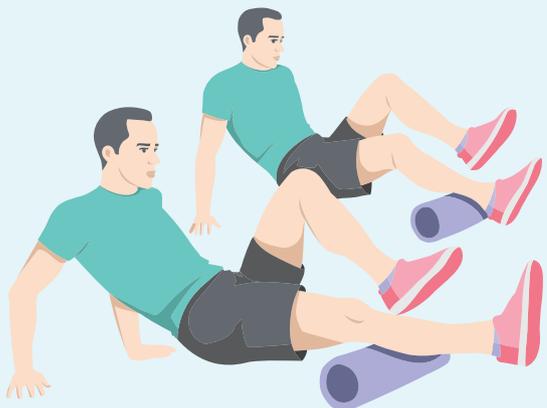
### 5 Shins (tibialis anterior)

Starting with the left side, kneel on all fours with the roller under your left ankle. Keep your head and neck lifted and use your wrists to keep yourself steady. Raise your left knee and push back, rolling up from your left ankle to your left knee, straightening your leg. Roll back down the left shin, keeping the left knee raised throughout. Repeat with the right leg.



### 6 Calves

Sit with the roller under your ankles, with your legs straight and your hands on the ground behind your buttocks. Lift your butt off the floor, hold your weight up and lift your right foot off the roller, supporting your body weight with your hands and biceps. Roll up and down your left calf muscle from ankle to knee, keeping the right calf lifted, pushing your body away with your hands. Switch legs and repeat.





### 7 Glutes

Sit upright on the roller with legs straight out in front and your hands on the mat behind your back. Start with your elbows straight. Roll back and forth over your buttocks from the top of your hamstrings to your lower back. Bend and straighten your legs, pushing with your heels as you roll back and forth.



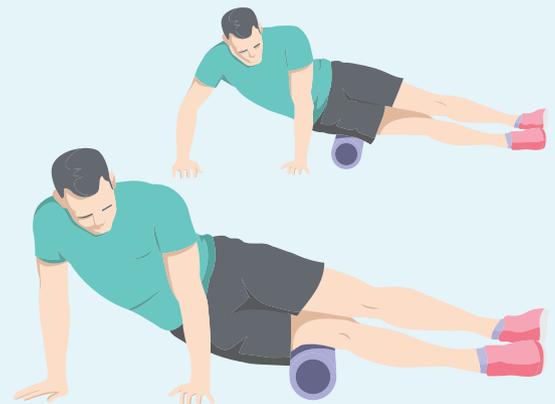
### 8 Hamstrings

Sit with a roller under the top of your hamstrings with your legs straight, your feet off the ground, and your hands behind your buttocks. Your chest should be at a 45-degree angle from the floor. Pull your body towards your hands, rolling down along the hamstrings to the back of your knees. Push your body back away from your hands, rolling up from your knees to your buttocks.



### 9 IT band

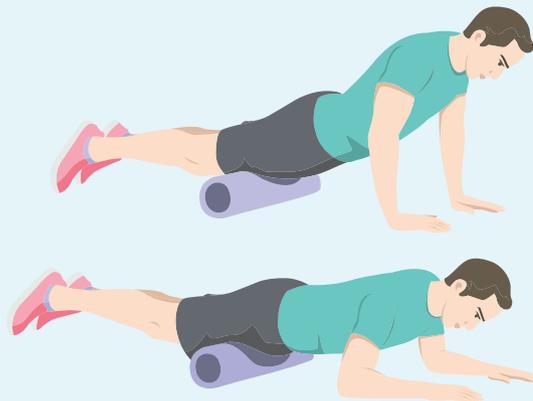
Using your arms, lift your body onto the foam roller in a side-lying position with the foam roller perpendicular to your body. Keeping your bottom leg straight and top knee bent, move your body in a back-and-forth motion from your knee to your hip, rolling along the outside of your thigh from your hip to your knee.





### 10 Quadriceps

Lie face-down with your lower thighs on top of a foam roller, just above your knee, supporting your weight on your palms and toes with your arms straight. Use your biceps to push backwards, lowering your body down, raising your feet, and roll up along the front of your thighs from your knee to mid-thigh or the top of your thighs, depending on soreness. Stop before you get to your pelvis. Pull forward, returning to a straight arm position, rolling down to the top of your knee again.



#### REFLECTION

Describe your experience using a foam roller. What are the perceived benefits? What are advantages and disadvantages to using these exercises as part of a cool-down?

Adapted from: <https://www.anytimefitness.com/ccc/how-to/how-to-effectively-foam-roll-your-upper-lower-body/>

#### CASE STUDY

#### DESIGNING A TRAINING SESSION

Erin is a 42-year-old woman who has been walking 30 minutes per day, 5 days per week, for 3 years. She has decided that she would like to begin running and participate in a 5-kilometre fun run in 6 weeks' time. She has decided to join a local Parkrun group and train with the group for the 5-kilometre run. Parkrun is a free community event where you can walk, jog, run, volunteer or spectate in a 5-kilometre trail on Saturday morning at various locations.

Using the template below, design the initial (week 1) training session for Erin that incorporates the Parkrun 5-kilometre activity.

	Warm-up	Conditioning phase	Cool-down
Activity/exercises		Running	
Intensity			
Time/duration/distance		5 km	



#### Assessment

14.3 Check-in questions

#### Command term

##### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

### 14.3 CHECK-IN QUESTIONS

- 1 What is the purpose of the cool-down component of the training session?
- 2 Grace has just completed a 5-kilometre training run at 80% max HR. **List** two activities that would be part of an appropriate cool-down for Grace.
- 3 **Explain** how a cool-down aids recovery from exercise.

## To stretch or not to stretch, that is the question!



iStock.com/Wavebreakmedia

**FIGURE 14.15** Static stretching before exercise may not provide any benefits and may be detrimental to performance.

Static stretching has been part of warm-up routines of many years, with the aim of decreasing the risk of injury and improving performance. Some studies have shown static stretching to have little or no effect on performance or on reducing injuries.

However, there is a growing body of evidence that suggests that static stretching as part of a warm-up can be detrimental to performance by decreasing force production, power output, running speed, reaction time, strength and endurance (Jeffreys, 2007). This evidence has called into question the use of static stretching in the warm-up. Additionally, a small number of studies have shown that including PNF and ballistic stretching in the warm-up can be detrimental to performance.

Conversely, dynamic stretching doesn't seem to reduce performance and may actually improve performance in subsequent activities. The additional benefit of dynamic stretching is the activation of the muscles through a range of functional movements. Current understanding is that this contributes to the neural activation requirements of an effective warm-up.

Static stretching, at best, will have no effect on performance, and may actually decrease performance, so it should not be included in the warm-up unless the activity or sport is one that requires an increased range of motion – for example, gymnastics.

Dynamic stretching is likely to be the most appropriate form of stretching to include in the warm-up for activities and sports that include dynamic movement patterns.



enjoysun24/Shutterstock.com

**FIGURE 14.16** Dynamic stretching is more appropriate as a way of preparing the body for exercise.

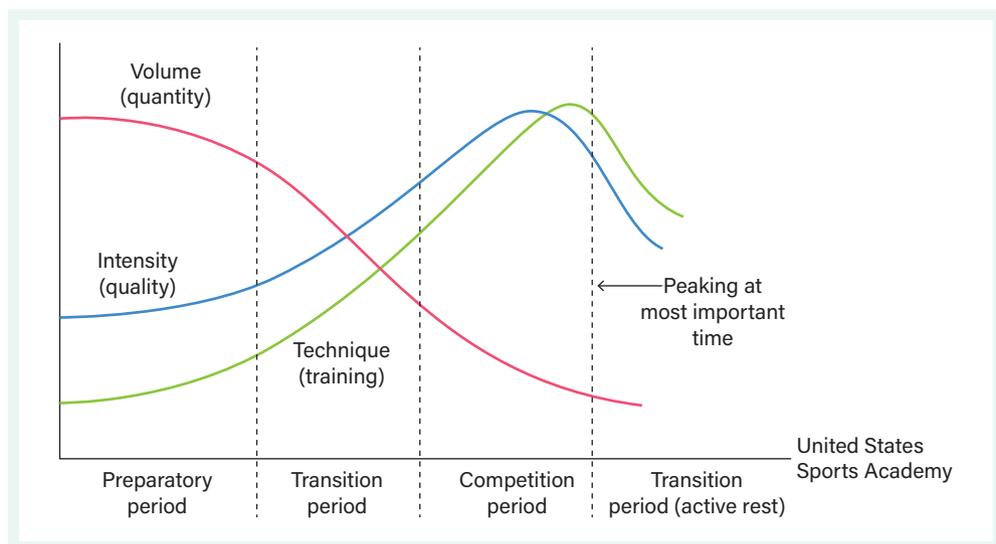
ABOVE  
AND  
BEYOND  
THE STUDY  
DESIGN



## Training phases (periodisation)

The conditioning phase of a training session will vary not only across different sports and athletes, but also across the year. Athletes plan their training to align with the competitive season or key events. The focus of training in different training phases will vary. Typically, pre-season training is high in volume and lower in intensity. As the athlete or team approaches the competition phase, volume decreases and intensity increases. The underlying principle for training is that an athlete should gradually progress from high volume and low intensity to low volume and high intensity as they prepare for competition.

Structuring training into phases (e.g. preparation, season, competition and regeneration/transition) allows athletes to reduce the risk of overtraining and injuries and to reach their peak performance at the right time, giving them the best chance of success in the tournament or event.



**FIGURE 14.17** Why don't athletes train at high volumes and high intensity at the same time?

There is no fixed timetable for the different phases of training, and the timing, length and focus of the different phases should be dynamic and adapted to the specific goals of the individual:

- Individuals who are training for a half marathon, for example, might have a 12-week training plan that builds in volume and intensity before tapering in the 7–10 days before the run.
- Tennis players will have a training plan that allows them to peak for grand slam tournaments such as the Australian Open, and then will have a 'micro' training plan for the 2 weeks of the tournament.
- Elite track and field athletes often plan to peak at the Olympic Games. Throughout the intervening 4 years, they will have multiple training phases that must incorporate the annual training plan, competitions and qualifying events.

# CHAPTER SUMMARY

## 14.1 Warm-up

- The warm-up precedes the conditioning phase and aims to prepare the body for physical activity, physiologically and psychologically.
- The warm-up has traditionally lasted between 10 and 30 minutes and included two phases:
  - general warm-up: consisting of low- to moderate-intensity aerobic exercise
  - specific warm-up: consisting of dynamic stretching and sport/activity-specific movements.
- RAMP is a contemporary framework for effective warm-ups:
  - R: raise
  - A: activate
  - M: mobilise
  - P: potentiate/prepare.



### Resource

Self-assessment checklist

### Video

Masterclass: Chapter 14

## 14.2 Conditioning phase

- The conditioning phase is where the work is done to improve the relevant energy systems and fitness components.
- The conditioning phase aims to improve areas of weakness or to improve or maintain specific fitness components or energy systems.
- The appropriate training method is selected for the conditioning phase to achieve the desired outcome of the program.

## 14.3 Cool-down

- The purpose of the cool-down is to aid recovery and return the body to pre-exercise state.
- The cool-down usually lasts 5–15 minutes and consists of low- to moderate-intensity exercises that use the same muscle groups and movement patterns as were used during the conditioning phase of the training session.
- Foam rolling in the cool-down can aid recovery and reduce DOMS.
- The use of static stretching in the warm-up (and cool-down) is contentious and is generally not recommended.
- The design of an effective training program will:
  - include a clear aim
  - be specific to the requirements of the activity
  - utilise appropriate training methods
  - have correctly applied training principles
  - be monitored and evaluated.

# CHAPTER REVIEW



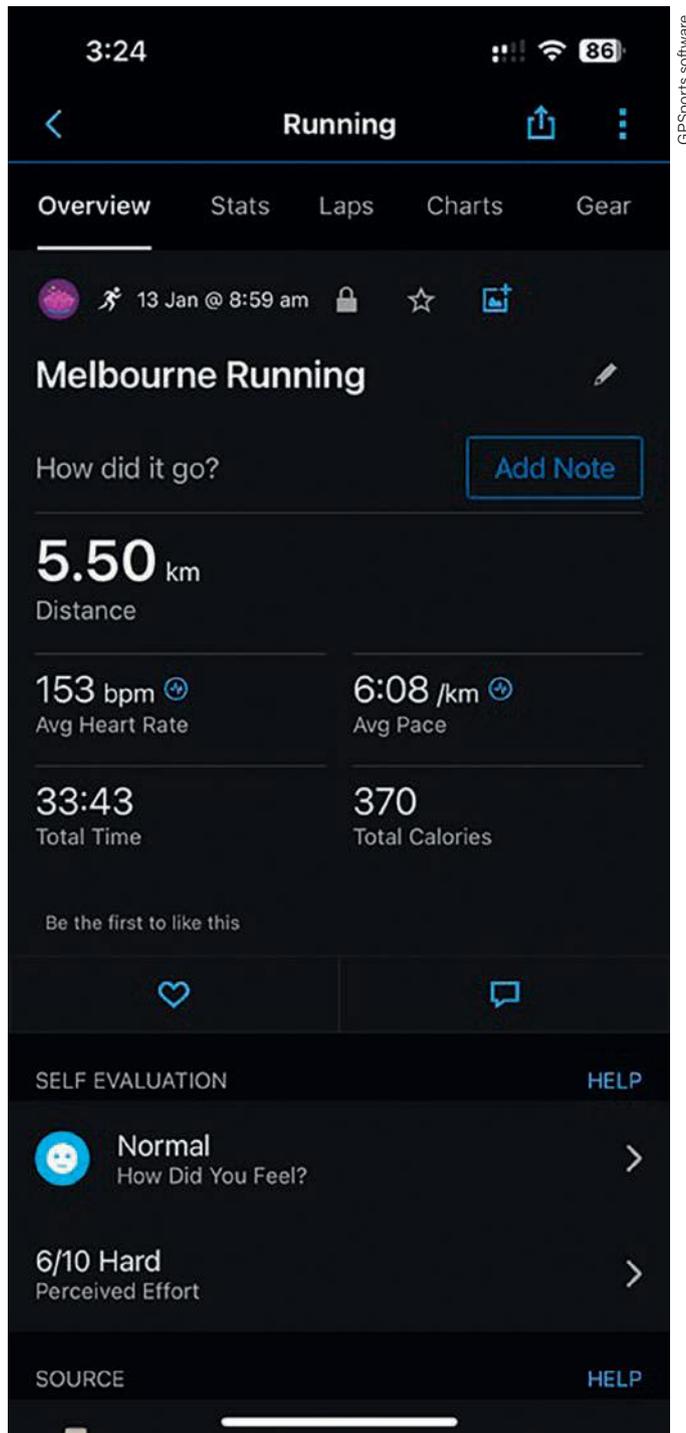
## Assessment Chapter 14 Review

- 1 Which training method would be most appropriate to include in the conditioning phase of a training session for improving a soccer player's kicking power?
  - A interval training
  - B plyometrics
  - C continuous training
  - D HIIT
- 2 You have been asked to design the conditioning phase for a group fitness class focused on improving aerobic power and muscular strength. The participants are diverse, with varying fitness levels and goals. Which exercises would be most suitable for achieving the diverse goals of the participants while focusing on the aims of the class?
  - A high-intensity interval training (HIIT) incorporating exercises such as burpees, jumping jacks and mountain climbers
  - B low-intensity steady-state cardio, such as brisk walking or light jogging for an extended duration
  - C strength training exercises with heavy weights and low repetitions, such as deadlifts and bench presses
  - D static stretching routines focusing on flexibility and mobility exercises for the entire body
- 3 What is the primary purpose of including a cool-down in an exercise session?
  - A to increase the heart rate
  - B to prepare the body for intense exercise
  - C to gradually return the body to pre-exercise levels
  - D to build muscle strength
- 4 What is the primary objective of an effective warm-up, and how does it prepare the body for more intense exercise?
- 5 Provide two examples of dynamic warm-up exercises that target major muscle groups. How do these differ from static stretching in terms of preparation for exercise?
- 6 How can the conditioning phase be tailored to accommodate individuals with different fitness levels and goals? Provide examples of how intensity and the exercises chosen may vary.
- 7 How does the cool-down phase contribute to the prevention of muscle soreness and injury, especially after an intense conditioning phase?
- 8 How might ongoing research influence the way athletes approach static and dynamic stretching in the coming years?
- 9 Digital activity trackers are useful tools for monitoring training. The data in the screenshot on the next page is from the conditioning phase of a training session for a 51-year-old female recreational runner who is aiming to complete 5 kilometres in 30 minutes. From the data provided, **evaluate** the effectiveness of the conditioning phase of the training session in achieving the runner's goal.

### Command term

#### evaluate

Ascertain the value or amount of; make a judgment using the information supplied, criteria and/or own knowledge and understanding to consider a logical argument and/or supporting evidence for and against different points, arguments, concepts, processes, opinions or other information



- 10 You have been asked to design a strength training session for a friend who is an avid hiker and currently hikes moderate trails regularly, but wants to improve their leg strength before tackling some more challenging hikes. Your friend has a reasonable level of fitness but has never done strength training before.

Design a strength training session, including the warm-up, conditioning phase and cool-down, that specifically targets the leg muscles, your friend's hiking goals and their fitness level.

# CHAPTER 15

## CHRONIC TRAINING ADAPTATIONS

UNIT 4 - AREA OF STUDY 2



Sam Barnes/Sportsfile/Getty Images

**FIGURE 15.01** At the Tokyo Paralympic Games in 2021, Madison de Rozario became the first Australian woman to win wheelchair marathon gold.

### Quizzes

Chapter 15 Pulse check

- 15.1** Check-in questions
- 15.2** Check-in questions
- 15.3** Check-in questions
- 15.4** Check-in questions
- 15.5** Check-in questions
- 15.6** Check-in questions

Chapter 15 Review

### Videos

Masterclass: Chapter 15

- 15.1** In focus: Improving  $VO_2$  maximum
- 15.3** In focus: Improving speed and force of muscular contractions
- 15.6** In focus: Improving the lactate inflection point
- 15.6** In focus: Improving lactate tolerance

### Resources

Chapter 15 Self-assessment checklist

 Nelson MindTap

To access resources above, visit  
[cengage.com.au/nelsonmindtap](https://cengage.com.au/nelsonmindtap)



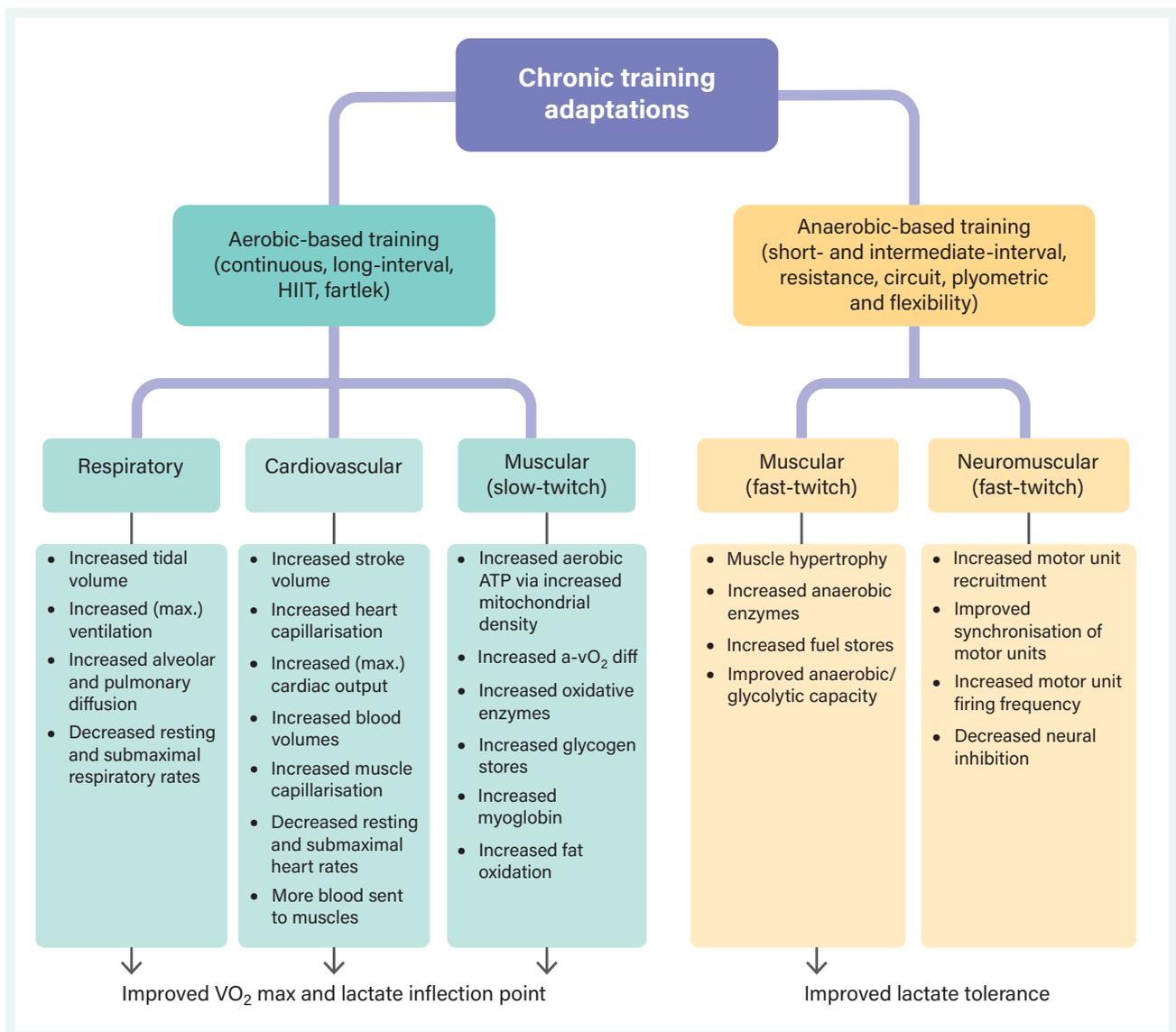
- » chronic adaptations of the cardiovascular, respiratory and muscular systems to aerobic, anaerobic and resistance training that produce improvements in:
  - $\text{VO}_2$  max
  - lactate inflection point (LIP)
  - speed and force of muscular contraction
  - lactate tolerance

## KEY KNOWLEDGE

- » explain how the cardiovascular, respiratory and muscular systems' chronic adaptations to training lead to improved performance

## KEY SKILLS

Source: Victorian Certificate of Education Physical Education Study Design (2025–2029)



**Video**

Masterclass: Chapter 15

Training aims to bring about improvements to the cardiovascular, respiratory and muscular body systems. Remember that these body systems do not work in isolation; they combine to bring about improved sporting performances, physical fitness or participation in recreational activities.

Long-term training effects are also referred to as chronic adaptations and occur as a result of our bodies changing to better meet training demands. Once the adaptations have occurred, they will be retained unless training ceases, which will see the adaptations revert to pre-training levels in less than the time it took for them to be achieved. Chronic adaptations will occur in response to the:

- type of training undertaken
- intensity, duration and frequency of training
- individual training status and capacity.

**Assessment**

Pulse check

**PULSE CHECK**

Take the pulse check quiz to check your prior knowledge and understanding of the concepts covered in this chapter.

- 1 When undertaking aerobic training, what changes occur at the heart that allows more blood to be pumped out per beat?
- 2 What changes occur at the lungs of triathletes that enable them to take in more oxygen per breath/minute?
- 3 What allows sprinters to make reasonable middle distance (5,000–10,000 metre) runners, while marathon runners struggle to perform well in sprint events?
- 4 Tour de France cyclists can have more than twice the blood volume (10+ litres) of the average adult (4–5 litres). How would this provide them with significant advantages as endurance athletes?
- 5 Power-based athletes typically include plyometrics in their training. **List** two changes that occur at their muscles to enable them to jump, throw, kick and strike with greater power.

**Video**In focus: Improving  
VO<sub>2</sub> maximum

## 15.1 RESPIRATORY ADAPTATIONS

In this module you will learn about:

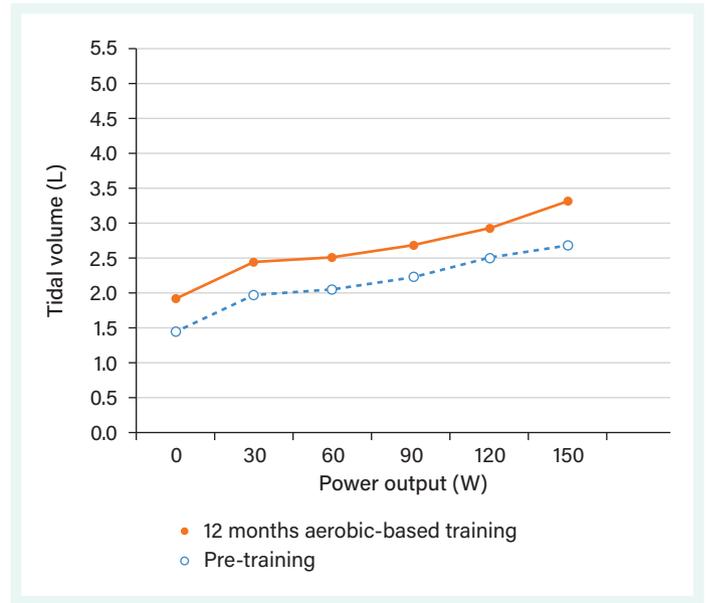
- increased ventilation and associated respiratory functions
  - improved gaseous exchange and diffusion at the lungs
- and learn to:
- link respiratory adaptations to improved respiratory efficiencies.

Aerobic-based training seeks to improve both the amount of energy/ATP the aerobic energy system can produce and the efficiency of its production. Respiratory adaptations essentially occur at the lungs and work towards increasing the uptake of oxygen by the performer, and thus contribute to greater amounts of aerobic ATP being available to working muscles.

## Increased tidal volume

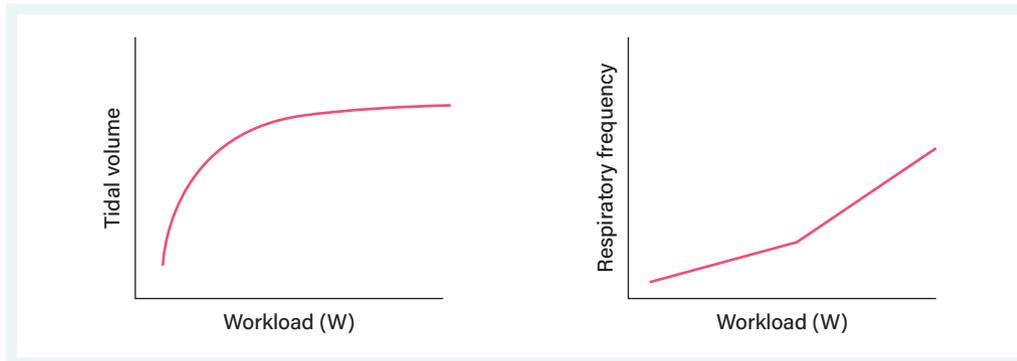
The amount of air breathed in and out with each breath increases when there is an improved efficiency of the respiratory muscles – the **diaphragm** and the **intercostal muscles**. These muscles contract more forcefully, expanding the thoracic cavity and lung volume and causing the rib cage to expand and move outwards, which allows more air to be taken in. As a consequence, more oxygen then becomes available to diffuse into the capillaries surrounding the **alveoli** to start the journey to the muscles via the bloodstream.

It is worth noting that, in the example shown in Figure 15.02, tidal volume continues to increase in a linear fashion along with exercise intensity. However, a power of 150 watts is quite moderate, and tidal volume will most likely stop increasing just beyond this point when it reaches a **finite capacity**. At this stage, subjects cannot expand their chest cavity any further as the diaphragm and intercostal muscles are at their contraction limits, and tidal volume plateaus.



**FIGURE 15.02** Tidal volume during an incremental test

Adapted from Kapus, J., Ušaj, A. & Lomax, M. (2013), 'Adaptation of endurance training with a reduced breathing frequency,' in *Journal of Sports Science & Medicine*, 12(4), pp. 744–752.



**FIGURE 15.03** Changes in tidal volume and respiratory rate with increasing workload

### diaphragm

A thin, dome-shaped muscle, located below the lungs, that assists us to inhale and exhale

### intercostal muscles

Muscles, located between the ribs, that create and move the chest wall

### alveoli

The very small air sacs, found at the lungs, where exchange of oxygen and carbon dioxide (gaseous exchange) takes place

### finite capacity

An amount or point beyond which no further increases are possible

## LOOKING BACK

### Training principles

#### Chapter 12

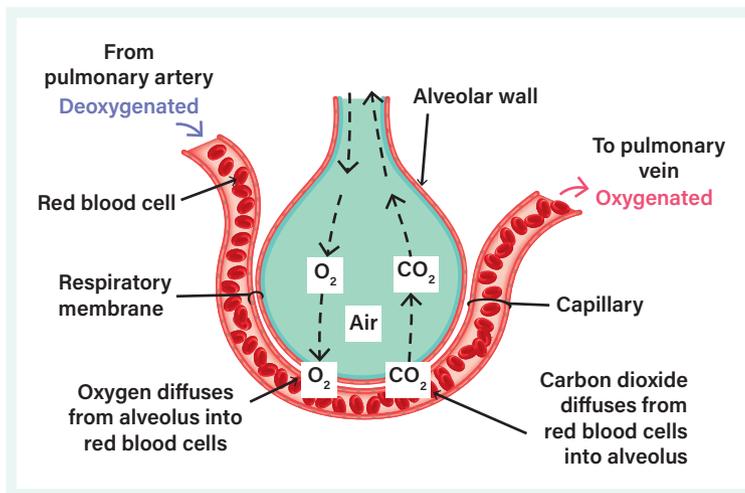
The type of training and the correct application of training principles are vital to ensure specific and long-term adaptations occur.

## DID YOU KNOW?

Air is a mixture of different gases, and oxygen only makes up about 21 per cent of the air we breathe. About 78 per cent of air is nitrogen, and the remainder is made up of a variety of other gases.

## Increased pulmonary and alveolar diffusion

After engaging in aerobic-based training, the size and number of the alveoli found within the lungs increases significantly. This, in turn, increases the surface area over which oxygen and carbon dioxide



**FIGURE 15.04** Increases in the size and number of alveoli as a result of aerobic training lead to increased pulmonary diffusion.

### **gaseous exchange**

The process by which oxygen moves from the lungs to the bloodstream and, at the same time, carbon dioxide passes from the blood to the lungs

### **systemic circuit**

Blood vessels that transport oxygenated blood from the left side of the heart to the tissues of the body

### **steady state**

A situation that occurs when exercise intensity remains unchanged or within a small range, and variables such as oxygen uptake and heart rate remain stable, because almost all of the ATP is being produced aerobically

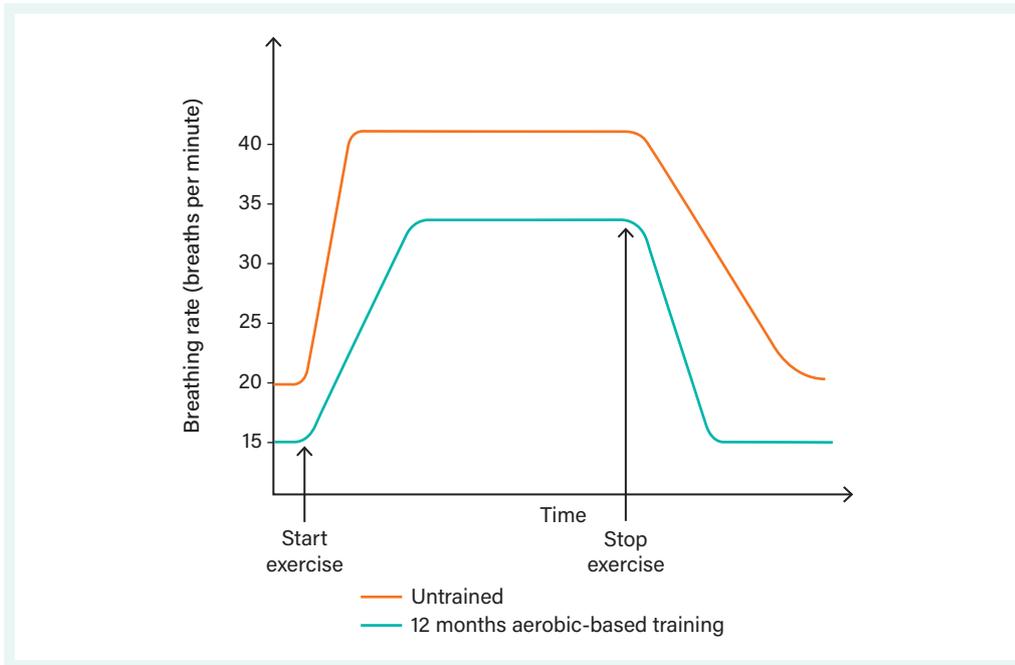
can be exchanged and can diffuse from areas of high concentration to areas of lower concentration – a process known as **gaseous exchange**. Because the air in the alveoli has a higher oxygen concentration than that in the surrounding capillaries, oxygen will diffuse into these capillaries, to be taken to the heart and then pumped out to working muscles via the **systemic circuit**.

Conversely, carbon dioxide is found in higher concentration in the same capillaries surrounding the alveoli than in the air space within them. Thus it diffuses out of the capillaries and into the alveoli, to be exhaled with the next breath. Increased respiratory rate and tidal volume combine to produce ventilation and, when this increases, more oxygen is made available for working muscles.

## Decreased resting and submaximal respiratory rates

Because the lungs have increased their efficiency and are able to take in larger amounts of oxygen at less cost (energy) there is an associated decrease in resting and submaximal respiratory rate. Essentially, the body can supply sufficient oxygen with fewer breaths per minute up to submaximal workloads. The direct performance benefit is that this decreases the rate of fatigue by allowing the performer to work at higher aerobic workloads with less oxygen and fuel usage.

In the graph in Figure 15.05, it is worth noting that the respiratory rate plateaus – that is, it reaches a stage where it no longer continues to increase. There would be an associated plateau in heart rate, and this is referred to as **steady state**. This provides evidence that the subject was working submaximally.



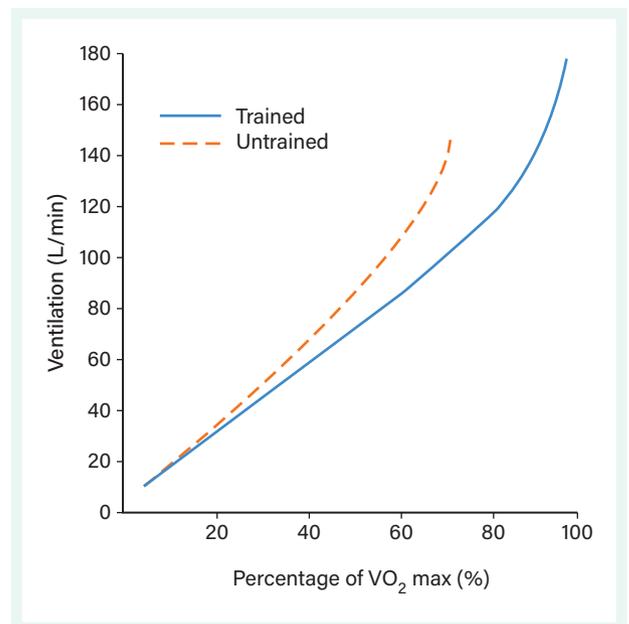
**FIGURE 15.05** Breathing rate before, during and after moderate-intensity exercise in a trained and an untrained subject

## Increased maximal ventilation

Ventilation (VE) is also known as pulmonary ventilation and minute ventilation. It measures the volume of inhaled and exhaled air over 1 minute and is usually expressed in litres per minute (L/min).

$$\text{ventilation} = \text{tidal volume} \times \text{respiratory rate}$$

We have seen that tidal volume increases up to a finite level. Beyond this point, the respiratory rate is the only variable leading to increased ventilation. At maximal workloads, the respiratory rate is also at its peak. Aerobic training leads to larger amounts of air being inhaled and exhaled per minute, resulting in greater amounts of oxygen being made available for diffusion and subsequent transport to working muscles.



**FIGURE 15.06** Ventilation in trained and untrained subjects during an incremental test to fatigue

Adapted from Brooks, G.A., Fahey, T.D. & White, T.P. (2005), *Exercise Physiology: Human bioenergetics and its applications* 4th edn, McGraw-Hill Education



## Assessment

15.1 Check-in questions

## Command terms

**state**

Give a specific name or value or other brief answer without explanation or calculation

**propose**

Suggest or put forward a point of view, idea, argument, diagram, plan and/or suggestion based on given data or stimulus material for consideration or action

**hypertrophy**

The enlargement of an organ or tissue due to an increase in size of its cells

## 15.1 CHECK-IN QUESTIONS

- State** the formula for ventilation.
- ©VCAA Exam 2020, Section A, Q6  
Which one of the following adaptations would be observed in the respiratory system after 12 weeks of fartlek training three times per week?
  - maintained lung volumes
  - increased haemoglobin levels
  - decreased alveolar surface area
  - increased ventilation at maximal intensity
- Clearly **explain** what is meant by tidal volume having a 'finite capacity'!
- A training adaptation accompanying aerobic-based training increases respiratory efficiency. **Discuss** how this allows more oxygen to become available for working muscles.
- Propose** how training under high-altitude conditions, where there is less oxygen in air that is inhaled than under normal conditions, eventually leads to increased alveolar surface area as an adaptation.

## 15.2 CARDIOVASCULAR ADAPTATIONS

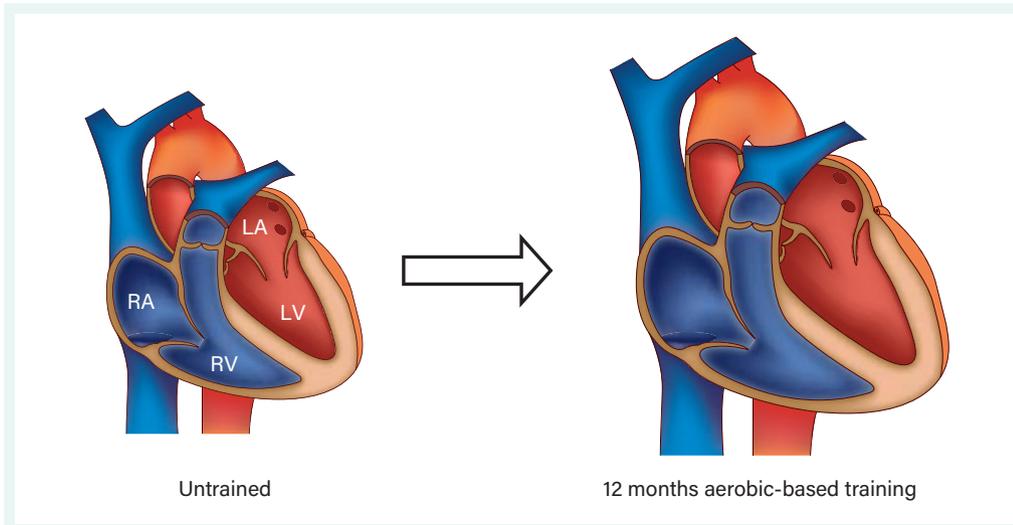
In this module you will learn about:

- cardiac output increasing due to multiple training adaptations
  - increased vascularisation and blood volumes
- and learn to:
- explain how the heart becomes more efficient with aerobic exercise
  - describe how blood is redistributed via the 'vascular shunt' to areas of 'need'.

Cardiovascular adaptations include those occurring to the heart, blood vessels and blood. Essentially, these work towards increasing the delivery or supply of oxygen and fuels to working muscles, while also improving the removal of wastes and metabolic by-products that occur as a result of increased muscle contractions.

### Increased stroke volume

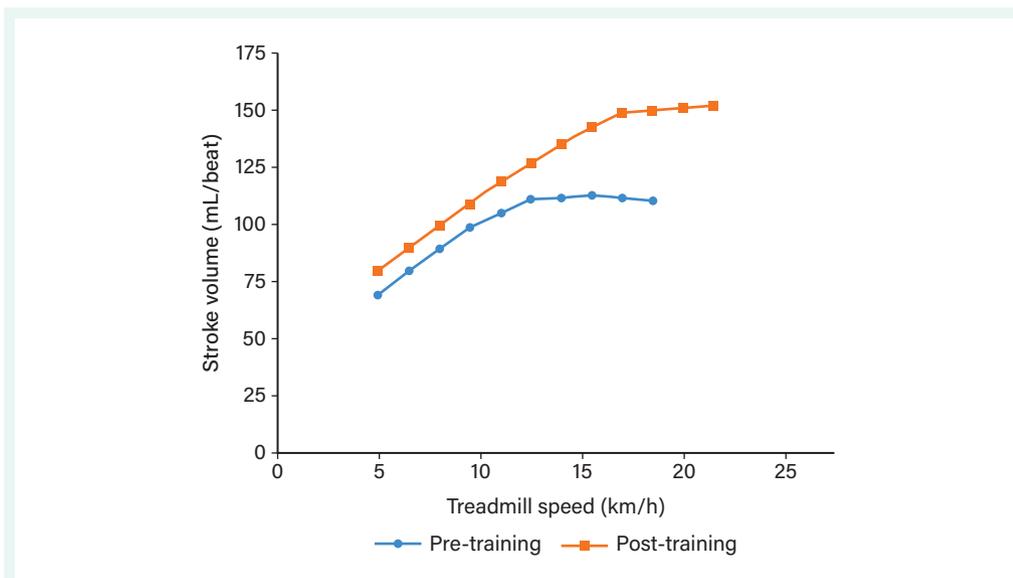
Consistent participation in aerobic-based activities and training will lead to **hypertrophy** of the heart muscle. Both left and right atria and ventricles will increase in size and will be able to take in and squeeze out more blood, respectively. This has a great advantage for endurance athletes in that it also allows more oxygen to be transported to working muscles. Additionally, like any other muscle, the heart wall will respond to training by becoming bigger and able to contract more forcefully. Figure 15.07 reveals a significant difference occurring to the left side of the heart (atrium, ventricle and muscle/wall) which is responsible for pumping blood to the rest of the body.



**FIGURE 15.07** Changes to the heart's atria (RA and LA) and ventricles (RV and LV) resulting from aerobic-based training

Because cardiac output ( $Q$ ) is the product of stroke volume ( $SV$ ) and heart rate ( $HR$ ), increases in stroke volume will bring an associated increase in the amount of blood pumped out of the heart, not just per beat, but also per minute. (We will learn later why this leads to lower heart rates at rest and at submaximal intensities.) As a result, the heart muscle requires less oxygen to achieve what it could before training up to maximal levels (this is sometimes referred to as the heart becoming 'more efficient') and more oxygen becomes available for working muscles.

Figure 15.08 suggests further advantages that endurance athletes gain by having a higher stroke volume. As well as the ability to pump out more blood, oxygen and fuels per beat, higher stroke volume also contributes to endurance athletes being able to perform for longer and at higher intensities.



**FIGURE 15.08** Changes in stroke volume resulting from aerobic-based training



## COLLABORATIVE TASK

### Prac activity/Lab activity

#### Cardiovascular adaptations indicated by resting heart rate and submaximal response to exercise

Your resting heart rate can give an indication of your fitness level and possible training adaptations.

##### HOW TO MEASURE RESTING HEART RATE

Lie down for at least 10 minutes before measuring your heart rate. The best time to do this is early in the morning, before you get out of bed. Even getting up and walking around your bedroom can increase your heart rate (acute response). However, do not start measuring your heart rate as soon as you wake up. Allow your body a few minutes to relax, then use one of the following methods:

- radial pulse (wrist) – place the tips of your index and third fingers on the thumb side of your other wrist. Press gently and you will sense the beats. Timing yourself with a clock (or the stopwatch on a mobile phone), count the beats for 10 seconds. Multiply the result by 6.
- carotid pulse (neck) – place your fingertips below your jaw, along the windpipe and throat. Measure as for radial pulse.
- smart watch with pulse read technology.

##### HEART RATE RESPONSE TO SUBMAXIMAL EXERCISE

Use a smart watch or chest-strap heart rate monitor to record your heart rate before exercise (resting) and in response to 5 minutes of submaximal running (jogging) around a netball or basketball court. Present your results, and those of two classmates, in the following table:

	My heart rate	Classmate 1 heart rate	Classmate 2 heart rate
Resting (at home)			
Resting (pre-exercise at school)			
After 1 minute			
After 2 minutes			
After 3 minutes			
After 4 minutes			
After 5 minutes			
After 1 minute of recovery			
After 2 minutes of recovery			
After 3 minutes of recovery			



**DISCUSSION**

- 1 **Compare** your resting heart rate with those of your classmates. Who has the lowest resting heart rate? What factors might contribute to a low resting heart rate?
- 2 Is there any relationship between resting heart rate and the activities/sports you and your classmates train for or perform outside school hours?
- 3 **Explain** how a lower resting heart rate is indicative of a more efficient cardiovascular system. (Hint: remember  $Q = SV \times HR$ .)
- 4 Did you or either of your classmates reach 'steady state' during the 5-minute jog? What occurs at steady state in the respiratory and cardiovascular systems?
- 5 It is likely that there was a difference in the rate of increase in heart rate in response to the jog around the court. Briefly **discuss** why some heart rates increased more rapidly than others despite all subjects running at the same or similar pace.
- 6 **Compare** recovery heart rates following the 5-minute jog. Is there any relationship between the speed of return towards resting heart rate and the aerobic fitness of subjects? Briefly **discuss** why this might be the case.

**Command term****compare**

Recognise similarities and differences and the significance of these similarities and differences

**LOOKING BACK****Acute responses to exercise****Chapter 5**

Acute responses such as increased stroke and tidal volumes become permanent as a result of regular training.

**DID YOU KNOW?**

The heart is the hardest-working muscle in our body, and over the course of a lifetime it may contract and relax repeatedly to record more than 3 billion beats.

## Decreased resting and submaximal heart rates

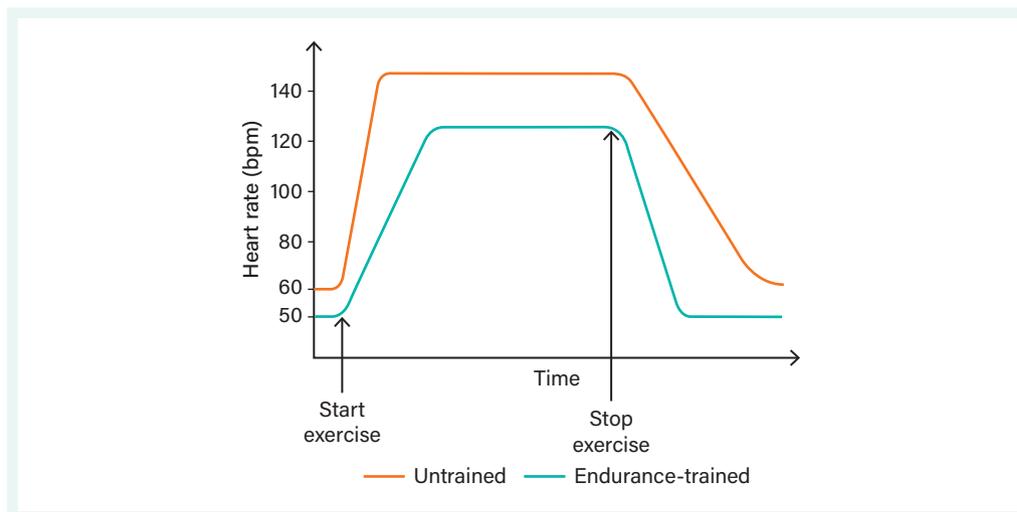
If the heart is able to pump out more blood as a result of cardiac hypertrophy, it will not need to pump as frequently to supply muscles with the amounts of oxygen and fuels they need to meet the demands of the activity. The following example clearly shows this, while also considering cardiac output and how changing stroke volumes impact on heart rate, at rest and submaximal levels.

Let's assume it takes 4.2 litres of blood to supply sufficient oxygen to meet the body's demands at rest, and this increases to 9.0 litres of blood when performing a jog. We can see that the resting and submaximal heart rates have both decreased by just over 20 per cent as a result of having a higher stroke volume.

**TABLE 15.01** Cardiac output at rest and during submaximal exercise (jogging) before training and after 6 months of aerobic-based training

	Cardiac output (Q) (mL/min)	Stroke volume (SV) (mL/beat)	Heart rate (HR) (bpm)
<b>Pre-training</b>			
Rest	4,200 = 4.2 L/min	70	60
Jogging	9,000 = 9.0 L/min	70	129
<b>Post-training</b>			
Rest	4,200 = 4.2 L/min	90	47
Jogging	9,000 = 9.0 L/min	90	100

It is also worth noting that a higher stroke volume allows athletes to respond more quickly to increased exercise oxygen demands, and will also allow them to reach steady state sooner. Figure 15.09 shows the less rapid increase in stroke volume from rest and the quicker ability to plateau at submaximal intensities. Notice the similarity between this relationship and that shown in Figure 15.05. This results from the fact that the heart pumps blood, which carries oxygen, and both heart rate and respiratory rate respond similarly to exercise demands and aerobic-based training when considering tidal/stroke volumes.

**FIGURE 15.09** Resting heart rate and response to submaximal exercise in untrained and endurance-trained athletes

### DID YOU KNOW?

Resting heart rates are an indicator of how aerobically trained an athlete is, with lower rates being associated with higher levels of aerobic fitness. Conversely, an elevated resting heart rate is often a 'red flag' that something is not quite right with training loads, that recoveries may not be occurring efficiently or that the person may be under some form of psychological stress.

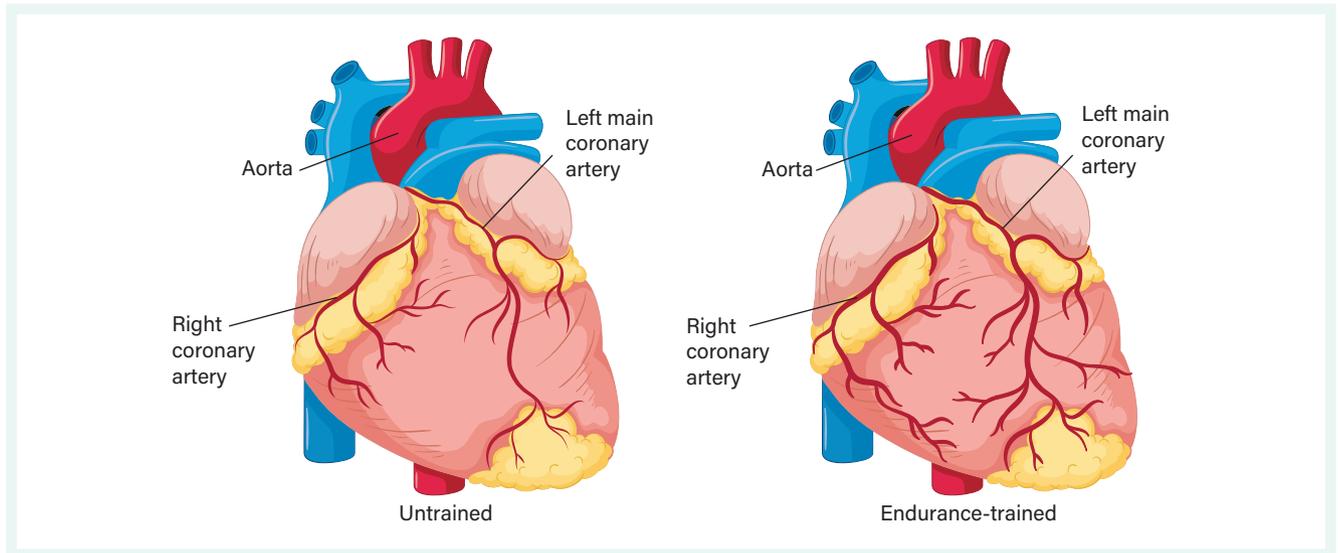
## Increased heart capillarisation

Aerobic training leads to increased cross-sectional area of the coronary arteries and associated capillaries that supply the heart. Increased arterial size and capillary numbers results in more blood reaching the heart, which in turn also means more oxygen feeding the **myocardium**.

---

### myocardium

The muscular tissue of the heart



**FIGURE 15.10** Capillarisation of the heart in untrained and endurance-trained subjects

## Increased cardiac output (maximum)

### Increased blood volumes

Regular aerobic-based training can significantly increase blood volumes with the greatest changes occurring to plasma levels and then red blood cell concentration. **Plasma** is vital in reducing the viscosity of blood and allowing it to flow at a faster rate throughout the body. This means that oxygen is transported to working muscles at a faster rate, with less resistance throughout the circulatory system. Endurance athletes need as much aerobic ATP to be produced as possible at the highest intensity below LIP and higher plasma levels contribute to this.

Higher plasma levels are also advantageous to endurance athletes trying to **thermoregulate** in the face of elevated body temperatures and dehydration. Plasma also helps to remove waste products by transporting them to the liver, lungs, kidneys or skin, and also transports fuels, electrolytes and hormones throughout the body. See Figure 15.11 on the next page.

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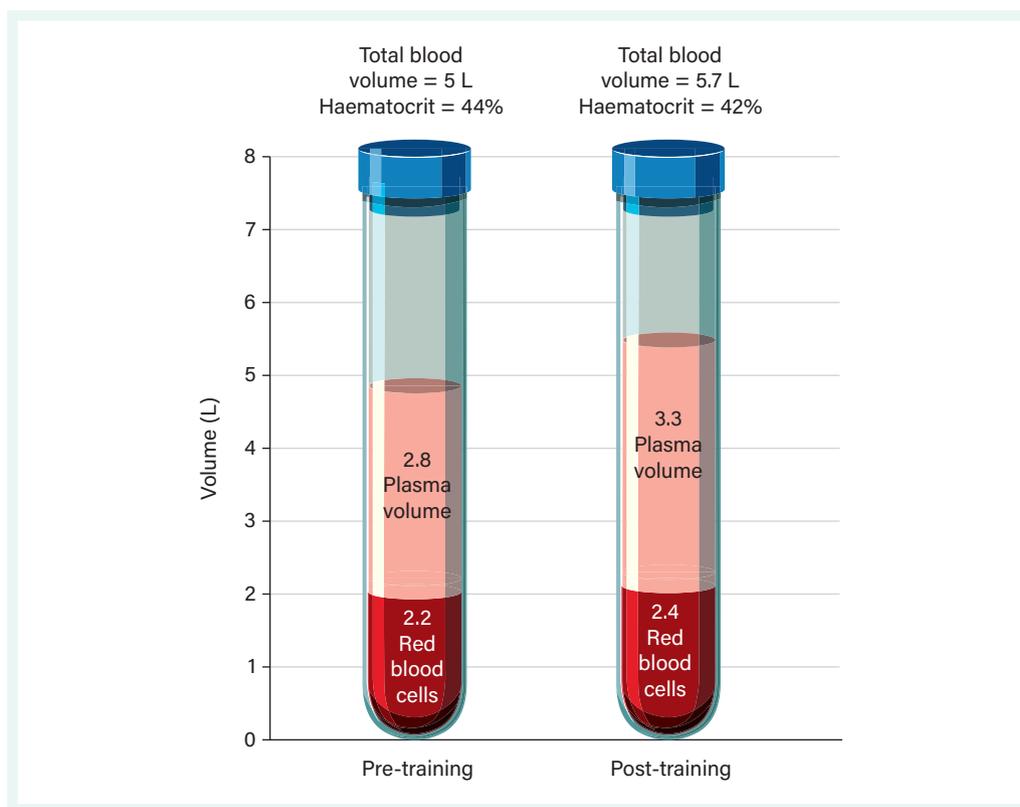
### plasma

The liquid portion of blood that transports fuels to cells, removes wastes from cells and helps maintain body temperature

---

### thermoregulate

To maintain a steady internal body temperature through a homeostatic process



**FIGURE 15.11** Blood changes in response to aerobic-based training

Adapted from Wilmore, J.H. & Costill, D.L. (2004), 'Cardiovascular and respiratory adaptations to training,' in *Physiology of Sport and Exercise* 3rd edn, Human Kinetics, pp. 270–305



## ABOVE AND BEYOND THE STUDY DESIGN

Haematocrit, page 623

### LOOKING BACK

#### Fatigue and recovery

##### Chapter 7

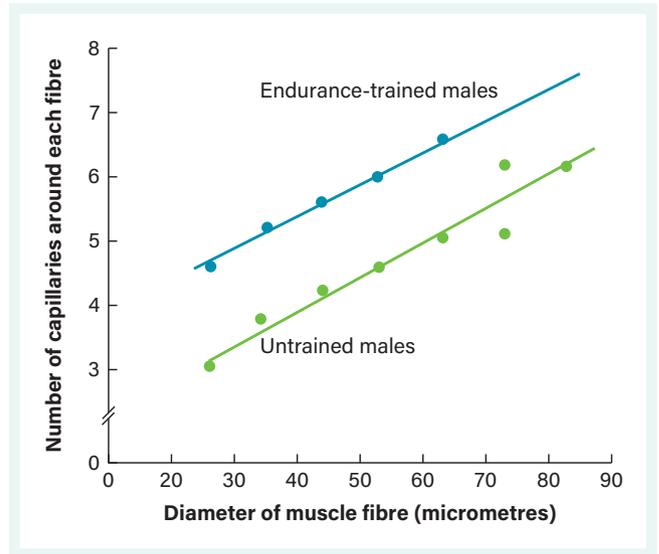
Increased numbers of red blood cells capable of carrying more oxygen, and greater plasma levels, which assist in thermoregulation and removal of wastes, contribute to delayed fatigue and improved recovery from exercise and training.

## Increased muscle capillarisation

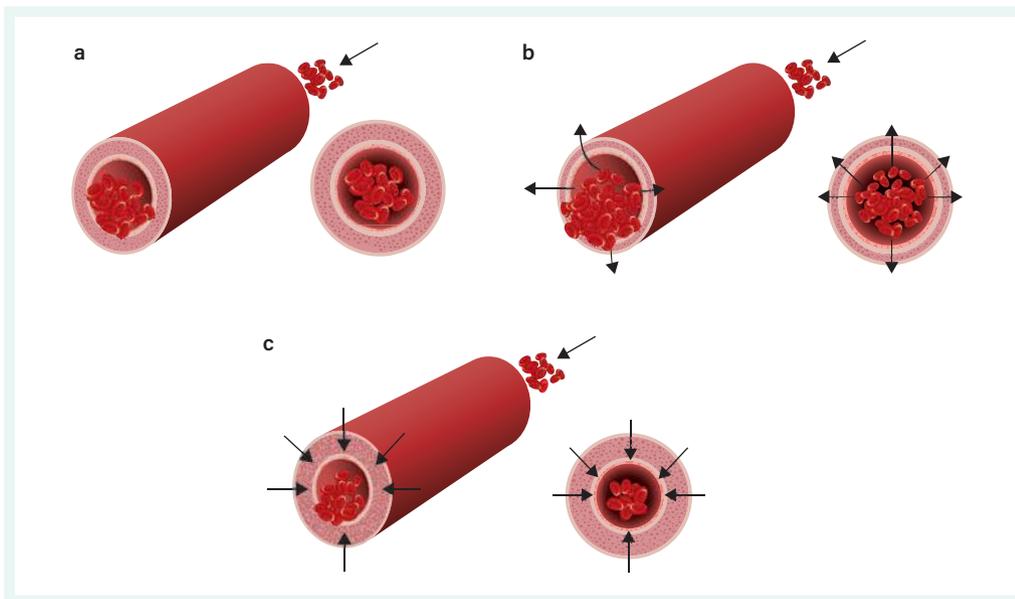
Capillaries are small blood vessels within the body's tissues that help to transfer blood to and from the muscles. As you have previously read, increased capillarisation occurs when the capillaries supplying muscles – in particular, slow-twitch fibres – increase in both size and number. This is sometimes referred to as increased capillary density, since it results in more capillaries being found per square millimetre of muscle tissue. A high muscle capillary density

means a large surface area for muscle-to-blood exchange, short oxygen diffusion distance, and high average red blood cell transit time – all contributing to greater exchange of gases, supply of fuels and removal of wastes from muscles. The more quickly waste products can be removed, the faster the repair and recovery processes can occur, and the shorter the time required between training sessions.

An increase in capillaries results in an increase in blood flow to the muscles, which also increases supplies of oxygen and fuels required to produce energy. When capillarisation is increased, muscles are able to work at higher intensities aerobically for longer periods without the accumulation of fatiguing by-products.



**FIGURE 15.12** Number of capillaries based on fibre size and endurance training



Julia Dolovanuk/Shutterstock.com

**FIGURE 15.13** Blood vessels permit more or less blood to flow according to whether they are: **a** at rest (normal); **b** undergoing vasodilation (increasing blood flow); or **c** undergoing vasoconstriction (decreasing blood flow).

**vascular shunt**

The process of redistributing blood throughout the body through simultaneous vasoconstriction and vasodilation, depending on physiological needs

**vasodilation**

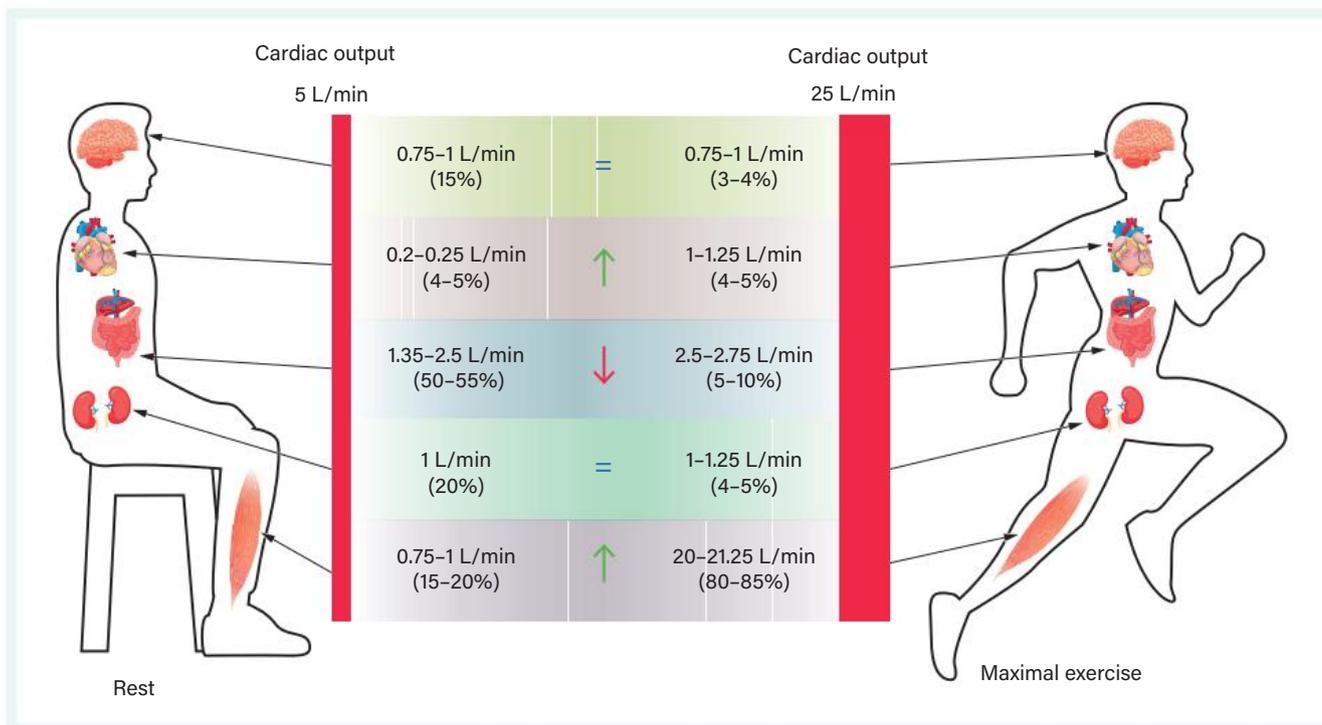
A process whereby blood vessels increase/expand their internal diameter, resulting in an increase in blood flow

**vasoconstriction**

A process whereby blood vessels narrow/constrict their internal diameter, thereby decreasing blood flow

## Redistribution of blood

During exercise, the cardiovascular system redistributes the blood so that more of it goes to the working muscles and less goes to other body organs, such as the digestive system. This redirection of blood flow is caused by a mechanism (or process) called the **vascular shunt** mechanism. More blood is sent to working muscles when blood vessels supplying them undergo **vasodilation** and, simultaneously, less blood flows to body organs when **vasoconstriction** of supplying blood vessels occurs. More blood means more oxygen and fuels supplied and more waste removed, which all combine to meet the exercise demands and delay the onset of fatigue.



**FIGURE 15.14** Blood flow during rest (left) and redistribution during exercise (right)

Adapted from Taylor, J.A. et al. (2023), 'Multisystem physiological perspective of human frailty and its modulation by physical activity', in *Physiological Reviews*, 103(2), 1137–1191. CC BY 4.0



**Assessment**

15.2 Check-in questions

**Command terms**

**define**

Give the precise meaning and identify essential qualities of a word, phrase, concept or physical quantity

**outline**

Provide an overview or the main features of an argument, point of view, text, narrative, diagram or image



**Video**

In focus: Improving speed and force of muscular contractions

## 15.2 CHECK-IN QUESTIONS

- Define** 'cardiac output' and **list** the variables that combine to produce it.
- Explain** what is meant by the following statement: 'Vasodilation is always matched by vasoconstriction.'
- Outline** two performance benefits for a triathlete that are associated with increased plasma volumes.
- Discuss** changes to the composition of blood that allow endurance athletes to deliver more oxygen to their working muscles as a chronic adaptation.
- Propose** how a decreased submaximal heart rate contributes to improved endurance performance for an athlete such as a Tour de France cyclist.

## 15.3 MUSCULAR ADAPTATIONS: AEROBIC-BASED TRAINING

In this module you will learn about:

- linking slow-twitch adaptations to improved aerobic ATP production
- improved fuel storage and usage due to aerobic training and learn to:
  - differentiate between slow- and fast-twitch relevance to performance
  - identify and explain how muscle fibre adaptations improve endurance performance.

Muscles are made up of a mixture of slow-twitch and fast-twitch fibres, which preferentially respond to specific training methods. Slow-twitch fibres have significant adaptations to aerobic-based training, whereas fast-twitch fibres change more in response to anaerobic-based training. Some fast-twitch fibres can adopt slow-twitch characteristics and change when aerobic training is undertaken.

Aerobic training will preferentially target slow-twitch fibres, which is where the greatest adaptations occur. Few, if any, changes occur at fast-twitch fibres in response to aerobic-based training; power, strength and speed of contraction remain relatively unchanged. Muscular endurance may be improved as a result of reliance on the aerobic energy system and contribution from slow-twitch fibres (any repeat contractions occurring over more than 1 minute: e.g. arms and legs when used to row 2,000 metres; legs when used to propel a cross-country skier 50 kilometres; or a windsurfer isometrically contracting on the boom during a 4-minute heat).



iStock.com/LifeJourneys

**FIGURE 15.15** Slow-twitch fibres contract over extended periods and respond to aerobic-based training.

## REAL WORLD APPLICATIONS

### Which muscle fibre is that?

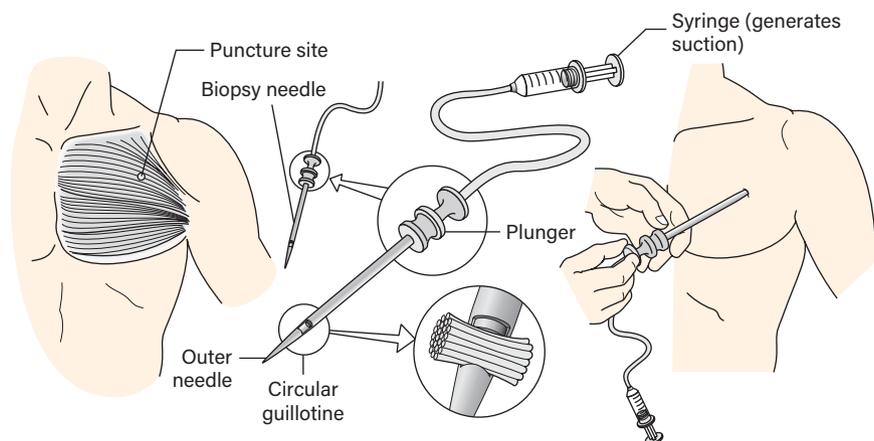
Muscle biopsies are used to examine small pieces or samples of muscle tissue. The sample can be obtained by either an 'open' or a 'needle' method, and the procedure is usually performed under local anaesthetic.

Open biopsies involve a small incision through skin and into the muscle so that a sample of tissue can be removed and sent off for analysis.

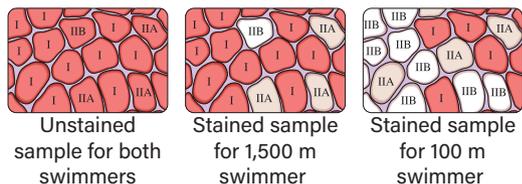
Needle biopsies are less invasive than open biopsies. A small 'plug' of tissue remains in the needle when it is removed from the muscle, and this is sent to a pathologist for examination.

Muscle biopsies are used to:

- distinguish between neurogenic (nerve) and myopathic (primary muscle) disorders
- identify specific muscular disorders, such as muscular dystrophy or congenital myopathy
- identify metabolic functions occurring in muscles
- diagnose infections that affect the muscles
- determine the structure of muscle cells (fibre composition).



**FIGURE 15.16** Muscle biopsies using a needle are done under local anaesthesia. A small plug of tissue is removed for analysis.



**FIGURE 15.17** Muscle biopsies and staining reveal different fibre compositions in 100-metre and 1,500-metre swimmers. Both samples are taken from the pectoralis major muscle. I = slow-twitch fibres; IIa and IIb = fast-twitch fibres

Histology tests (histo = tissue) use chemical stains to see the muscle's overall appearance and the structure of the muscle cells. These tests are often used to determine the fibre 'make-up' an athlete possesses in certain muscles, and to analyse how muscle fibres are responding to different training conditions.

### mitochondrion

A small organelle, found in muscle cells, that is responsible for producing energy from food through cellular respiration which is converted and stored as ATP

### enzymes

Protein-based structures that help speed up chemical reactions in our bodies, that build some substances and break others down

### free fatty acid

The broken-down and transportable form of fats

### arteriovenous oxygen difference

A measure of the amount of oxygen taken up from the blood by the tissues, as indicated by the difference in oxygen concentration between arterial blood and venous blood; measured per 100 mL of blood

### myoglobin

An oxygen-binding protein, mainly found in muscles, the main roles of which are storing oxygen and transporting it to the mitochondria, where aerobic ATP is produced

## Increased mitochondrial density

The **mitochondrion** (plural: mitochondria) is responsible for the conversion of fats and carbohydrates into ATP at the muscles via aerobic or cellular respiration. The higher the aerobic demands placed on muscles, especially slow-twitch fibres, the greater the increase in the size and number of mitochondria to meet these demands. More mitochondria means greater use of oxygen to produce more ATP and energy.

There is also an increase in mitochondrial **enzymes**, which are responsible for producing aerobic ATP at a faster rate. The mitochondria link oxygen delivery to ATP production in order to meet the oxygen demand and energetic needs of muscles. Many researchers and exercise physiologists maintain that increases in mitochondrial volume are the most important change that improves endurance performance over other adaptations at the cardiovascular and respiratory levels. How? Improved oxygen uptake and use by mitochondria increases **free fatty acid** (FFA) oxidation and limits lactate production at a given workload.



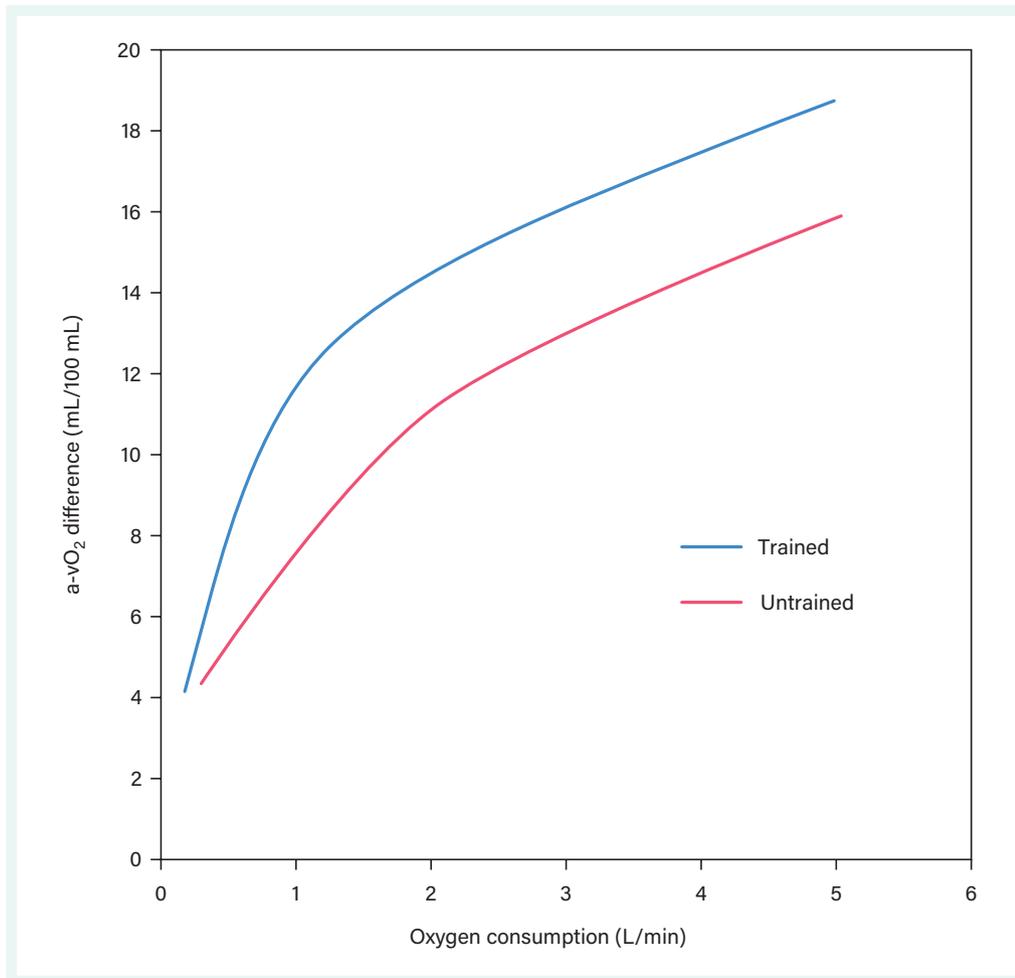
### ABOVE AND BEYOND THE STUDY DESIGN

Regulating mitochondrial changes with exercise, page 623

## Increased arteriovenous oxygen difference

We have learnt that muscles extract more oxygen with increased exercise intensity, and there is a direct linear relationship between these. Aerobic training allows the muscles to extract much more oxygen in endurance-trained athletes than untrained athletes. The **arteriovenous oxygen difference** ( $a-vO_2$  diff) increases both submaximally – when energy is being produced aerobically – and at maximal intensity, when the aerobic energy system is the major contributor to energy supply. Note that, during steady state, there will be a plateau in  $a-vO_2$  diff as oxygen supply meets oxygen demand.

Multiple factors contribute to more oxygen being supplied to working muscles as a result of adaptations to the respiratory and cardiovascular systems. At the muscular level, more **myoglobin**, more mitochondria and the ability of oxidative enzymes to produce more aerobic ATP work together to contribute to increases in  $a-vO_2$  diff.



**FIGURE 15.18** Arteriovenous oxygen difference at different exercise intensities for trained and untrained subjects

## LOOKING BACK

### Acute responses to exercise

#### Chapter 5

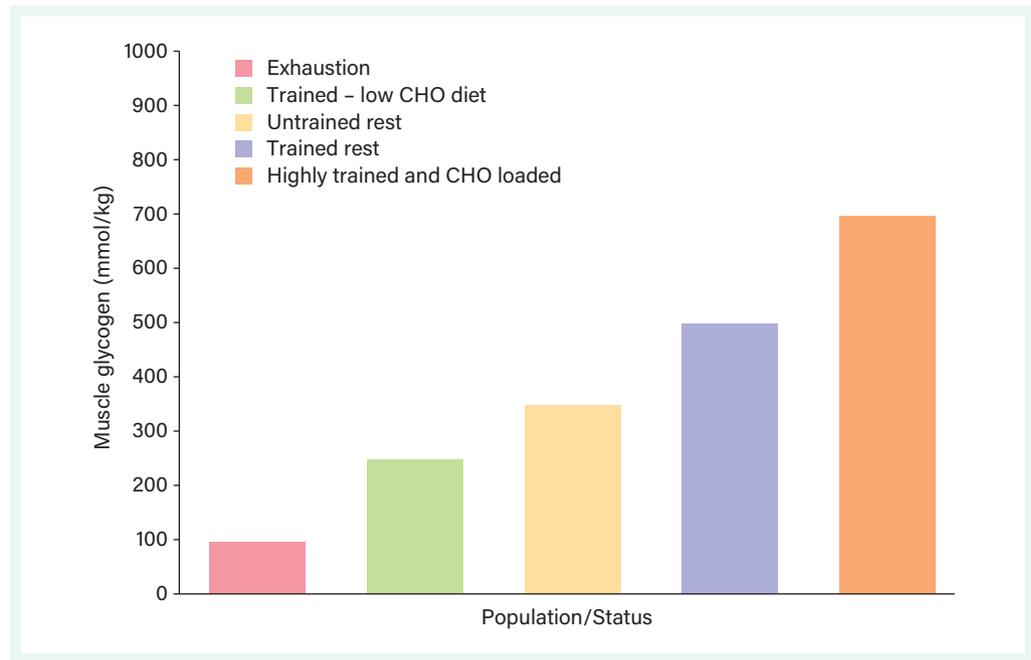
Increased a-vO<sub>2</sub> diff provides muscles with greater amounts of oxygen in response to exercise, which result in greater amounts of aerobic ATP production.

## Increased oxidative enzymes

The energy systems are constantly breaking down and rebuilding ATP to allow muscle contractions and vital body functions to occur. Aerobic-based training leads to significant increases in oxidative enzymes and, to a lesser extent, glycolytic enzymes. Oxidative enzymes – in particular, ATP synthase – convert ADP and phosphate to ATP in the mitochondria. When combined with increased mitochondrial density, more oxidative enzymes increase the amount of aerobic ATP that can be produced and decrease the involvement of the anaerobic energy systems in ATP production.

## Increased glycogen stores

Aerobic training increases stores of both muscle and liver glycogen, especially in slow-twitch muscle fibres. Because carbohydrates are our preferred exercise fuels due to their more rapid breakdown and lower oxygen cost than fats, any increase in their availability contributes greatly to improved endurance performance.



**FIGURE 15.19** Muscle glycogen concentration in different population groups

Harris, M.A. et al. (2018), 'Regulation of muscle glycogen metabolism during exercise: Implications for endurance performance and training adaptations', in *Nutrients* 10: 298. CC BY 4.0

### DID YOU KNOW?

The average person stores approximately 100 grams of glycogen in the liver and 400 grams of glycogen throughout the body's muscles. Many endurance athletes increase the amount they have when they start an event by carbohydrate loading, and many also consume carbohydrates throughout events lasting longer than 2–3 hours.

## Increased fat oxidation

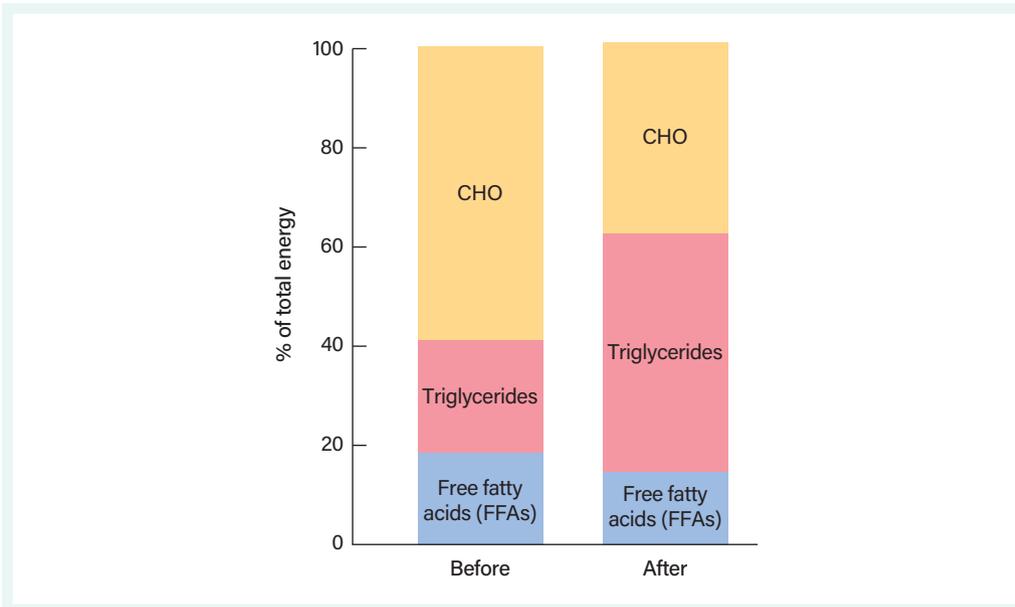
Aerobic-based training changes the way the body uses carbohydrates and fats to produce ATP while resting and performing at submaximal intensities. Increases in intramuscular triglycerides and free fatty acids fuel the oxidative enzymes, resulting in an increased ability to oxidise fat.

Being able to oxidise more fat submaximally gives endurance athletes a significant advantage because it allows them to conserve glycogen stores – which is known as **glycogen sparing**. We have limited stores of liver glycogen, and during most sporting events it is highly unlikely we will run out of fat stores. Glycogen sparing resulting from aerobic-based training allows endurance athletes to use more fat to supply energy while working at steady state. This has the following major benefits in events lasting longer than 90 minutes:

- extended carbohydrate availability, for up to 4 hours or more
- increased ability to call on carbohydrates when working above LIP, such as during high-intensity surges in the later stages of an event.

### glycogen sparing

The process whereby triglycerides are used instead of glycogen in the early stages of an endurance performance

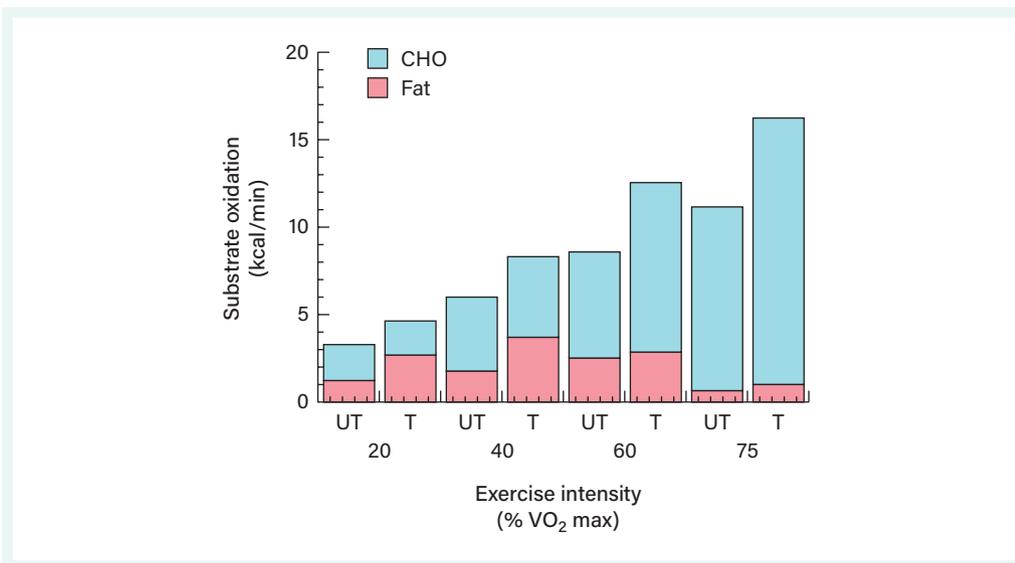


**FIGURE 15.20** The effect of endurance training on carbohydrate and fat oxidation while working at steady state: (left) before training and (right) after

Maclaren, D. (2023), 'X Change Vol 17. Fats: Relevance for exercise performance', Nutrition X

## Increased myoglobin

Myoglobin is vital in transporting oxygen across cell membranes to reach the mitochondria. It acts like a 'shuttle', bringing oxygen from the bloodstream into the muscle. It makes sense that, when mitochondria increase in size and number, they need oxygen delivery to increase (via more capillaries) and pathways into the muscles to increase (via more myoglobin). Endurance training can almost double the amount of myoglobin present in slow-twitch fibres. Figure 15.22 shows the close relationship between several of the muscle adaptations we have covered in this module.

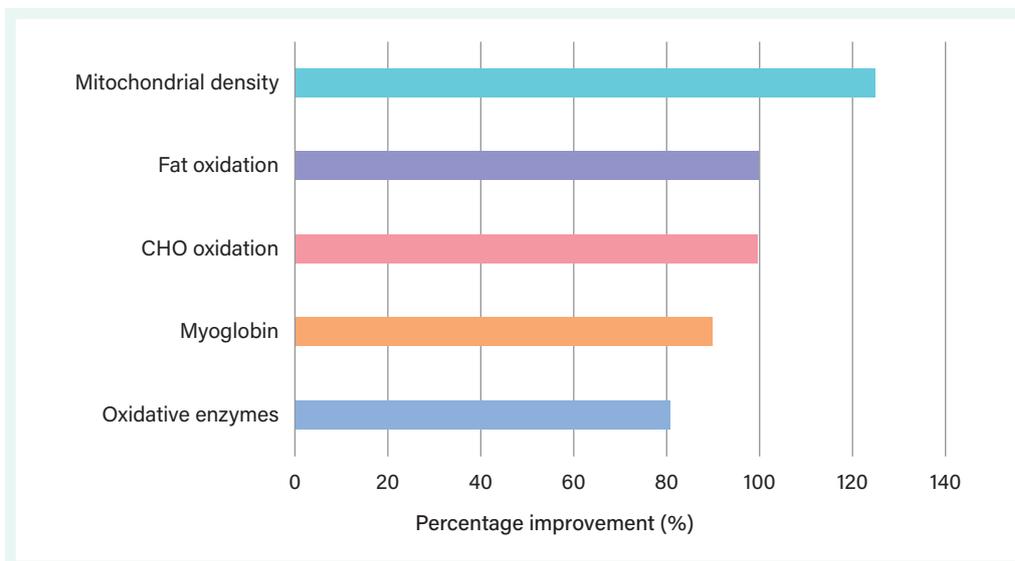


**FIGURE 15.21** The effect of aerobic-based training on fat and carbohydrate oxidation at various exercise intensities (UT = untrained, T = trained)

Adapted from Bergman, B.C. & Brooks, G.A. (1999), 'Respiratory gas-exchange ratios during graded exercise in fed and fasted trained and untrained men', in *Journal of Applied Physiology*, 86(2), 479-487.

**LEARNING HACK**

Slow-twitch adaptations are primarily concerned with increasing the endurance characteristics of muscle fibres and increasing the amount of aerobic ATP production.



**FIGURE 15.22** Chronic adaptations in slow-twitch fibres resulting from 12 months of aerobic-based training

**Assessment**

15.3 Check-in questions

**15.3 CHECK-IN QUESTIONS**

- ©VCAA Exam 2020, Section A, Q3

The most likely muscular adaptation resulting from a 12-week long-interval training program is:

  - A increased Type II fibres.
  - B decreased resting heart rate.
  - C increased CP stores.
  - D increased size and number of mitochondria.
- In your own words, **state** the role oxidative enzymes play during performances in which athletes remain at steady state for extended periods, such as a 1,500-metre swim or 20-kilometre cross-country ski race.
- By referring to an endurance event of your choice, clearly **discuss** how increased fat oxidation at submaximal intensities brings about improved performances.
- Explain** why increasing the number of mitochondria alone through aerobic-based training would be inefficient unless there was an accompanying increase in myoglobin density.
- Increased arteriovenous oxygen difference ( $a-vO_2$ ) is evident in endurance-trained athletes when compared to untrained subjects. **State** how this allows them to perform at higher intensities aerobically and what this means for their overall performance.

## 15.4 MUSCULAR ADAPTATIONS: ANAEROBIC-BASED TRAINING

In this module you will learn about:

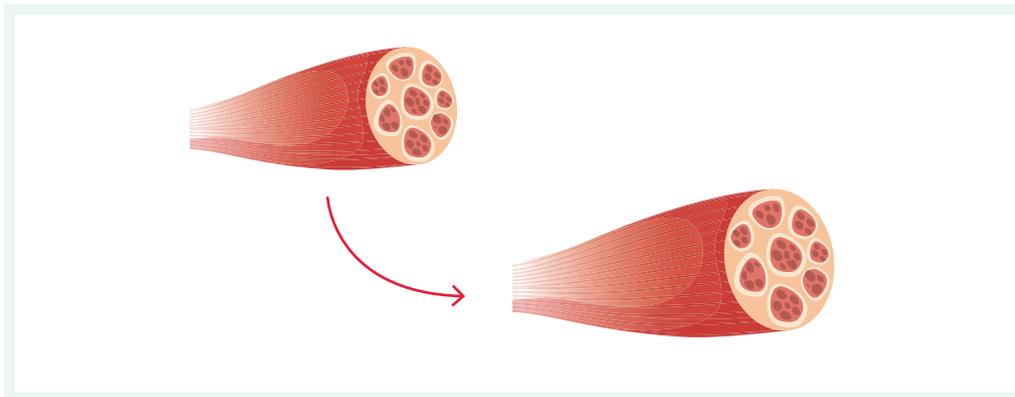
- anaerobic-based training primarily targeting fast-twitch fibres
- muscle hypertrophy and associated performance benefits
- neuromuscular adaptations that bring about improved force production and learn to:
- link fast-twitch adaptations to improved anaerobic capacity and associated energy systems.

### Muscle hypertrophy

Anaerobic training targets fast-twitch Type IIb fibres, but also sees fast-twitch Type IIa fibres increase in the cross-sectional area of their myofibrils, as well as increased numbers of **actin and myosin filaments**. This muscular hypertrophy leads to increased contraction speed and force production, which favours strength and power athletes. An additional benefit of having larger myofibrils is that they can store greater amounts of anaerobic fuels (ATP, CP and glycogen) and the enzymes that help to convert these fuels to energy as rapidly as possible.

#### actin and myosin filaments

Protein-based filaments, located within muscles, that are responsible for muscle contractions and production of movement



**FIGURE 15.23** Typical fast-twitch hypertrophy, resulting from resistance or plyometric training. Note the increased thickness of the tendon, which connects muscles to bones, allowing more forceful contractions to occur with reduced risk of injury/tears.

### Increased anaerobic enzymes

Enzymes increase the rate at which reactions occur in our bodies. Two important anaerobic enzymes, which allow ATP and CP to be broken down rapidly, are ATPase and creatine kinase, respectively. Rapid production of energy via the breakdown of these two chemical fuels is essential for athletes producing explosive and powerful muscle contractions, such as a javelin thrower, a cricket fast bowler or a swimmer diving off the starting blocks into the pool.

Glycolytic enzymes are responsible for the production of ATP from ADP, using glucose as the food fuel in this case. Different glycolytic enzymes operate in aerobic and anaerobic conditions, with aerobic glycolysis resulting in 20–39 times more ATP being produced than anaerobic glycolysis, which produces only 2–3 molecules of ATP per molecule of glucose.

## Increased fuel stores

Fast-twitch fibres (Types IIa and IIb) need fuels that can produce ATP anaerobically – that is, creatine phosphate (CP), adenosine triphosphate (ATP) and glucose (CHO). These substrates have larger myofibrils in which these fuels can be stored.

**TABLE 15.02** Anaerobic energy substrate increases as a result of heavy resistance training.

Anaerobic substrate	Pre-training (mmol/kg)	Post-training (mmol/kg)	Difference (%)
Creatine phosphate	10.74	14.52	+35.2
ATP	5.07	5.97	+17.8
Glycogen	57.4	113.9	+98.0

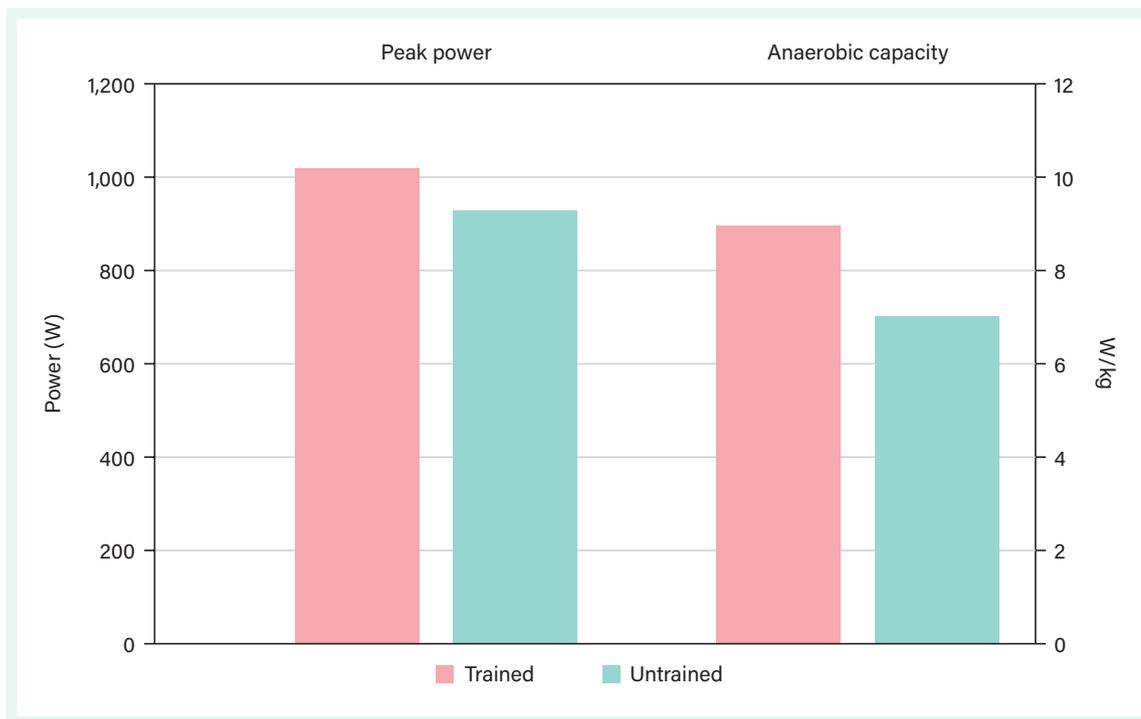
Adapted from: McArdle, Katch & Katch (2015), *Exercise Physiology* 5th edition

## Improved anaerobic capacity

### anaerobic capacity

The total amount of energy available via the ATP-CP and anaerobic glycolysis systems

**Anaerobic capacity** is the ability to produce energy via the two anaerobic energy systems – the ATP-CP and anaerobic glycolysis systems. Increased CP and glycogen stores, along with the actions of the anaerobic enzymes discussed earlier, increase the rate and duration of anaerobic energy, especially in those events relying on anaerobic glycolysis, such as the 400-metre sprint, the 100 metres freestyle or a 45-second skateboarding heat. The accumulation of metabolic by-products limits how long the anaerobic systems can contribute to ATP production; this will be covered later in this chapter.



**FIGURE 15.24** A higher rate of ATP turnover (breakdown and resynthesis) contributes to improved anaerobic capacity resulting from plyometric training.

Adapted from: Oehler, E. (2020), 'Effectiveness of plyometric drills on peak, average and end anaerobic power in trained and untrained individuals'

## Neuromuscular adaptations: anaerobic-based training

It is worth noting that resistance and plyometric training programs produce increases in both muscular strength and power without any accompanying increases in muscle fibre size/cross-sectional area. How is this possible? The factors most likely to be responsible for this initial change in force production are the following neural adaptations.

### Increased motor unit recruitment

Anaerobic-based training such as plyometrics, short-interval and resistance training targets fast-twitch fibres and enhances the body's ability to recruit motor units. Essentially, the more **motor units** within a whole muscle that can be recruited to perform a contraction, the greater the force that can be generated. Figure 15.26 shows that recruitment of small motor units will result in lower forces than when larger motor units are recruited. Maximal force requires as many motor units as possible to be involved in the contraction.

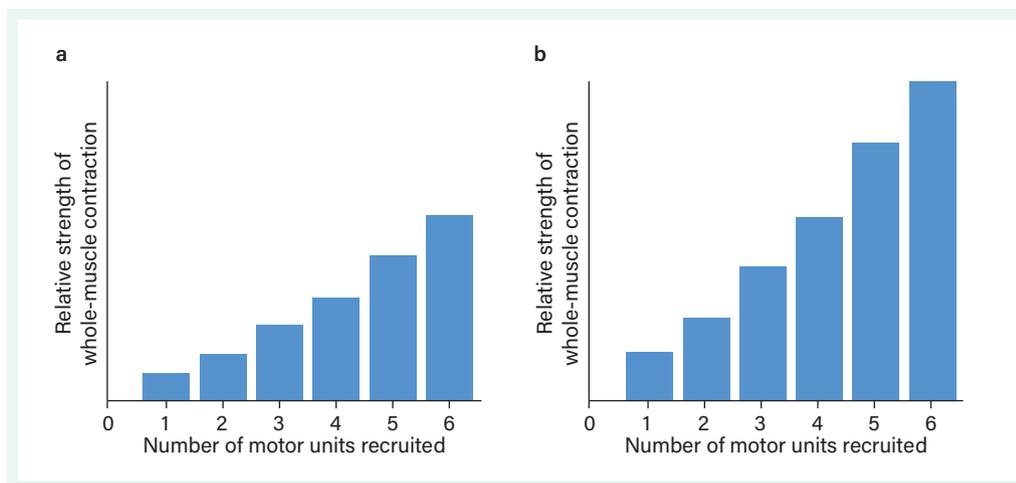


**FIGURE 15.25** These 400-metre sprinters are rounding the final bend before the sprint finish in the last 100 metres of the race. Consider the importance of having a highly developed anaerobic capacity.

BSF Agency/Getty Images Sport/Getty Images

#### motor unit

A single motor neuron (nerve cell) and all the muscle fibres that neuron can potentially stimulate



**FIGURE 15.26** The larger the number of motor units recruited, the greater the strength of the whole-muscle contraction for both: **a** small motor units; and **b** large motor units.

## Improved synchronisation of motor units

According to the size principle, motor units and muscle fibres are recruited in order from smallest to largest, always with slow-twitch muscle fibres first. When a heavy load is used, slow-twitch fibres will begin the contraction, but they will quickly be taken over by fast-twitch fibres. When loads increase, the central nervous system (CNS) will detect the greater weight or speed and recruit high-threshold motor units.

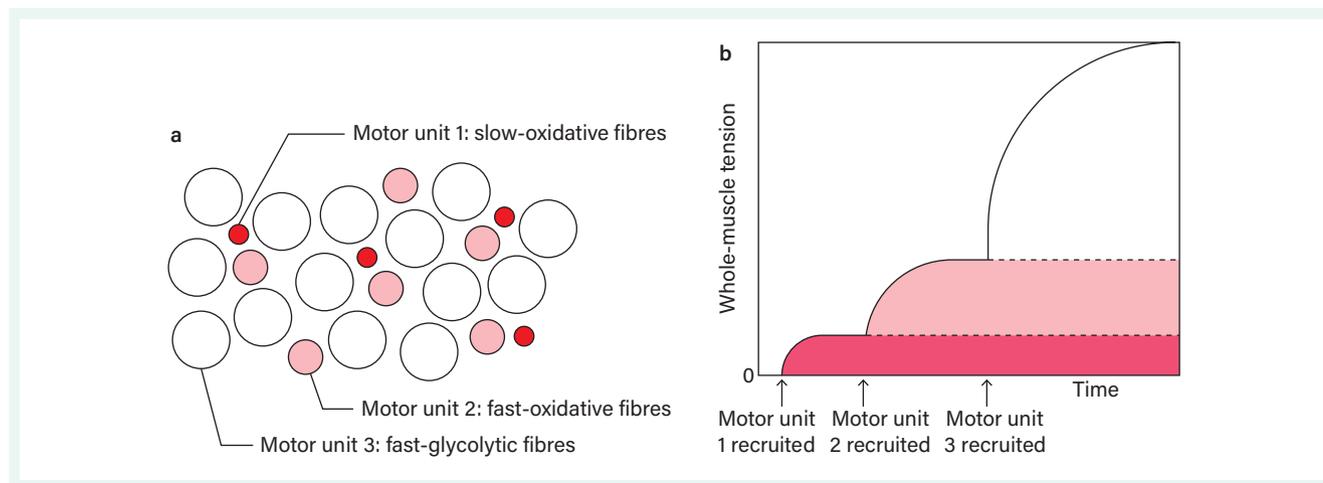
#### LEARNING HACK

'CNS' is a commonly accepted abbreviation for the central nervous system, which is made up of the brain and spinal cord.

**ballistic**

Muscle contractions exhibiting maximum velocities and accelerations over an extremely short period of time

During movements with a lighter load, you will recruit lower-threshold motor units because such movements are typically of lower intensity. Conversely, if movements with heavy loads or explosive **ballistic** movements are being performed, requiring high levels of force and power, higher-threshold motor units (typically stimulating fast-twitch fibres) will be activated at a very rapid pace.



**FIGURE 15.27 a** Cross-section through a motor unit consisting of all three fibre types: slow-twitch (slow-oxidative), fast-twitch Type IIa (fast-oxidative) and fast-twitch Type IIb (fast-glycolytic); **b** tetanic/summative muscle tension resulting from the activation of all three fibre types

BGStock72/Adobe Stock



**FIGURE 15.28** Plyometric exercises preferentially recruit large motor units and fast-twitch fibres, and rely on increased frequency of neural signals and firing.

**neuromuscular**

Involving both the nervous and the muscular body systems

**rate coding**

The frequency with which motor units discharge action potentials/signals

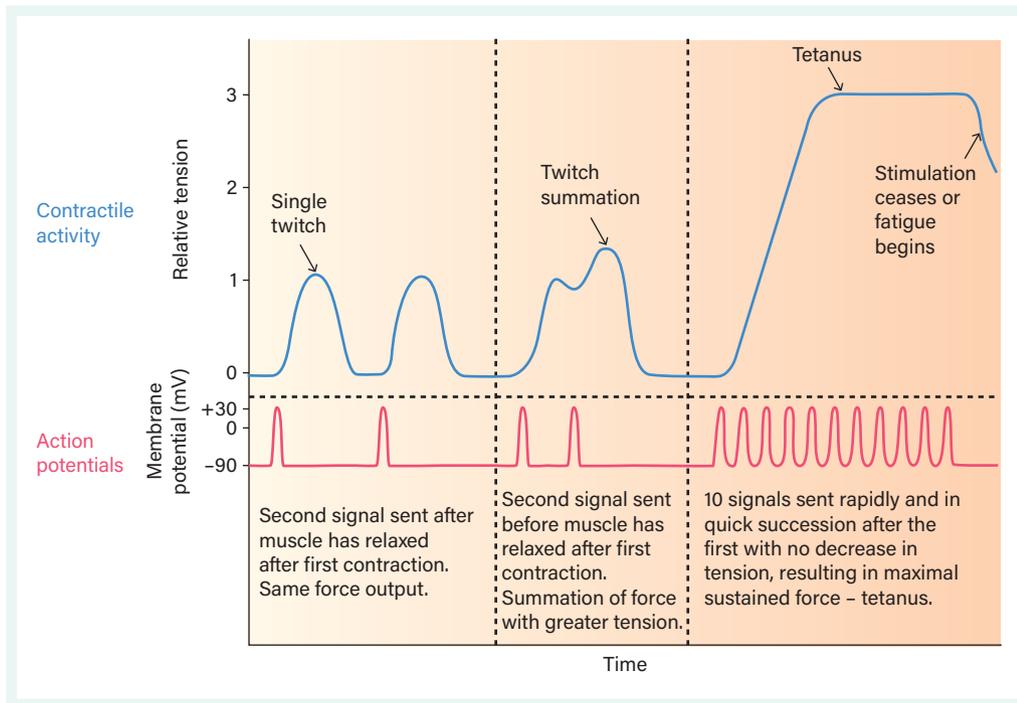
**summation**

The process of adding together several of the same or different variables

Resistance, short-interval and intermediate-interval training result in the rapid involvement of high-threshold motor units as well as the ability to coordinate or synchronise the activation of more motor units at the same time (this does not normally happen). Plyometric training increases **neuromuscular** performance by increasing the set speed in which the muscles perform. This allows neuromuscular coordination to become more automatic and results in rapid and more powerful muscle contractions.

## Increased motor unit firing frequency

Resistance and plyometric training have been found to increase the firing rate of neural impulses to individual motor units that make up the muscle. The firing rate is sometimes referred to as **rate coding** and directly influences the force and duration of the associated muscle contraction. However, this principle only works if successive signals are sent to the muscle fibre before it has had a chance to relax from the previous one – this results in a **summation** of impulses, which produce higher contractile forces. This can be seen in Figure 15.29 – look closely at the action potentials (signals) and what occurs when they are sent in rapid succession.



**FIGURE 15.29** Firing rate (rate coding) and its effect on muscle contraction and relaxation patterns and potential for summation of impulses and force

## Decreased neural inhibition

A muscle strain is an injury to a muscle or a tendon. Minor injuries may occur when excessive tension occurs at muscles, or the muscles and tendons only overstretch. This may result in partial or complete tears to these tissues.

Our tendons have a built-in protective mechanism in the form of receptors that detect when excessive tension is being applied to a muscle, or when body parts start to move beyond their normal range of motion at joints. These are known as **Golgi tendon organs** and, as soon as they detect excessive changes in muscle tension, they create a 'reflex inhibition' on the neurons supplying the muscle, causing an instantaneous drop in force output.

Physiologists have discovered that regular resistance training leads to a decrease in the inhibitory signals sent. This allows muscles to generate greater forces, but still with low risk of injury occurring.

### Golgi tendon organs

Proprioceptors, located in the tendons, that are responsible for moderating muscle tension



### ABOVE AND BEYOND THE STUDY DESIGN

The three different fibre type classifications and their characteristics, page 624

## 15.4 CHECK-IN QUESTIONS

- 1 How does improved 'synchronisation' of motor units contribute to more powerful muscle contractions?
- 2 By combining your understanding of fast-twitch adaptations such as increased fuel stores and energy system interplay, clearly **discuss** how having more creatine phosphate and muscle glycogen would contribute to faster 100-metre swim or 400-metre sprint times.



### Assessment

15.4 Check-in questions





### Command term

#### justify

Show, prove or defend, with reasoning and evidence, an argument, decision and/or point of view using given data and/or other information

### LEARNING HACK

When thinking about anaerobic-based training adaptations, consider how changes lead to the increased development of power or speed and the overall production of greater muscular force.

- 3 Explain** how increased motor unit firing frequency contributes to more powerful muscle contractions while performing 'bench blasts' or other similar plyometric exercises.
- 4 a** Which of the following scenarios involving the biceps muscle being used to throw a javelin will result in the greatest distance being thrown?
- A** activation of 60% slow-twitch fibres within the biceps muscle
  - B** activation of 80% fast-twitch fibres within the biceps muscle
  - C** activation of 50% slow-twitch and 50% fast-twitch fibres within the biceps muscle
- b Justify** your response to part **a** by specifically referring to fibre type and motor unit recruitment.
- 5** **©VCAA** Exam 2022, Section B, Q4 d
- A typical point in volleyball involves a player performing repeated vertical jumping actions, such as a serve followed by blocks and/or spikes.
- Explain** how the physiological adaptations of increased phosphocreatine (PC) stores and increased motor unit recruitment as a result of the conditioning phase to improve muscular power could improve the performance needed for scoring a typical point in volleyball.

## 15.5 COMBINING RESPIRATORY, CARDIOVASCULAR AND SLOW-TWITCH ADAPTATIONS TO INCREASE VO<sub>2</sub> MAX

In this module you will learn about:

- suggested ways to improve VO<sub>2</sub> max
- absolute and relative VO<sub>2</sub> max and possible use and learn to:
- link the cardiovascular, respiratory and muscular adaptations that bring about improved VO<sub>2</sub> max
- interpret case study data to improve key knowledge.

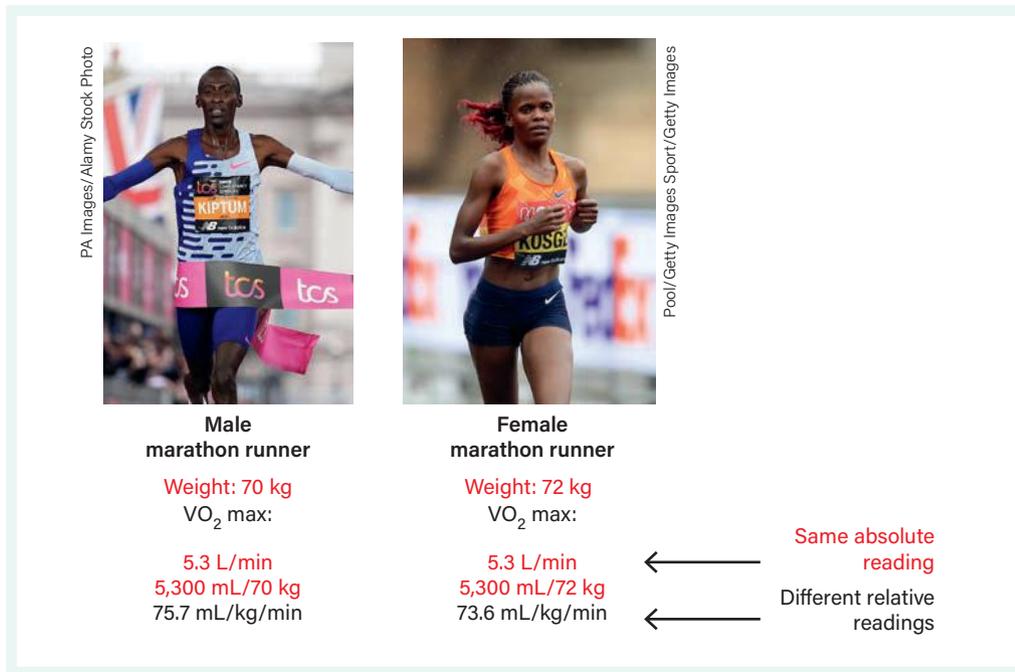
### absolute VO<sub>2</sub> max

The VO<sub>2</sub> max of a person expressed as L/min; lighter subjects with the same absolute VO<sub>2</sub> max as heavier subjects will have a higher relative reading and should perform better in endurance-based activities

### relative VO<sub>2</sub> max

The VO<sub>2</sub> max of a person once their body weight is taken into consideration, expressed as mL/kg/min; makes it easier to compare between individuals

VO<sub>2</sub> max is the maximum amount of oxygen that can be taken up by the respiratory system, transported by the cardiovascular system and utilised by the muscles to produce ATP. Aerobic training contributes significantly to increases in VO<sub>2</sub> max. **Absolute VO<sub>2</sub> max** is the amount of oxygen taken in per minute, measured in litres per minute (L/min). This provides an absolute reading without taking into consideration a person's body weight. When body weight is taken into account, a **relative VO<sub>2</sub> max** measurement is made possible. This is expressed as how much oxygen is taken in per kilogram of body weight per minute, and is measured in millilitres per kilogram per minute (mL/kg/min). Relative measurements make it much easier, and fairer, to compare the VO<sub>2</sub> max of different performers.



**FIGURE 15.30** Comparing the absolute and relative VO<sub>2</sub> max figures of two marathon runners of different weights

This chapter has looked at the way more oxygen can be taken up, transported and utilised as a result of chronic training adaptations. Table 15.03 lists some of the major adaptations at each of the three body systems that combine to make more oxygen available to produce ATP.

**TABLE 15.03** Chronic adaptations at the respiratory, cardiovascular and muscular systems responsible for making more oxygen available to working muscles

	Pre-aerobic training	Post-aerobic training (2+ years)
<b>Respiratory system</b>		
Alveoli (total number)	300–350 million	450–500 million
Pulmonary diffusion capacity, maximum (mL/min/mm Hg)	105	150
Tidal volume, maximum (mL/kg body weight)	40	50
Ventilation, maximum (L/min)	110	190
<b>Cardiovascular system</b>		
Stroke volume, maximum (mL)	120	180
Cardiac output, maximum (L/min)	15–20	25–30
Blood volume (L)	4–5	7–9
Haemoglobin mass (g/kg body weight)	9	17
Blood redirected to muscles, maximum (L/min)	17–18	30–35
<b>Muscular system</b>		
Aerobic enzymes (mmol/kg muscle weight)	5–10	15–20
Mitochondrial density (% of muscle cell)	2.15	8.0
a-vO <sub>2</sub> diff, maximum (mL/100 mL)	13	18
Capillarisation (slow-twitch, number/sq mm)	476	561
<b>Overall</b>		
VO <sub>2</sub> max (mL/kg/min)	40–50	70–80

## CASE STUDY

## HIGH-INTENSITY SHORT-DURATION VS LOW-INTENSITY HIGH-VOLUME AEROBIC TRAINING

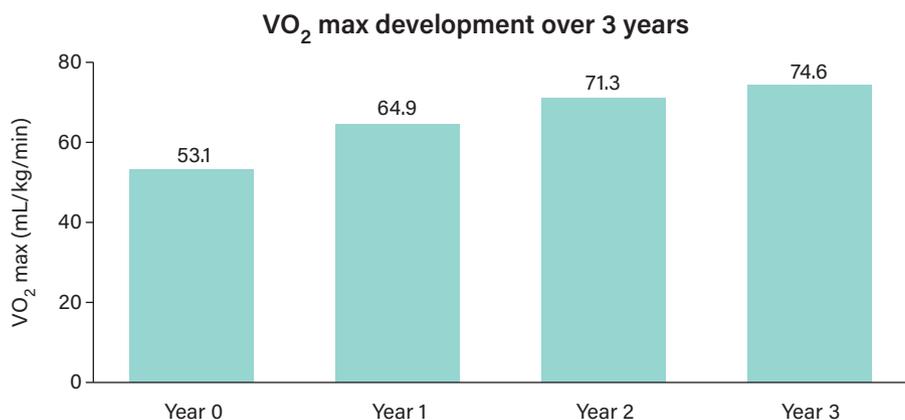
HOW 'TRAINABLE' IS VO<sub>2</sub> MAX REALLY? – A CASE STUDY

I started working with a young, middle-of-the-pack athlete with some big goals. He had come from a history of rotating through a number of intensity-based programs and was frustrated at the plateau despite 'working as hard as I could'. In more detail, the programs typically involved focused periods of 3–4 months before the key event, which would begin with high-intensity (threshold and 'VO<sub>2</sub>') intervals and progressively extend to a few specific long rides/runs before the event. After the event, he would take a couple of months off/unstructured to mentally recover from the high-intensity training and then begin the cycle again. As a part of the initial assessment, we got the athlete into the lab for a VO<sub>2</sub> max test. The result? A fairly modest 53 mL/kg/min.

With a trained VO<sub>2</sub> max of 53 mL/kg/min, his long-term goal of qualifying for the Ironman World Championship might be overly ambitious, at best. For comparative purposes, most male athletes in that age group who I have coached and who have achieved that level are closer to 65–70 mL/kg/min. Even at the low end, this would represent an improvement of 22% in VO<sub>2</sub> max (from an already trained state)!

Over the course of the next three years, this athlete shifted his VO<sub>2</sub> max from 53 to 74 mL/kg/min – an increase of 40% from a very middle-of-the-pack number to an elite level! And, in the process, he achieved his goal of qualifying for the Ironman World Championship.

The next figure shows the progression in VO<sub>2</sub> max values for this athlete over each year of training.



**FIGURE 15.31** The progression of VO<sub>2</sub> max values for an athlete we trained. Over the course of 3 years, he went from a middle-of-the-pack VO<sub>2</sub> max value of 53 mL/kg/min to an elite level of 74 mL/kg/min and met his goal of qualifying for the Ironman World Championship in the process.

While the majority of the short-term literature that has looked at interventions to increase VO<sub>2</sub> max has focused on the impact of high-intensity training (so-called 'VO<sub>2</sub> max intervals'), we took a different approach. In this case, the bulk of the athlete's training was

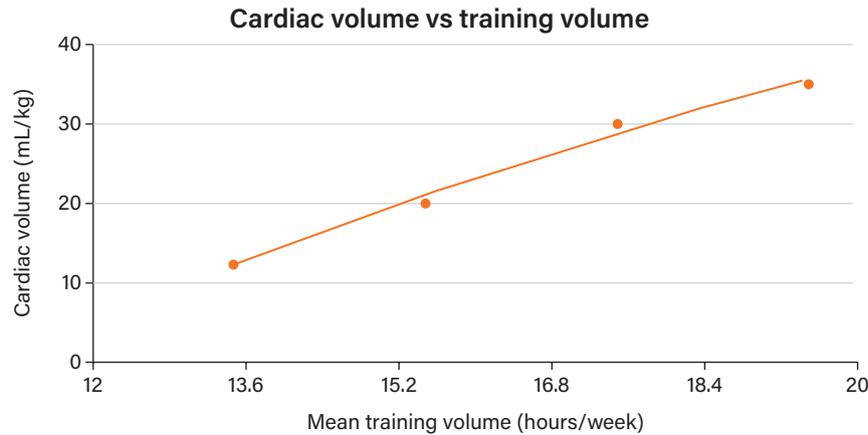
in and around the aerobic threshold (the first lactate turnpoint – i.e. at lactate levels of 1–2 mmol/L). A *long* way from VO<sub>2</sub> max.

My rationale for using low-intensity, high-volume training as a potent stimulus for large changes in VO<sub>2</sub> max comes from the observed



relationship between training volume and cardiac stroke volume, one of the most important and modifiable factors in  $\text{VO}_2$  max. In a large EKG study of athletes' heart morphology, Berbalk

discovered a strong, almost linear, relationship between training volume and total heart volume, as shown in [Figure 15.32].



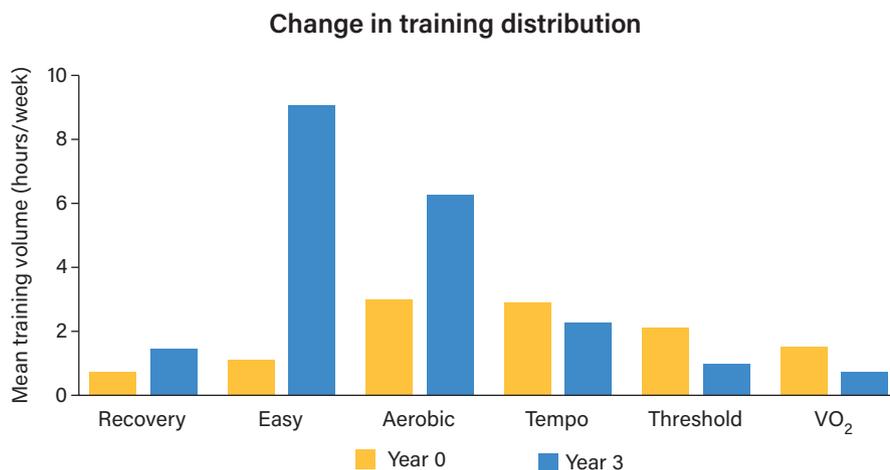
**FIGURE 15.32** My rationale for using low-intensity, high-volume training as a potent stimulus for large changes in  $\text{VO}_2$  max comes from the observed relationship between training volume and cardiac stroke volume, one of the most important and modifiable factors in  $\text{VO}_2$  max. (Data from Berbalk study.)

That is, the total volume of the athletes' hearts scaled not with the intensity of training, but with the average weekly volume! This makes good physiological sense, since we know that for the majority of people, stroke volume reaches its maximum limit at relatively low intensities of training (~40–60%  $\text{VO}_2$  max). However, as the Berbalk data suggests, it takes a whole lot of beats to make these significant changes!

Additionally, there are positive peripheral adaptations that are favoured by LSD ('long, slow, distance') work. Harms and Hickson concluded that changes in mitochondrial content within the aerobic fibres largely scaled with the number of contractions rather than the intensity of effort. Since mitochondria represent the oxygen processing 'factories' within the muscle, more available

mitochondria means more potential oxygen extraction from each beat.

This emphasis on low-intensity aerobic training represented a marked departure from what the athlete had done prior to working with me. One of the most interesting aspects of the current wave of technology and data collection for me, as a coach, is that I learn a lot about what other coaches are doing purely from the logs that the athlete brings with them. In this case, he had been doing a lot of threshold and  $\text{VO}_2$  max training. You can see the clear difference in relative proportions of the annual training intensity distribution in [Figure 15.33] from his year prior to working with me (year 0) to his highest fitness in year 3.



**FIGURE 15.33** My emphasis on low-intensity aerobic training with the athlete was a marked departure from what he had done prior to working with me. Paradoxically, less high-intensity 'VO<sub>2</sub> work' resulted in a significant boost to his VO<sub>2</sub> max.

Prior to working with me, the athlete did very little work below 80% max heart rate. Most of the work he did in this range was restricted to just warming up for the 'main event'. We made a large shift in this training emphasis by adding a lot of easier aerobic work (~65–80% max heart rate) and a lot less high-intensity work (~85–100% max heart rate). Paradoxically, less 'VO<sub>2</sub> work' resulted in a significant boost to the athlete's VO<sub>2</sub> max!

While the athlete didn't have VO<sub>2</sub> data from before beginning his high-intensity program, his recollection was that his power numbers on the bike improved quickly but then plateaued and then stayed 'stuck' at that point following each build. This pattern of stagnation with athletes who focus on high-intensity (traditional 'VO<sub>2</sub> max') training is a common one.

This is not to say that traditional VO<sub>2</sub> max intervals (3–5 mins @ 95–100% max heart rate, ~1:1 recovery) are useless; merely that they are the proverbial icing on the top rather than the cake itself. Athletes can certainly reach a point with pure aerobic training where they are so efficient that they are no longer able to max out their aerobic power. This is indicated by an inability to reach a VO<sub>2</sub> 'plateau' during a test where, despite increased work, VO<sub>2</sub> stabilises. When an athlete fails to get to this plateau, a small dose of VO<sub>2</sub> max intervals can be very

effective in eking out those last few mL/kg/min. However, in this case, this form of training represents the move from 70 to 74 mL/kg/min, *not* the move from 53 to 70. That shift was made with 'bread and butter' aerobic work!

The above distribution has some important implications in the training of athletes for anaerobic sports. Traditional VO<sub>2</sub> max intervals tend to run counter to a speed/power athlete's objectives of maximal rates of power production: i.e. they favour lactate tolerance over lactate production in the Type II fibres – endurance over speed. By focusing the aerobic development on the other end of the intensity spectrum, it allows the speed/power athlete to keep the adaptations of those Type II fibres very specific to the task at hand, while further developing the aerobic abilities of those Type I 'recovery fibres', which, frankly, aren't of much help to you in the rapid power generation game anyhow.

I've been fortunate to train with some very high-level sprint cyclists and this is their approach – the endurance work is very easy, and the fast work is very fast. This 'polarisation' of the training is likely of the most value to those athletes who wish to develop their ability to quickly generate energy anaerobically but also quickly recover from these efforts aerobically.

### Is this level of $\text{VO}_2$ max improvement typical?

I would have to say that this 40% improvement represents one of the largest jumps I have seen, and it's not typical. However, in my experience, jumps far greater than the 5–15% cited in the literature, with sustained aerobic training, are routine.

In fact, when I model the average response to training across the entire group that I have  $\text{VO}_2$  and long-term training data for, I see an average shift from 54 to 67 mL/kg/min (a change of 24%) when a long-term, high-volume training plan is undertaken.

Conversely, when a short-term, high-intensity training plan is undertaken, the model shows a maximal increase (in 4–6 weeks) to only 63 mL/kg/min (16%).

So, while a 40% increase in  $\text{VO}_2$  max may not be considered 'typical', after my experience testing and observing athletes over the past 10+ years, I would have to consider a ~25% increase in  $\text{VO}_2$  max to be very typical given the right training over a sufficient period of time.

### Maximise your athlete's talents

In summary, given the crucial role that the aerobic system plays, not only in providing energy for the vast majority of sports, but also in accelerating the recovery from anaerobic bouts, all athletes should pay proper attention to its development. Obviously, at a very high level of priority for endurance sports, but also to a larger extent than is commonly acknowledged for 'anaerobic sports', where a base level of aerobic development plays a large role in the overall work capacity of the athlete.

My years of testing and tweaking to develop this quality have led me to conclude that, whatever the sport, given the appropriate training over a sufficiently long period of time,  $\text{VO}_2$  max is a very trainable quality.

Source: Alan Couzens, M.Sc. (Sports Science), is an exercise physiologist and endurance sports coach in Boulder, Colorado. Alan works with top amateur and professional endurance athletes on applying the latest in exercise science to get the most from their training. How 'Trainable' Is  $\text{VO}_2$  Max Really? – A Case Study (simplifaster.com)

### QUESTIONS

- 1 Couzens observed a relationship between training volume and cardiac stroke volume. **State** this relationship and what impact this had on the type of training he prescribed in order to improve aerobic power.
- 2 Harms and Hickson concluded that changes in mitochondrial content within the slow-twitch fibres largely scaled with the number of contractions, rather than the intensity of effort. In your own words, what would this imply if you were going to design a training program to improve the endurance performance of an athlete?
- 3 Couzens states that a 'small dose of  $\text{VO}_2$  max intervals can be very effective in eking out those last few mL/kg/min' that favour endurance over speed. Research the type of training that involves  $\text{VO}_2$  max intervals and **describe** what a typical training session would include.
- 4 **Propose** why improvements to  $\text{VO}_2$  max take much longer to occur than the improvements that can be made at fast-twitch muscle fibres.

### DID YOU KNOW?

$\text{VO}_2$  max is often mistakenly thought of as being only associated with the respiratory system. Its definition tells us otherwise, and clearly shows all three body systems that contribute to it.  $\text{VO}_2$  max is defined as: the maximum amount of oxygen that can be taken up (at the lungs; i.e. respiratory), transported (pumped by the heart through blood vessels; i.e. cardiovascular) and taken up (extracted and utilised by the muscles; i.e. muscular).



## Assessment

15.5 Check-in questions

## LEARNING HACK

Anaerobic-based training leads to hypertrophy of the heart muscle (in particular, the wall) without significant changes to the size of the atria or ventricles. This produces more forceful cardiac muscle contractions with no significant improvement to anaerobic performance – that is, the contractions do not rely on increased blood and oxygen flow to working muscles.

## Command term

## Identify

Recognise and name and/or select an event, feature, ingredient, element, speaker and/or part from a list or extended narrative or argument, or within a diagram, structure, artwork or experiment

## lactate inflection point

The last point where lactate entry into, and removal from, the blood are balanced. It is identified as the final exercise intensity or oxygen uptake value at which blood lactate concentration is relatively low. It represents the maximal intensity at which blood lactate is said to be in steady state.

## lactate tolerance

The ability to buffer accumulating lactic acid so it does not interfere with muscle contractions and cause decreased force and frequency

## 15.5 CHECK-IN QUESTIONS

- List** two differences between male and female marathon runners at their respiratory and cardiovascular systems that account for the faster times recorded by male athletes.
- Justify** why using a relative  $VO_2$  max figure is a fairer way of assessing a person's aerobic power rather than stating their absolute  $VO_2$  max.
- Aerobic-based training is often said to benefit recovery from both aerobic- and anaerobic-based training. How might improving  $VO_2$  max lead to improved recovery from the repeat sprint efforts performed by a midfielder?
- By referring to Table 15.03 on page 609, select one respiratory, one cardiovascular and one muscular adaptation to aerobic-based training, and combine the three to **explain** how they would contribute to increased  $VO_2$  max.
- ©VCAA** Exam 2023, Section B, Q2 c  
An elite cyclist would have a much higher  $VO_2$  maximum compared with an untrained athlete. **Identify** and **describe** one chronic adaptation of the cardiovascular system to training and explain how this would lead to a higher  $VO_2$  maximum.

## 15.6 IMPROVING LIP OR LACTATE TOLERANCE?

In this module you will learn about:

- what the lactate inflection point (LIP) represents and how to improve it
- the benefits associated with having higher LIP
- what lactate tolerance is and how it is different from LIP and learn to:
  - link improved oxygen delivery and uptake at muscles with increased LIP
  - explain how LIP can be trained and improved
  - state how lactate tolerance can be improved, and what effect this has on performance.

Aerobic-based training targets the aerobic energy system and will lead to significant changes to the respiratory and cardiovascular systems along with slow-twitch muscles fibre adaptations. Anaerobic-based training targets the two anaerobic energy systems and will lead to significant fast-twitch fibre adaptations.

Some athletes train to improve their **lactate inflection point** (LIP), while others try to improve their **lactate tolerance**. Some will aim to improve both, which have very different outcomes. Improving LIP is aimed at delaying the accumulation of  $H^+$  ions and being able to work at higher intensities aerobically. Lactate tolerance training aims to increase an athlete's ability to cope with the ever-increasing amount of  $H^+$  ions while working above LIP.

## DID YOU KNOW?

Improving LIP does not increase lactate tolerance, and improving lactate tolerance has no effect on LIP. This is so because of the specificity of the training required to bring about these adaptations, which targets very different energy systems and muscle types.

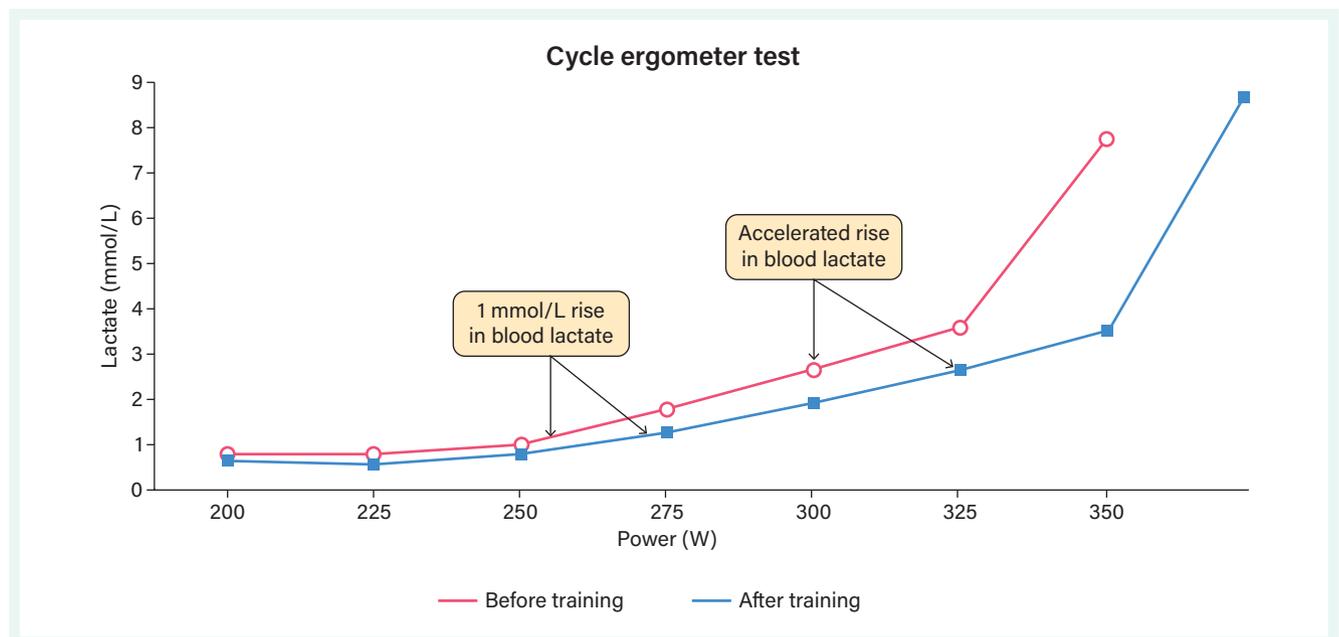
## Increasing the lactate inflection point (LIP)

The lactate inflection point (LIP) is the exercise intensity at which muscles produce maximum amounts of lactate at exactly the same rate as it can be removed. In essence, LIP represents the maximum workload where lactate does not accumulate. Working just above this intensity leads to an exponential rise in blood lactate and  $H^+$  concentration, and results in rapid onset of fatigue. Blood lactate concentration 'inflects', or increases more rapidly, when the lactate that enters the blood is greater than the lactate removed (via oxidation for ATP production or conversion to glucose or glycogen). Some exercise physiologists also refer to LIP as the maximum lactate steady state (MLSS), anaerobic threshold (AT), ventilatory threshold or lactate threshold (LT).



Video

In focus: Improving the lactate inflection point



**FIGURE 15.34** Endurance training results in the lactate inflection training point occurring at higher absolute exercise intensity.

Several studies have found that, in the general population, aerobic training often improves the exercise intensity corresponding to LIP without a corresponding increase in  $VO_2$  max. This is also the case in elite endurance athletes, and for this reason LIP is considered to be a better indicator of aerobic power than  $VO_2$  max. Both the continuous and interval types of aerobic training have beneficial effects, not only on  $VO_2$  max, but especially in raising the lactate inflection point.

For untrained individuals, training below LIP provides an adequate stimulus for improvement, but in endurance-trained athletes a higher stimulus, at or just below LIP, is required in order for gains to be made. An individual's training status will play a large part in setting the training intensity required to improve LIP. LIP in untrained individuals typically occurs between 55% and 70% of  $VO_2$  max, which equates to approximately 70–80% max HR. In endurance-trained individuals, LIP typically occurs between 75% and 90% of  $VO_2$  max, or 85–95% max HR.

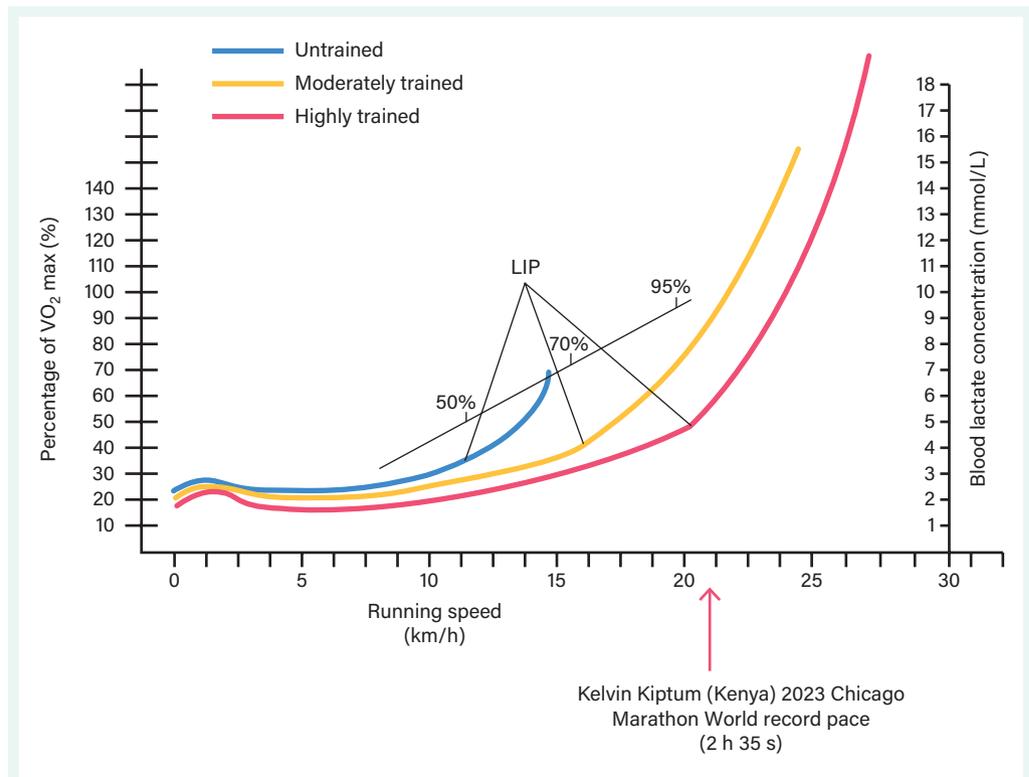
As a person increases their endurance capabilities and LIP, they need to adjust their training loads upwards for continued improvement to occur. The lactate inflection training point will occur at higher absolute exercise intensity ( $VO_2$ , speed, watts) and a higher relative exercise intensity (%  $VO_2$  max, % max HR) in a more trained athlete than in an untrained one. Figure 15.35 shows how increased LIP is associated with accumulation of  $H^+$  at significantly higher workloads and increased endurance training.

## LOOKING BACK

## Training principles

## Chapter 12

The law of diminishing returns and intensity reminds us that the closer we get to our genetic potential, the harder it is to keep improving. As adaptations occur, not only do we need to consider applying progression in order to keep improving, but the time it takes for changes to occur also will be longer.



**FIGURE 15.35** Different lactate inflection points and associated intensities, based on training status

Continuous and high-intensity interval training methods are effective when seeking to improve LIP. To achieve significant adaptations, it is recommended that workouts should alternate between continuous training (where duration takes priority over high intensity) and higher-intensity intervals (with workloads above LIP). Aerobic work should comprise the largest percentage of these training programs.

Increases in LIP have been found to owe more to increases in lactate clearance from muscles than to decreases in lactate production. Higher levels of fat oxidation, with less reliance on carbohydrates, result in lower levels of anaerobic glycolysis. The adaptations primarily responsible for the increased lactate clearance include:

- greater mitochondrial density, with an increased ability both to produce aerobic ATP and to oxidise lactate back to pyruvate
- increased transport of lactate from muscle cells to the bloodstream
- greater conversion of lactate back to glucose to produce more ATP.

## CASE STUDY

## ENDURANCE TRAINING AND ADAPTATIONS IN 3,000 METRES COMPETITORS



Michael Steele/Getty Images Sport/Getty Images

**FIGURE 15.36** A 3,000-metre event favours athletes who are endurance-trained and have a high lactate inflection point.

## A FIVE-YEAR PHYSIOLOGICAL CASE STUDY OF AN OLYMPIC RUNNER

A.M. JONES

### OBJECTIVE

To study physiological changes caused by long term endurance training in a world class female distance runner, and to compare these changes with alterations in 3,000 m running performance.

### METHODS

The subject underwent regular physiological assessment during the period 1991–1995. Physiological measures made included body composition, maximal oxygen uptake ( $\text{VO}_2 \text{ max}$ ), running economy and lactate threshold. In addition, the running speed at  $\text{VO}_2 \text{ max}$  was estimated. Test protocols, laboratory equipment and laboratory techniques used were the same for each test session.

### RESULTS

The 3,000 m race performance improved by 8% from 1991 to 1993 after which it stabilised. In contrast,  $\text{VO}_2 \text{ max}$  fell from 1991 (73 mL/kg/min)

to 1993 (66 mL/kg/min). Submaximal physiological variables such as lactate threshold (from 15.0 to 18.0 km/h) and running economy (from 53 mL/kg/min to 48 mL/kg/min at 16.0 km/h) improved over the course of the study. Despite no increase in  $\text{VO}_2 \text{ max}$ , the reduction in the oxygen cost of submaximal running caused the estimated running speed at  $\text{VO}_2 \text{ max}$  to increase from 19.0 km/h in 1991 to 20.4 km/h in 1995.

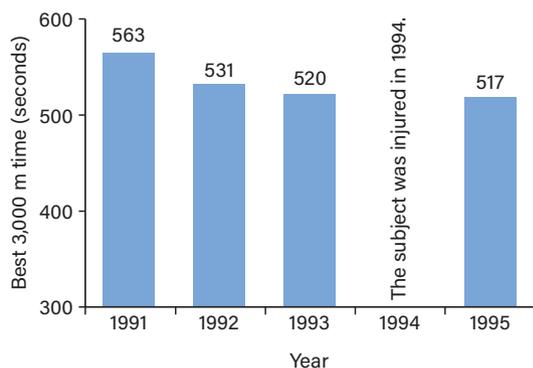
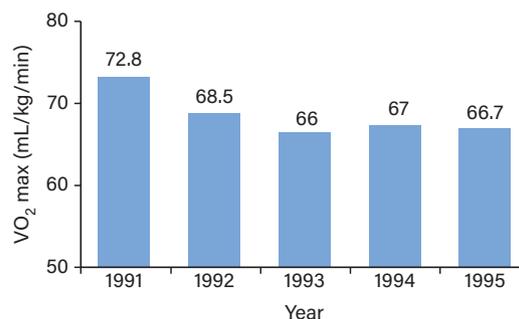
### CONCLUSIONS

Improvement in 3,000 m running performance was not caused by an increase in  $\text{VO}_2 \text{ max}$ . Rather, the extensive training programme adopted, together perhaps with physical maturation, resulted in improvements in submaximal fitness factors such as running economy and lactate threshold. These adaptations improved the running speed estimated to be associated with  $\text{VO}_2 \text{ max}$  and resulted in improved 3,000 m running performance.



**TABLE 15.04** Changes in various physical and physiological measures over five years of endurance training

	1991	1992	1993	1994	1995
Body mass (kg)	51.3	52.2	53.0	54.4	52.5
Body fat (%)	15.7	13.4	11.8	15.7	14.1
Lactate inflection point (km/h)	15.0	16.5	17.0	18.0	18.0
[Lactate] at 17 km/h (mM)	3.7	2.8	1.6	1.6	1.4
Maximum speed (km/h)	19.5	21.0	22.5	22.0	22.0

**FIGURE 15.37** Improvement in best time from 1991 to 1995. The subject was injured in 1994.**FIGURE 15.38** Changes in maximum oxygen uptake (VO<sub>2</sub> max) from 1991 to 1995

Source: Jones, A.M. (1998), 'A five-year physiological case study of an Olympic runner', in *British Journal of Sports Medicine* 32: 39–43. Reproduced with permission from BMJ Publishing Group Ltd.

## QUESTIONS

- Figure 15.38 shows a decrease in VO<sub>2</sub> max over the course of 5 years of endurance training, while Figure 15.37 shows an improvement in 3,000-metre running time of 46 seconds over the same 5-year period. **Discuss** two adaptations that might have contributed to this improvement in running time.
- Consult Table 15.04 and **state** any relationship that might exist between LIP and running speed.
  - How does increasing LIP contribute to improved performances in the 3,000 metres?
- The researchers found that a reduction in the oxygen cost associated with submaximal running occurred during the endurance training. **Suggest** how this contributes to improved LIP.

## Command term

### suggest

Put forward for consideration a solution, hypothesis, idea or other possible answer



### Video

In focus: Improving lactate tolerance

## Improving lactate tolerance

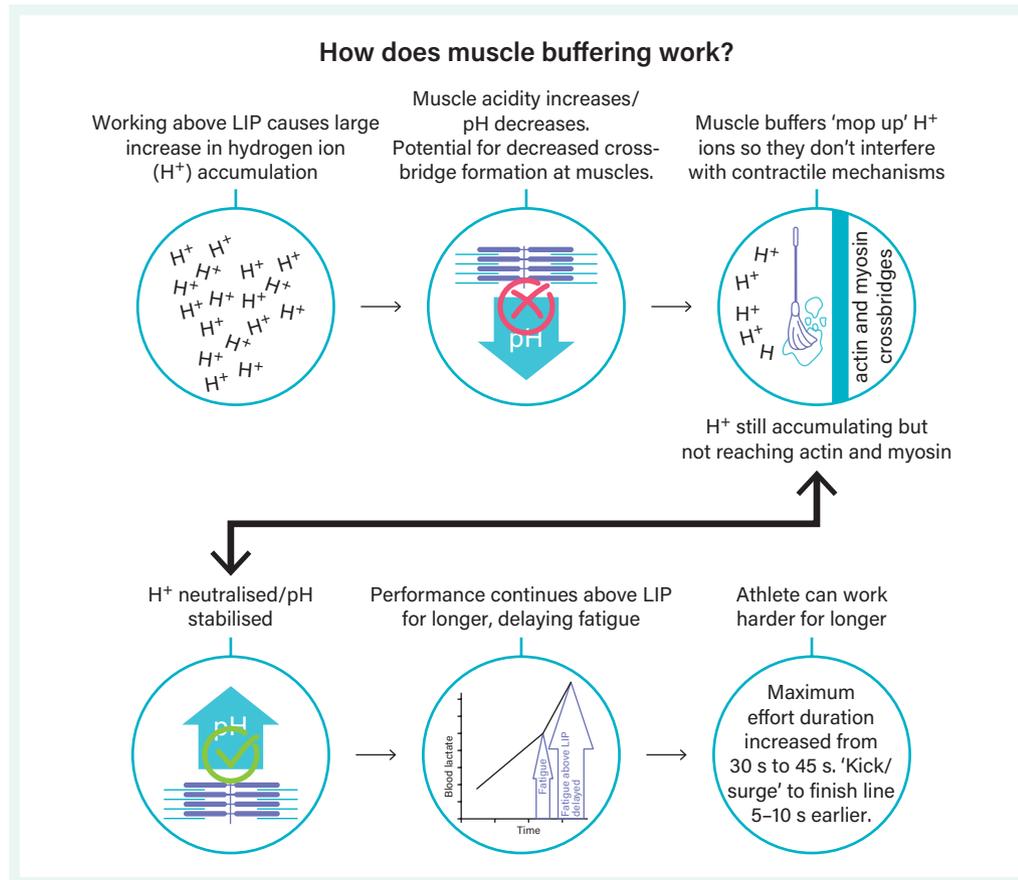
When performing high-intensity actions above LIP, steady state is surpassed, and lactic acid is produced at a faster rate than it can be removed and will start to accumulate. This causes an acidic environment in muscles commonly known as 'the burn', and pH levels drop. This increase in acidity results in decreased muscle contraction forces because our neuromuscular system doesn't function well under these conditions. Essentially, it means we need to slow down, decrease our workload and, in some cases, even stop.

Lactate tolerance training, such as intermediate-interval training, focuses on the anaerobic glycolysis system and places high stress within fast-twitch muscle fibres resulting in high amounts of lactic acid, lactate and H<sup>+</sup> accumulation. When the anaerobic glycolysis system is activated and trained over time, the number and function of 'muscle buffers' located within

muscles increases. **Muscle buffering** 'mops up' the accumulating  $H^+$  and helps stabilise the pH of muscles; this is known as 'buffering capacity'. Improved buffering and removal capacities of muscles contribute to increased concentration of muscle and blood lactate at the end of events.

### muscle buffering

The ability of muscles to neutralise accumulating lactic acid during high-intensity exercise, thus delaying the onset of fatigue



**FIGURE 15.39** Muscle buffering allows athletes to work above LIP for longer before fatigue sets in.

Lactate tolerance training:

- improves neuromuscular function
- allows athletes to maintain a higher work rate for longer
- transports lactate out of the cell more rapidly and efficiently
- regulates  $H^+$  more effectively
- allows muscle pain to be better tolerated
- improves energy production via anaerobic glycolysis
- allows more frequent high-intensity efforts with less fatigue
- promotes a quicker recovery from successive bursts of speed/power (common to many team sports).

### DID YOU KNOW?

Lactic acid is used as a fuel and is usually removed from the muscle tissue within 30–60 minutes after exercise, depending on the type of recovery undertaken. The liver, heart and kidneys use it as a source of energy. The liver can also convert it back into glucose, which is released into the bloodstream for muscle use or converted into glycogen for storage in the liver and later use.

## DID YOU KNOW?

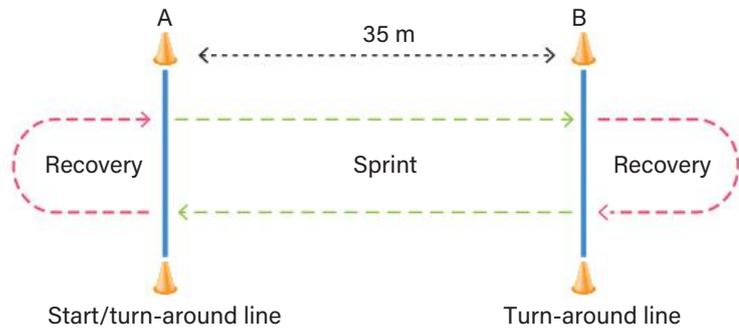
Carnosine is one of many substances that act as muscle buffers. It occurs in twice the concentration in fast-twitch fibres as it does in slow-twitch fibres.

## SIGNPOST

The running-based anaerobic sprint test (RAST) is a field test designed to measure an individual's anaerobic power and capacity. The test involves 6 × 35-metre sprints with short (10-second) rest intervals in between, and is designed to simulate the high-intensity demands of many team sports.



**Weblink**  
RAST test tutorial



**FIGURE 15.40** The running-based anaerobic sprint test (RAST) is very similar to the phosphate recovery test.

## COLLABORATIVE TASK

### Prac activity/Lab activity



### Running-based anaerobic sprint test

After viewing the tutorial on Nelson MindTap, perform the test with a partner and record times for each of the six sprints. Share your results and then consider the discussion points.

Repeat sprint times with minimal recovery

	My 35 m sprint time	Classmate 1 35 m sprint time	Classmate 2 35 m sprint time
Sprint 1			
Sprint 2			
Sprint 3			
Sprint 4			
Sprint 5			
Sprint 6			
$\% \text{ total decrement} = \frac{\text{Sprint 6} - \text{Sprint 1}}{\text{Sprint 1}} \times 100$			

### DISCUSSION

- 1 Identify** the fastest student in the first sprint. **List** two muscular adaptations that student would have that allow them to produce muscle contractions at a faster rate than other students.
- 2** What evidence is there that lactate tolerance contributed to the repeat sprint performances of some students more than others?



### LEARNING HACK

Improving LIP allows athletes to achieve higher workloads aerobically, and this results in faster running, swimming, cycling and rowing times – hopefully, outperforming other competitors or previous personal best efforts.

Improving lactate tolerance allows performers to work above LIP for longer, thereby delaying the decline in muscle contraction forces and fatigue.

- 3 Creatine phosphate (CP) depletion would be a significant factor contributing to decreased sprint times. **Discuss** how a 20–30 per cent increase in CP stores as a result of anaerobic-based training would contribute to improved performance in the RAST.
- 4 Midfield and mobile team players perform lots of aerobic-based training to improve the functioning of the aerobic energy system and increase their LIP. **Outline** how this may also be beneficial when performing repeat high-intensity efforts, with little rest in between.

## CASE STUDY

## LACTATE TOLERANCE

## MADISON DE ROZARIO BECOMES FIRST AUSTRALIAN PARA-ATHLETE TO WIN FOUR COMMONWEALTH GAMES GOLD MEDALS

AMANDA SHALALA



**FIGURE 15.41** Madison de Rozario won the marathon less than a week ago.

Five days ago, Madison de Rozario won one of the toughest marathons of her career. It left her completely exhausted – usually the marathon is the final event in para track and field. However, she wasn't going to let that stop her from adding to her growing legacy as one of Australia's finest athletes.

So, the defending champion hit the track for the 1,500-metre race and, in the process, won her fourth Commonwealth Games gold, the most of any Australian para-athlete. De Rozario had hoped to sit back in the race and watch the field fight it out in front of her before making her charge.

However, it was a slow start, and she knew that, if she was going to win, she was going to have to change her tactics and go for broke. 'I realised I was going to be out front from one lap in. When you commit to taking the lead, you have to just back yourself,' she said.

While she looked comfortable for most of the race, the final stretch was tense. De Rozario

looked to be tiring, as Scotland's Samantha Kinghorn started to push up. The Australian – who is coached by retired legendary para-athlete Louise Sauvage – managed to find just enough to pull ahead once again, while compatriot Angie Ballard produced a barnstorming final few metres to pip Kinghorn for silver.

'I definitely lost it for a little bit there. Angie came home so strong and Sam's last 300 [metres] was incredible. [I'm] so happy I just managed to hold on to win,' de Rozario said. It was extra special to share the podium with her teammate, too. 'She has been in my corner since day one. We've been to four Paralympic Games together and to get to do this is its amazing,' she said.

It was even more impressive considering the physical toll the marathon took on her – she described it as one of the most challenging courses she had ever tackled.

And even though the 28-year-old thought she had recovered, she quickly realised that wasn't the case. 'About maybe 600 metres into my warm-up, I was like, "Oh no, I'm definitely still feeling those 42 kilometres in the arms today". So, definitely brought that with me out there.'

De Rozario collected two Commonwealth Games gold medals on the Gold Coast in 2018, in the 1,500 m T54 race and the T54 marathon. 'Each race really does exist on its own, and so each one means as much as the last one.' And this moment feels as good as gold.

Source: Shalala, A. (2022), 'Madison de Rozario becomes first Australian para-athlete to win four Commonwealth Games gold medals', ABC News

**QUESTIONS**

- 1 While trying to 'hold on' in the last stages of either a marathon or a 1,500-metre track event, Madison de Rozario needs to call upon lactate tolerance that she has developed during training. **Discuss** how this is different from improving her LIP.
- 2 De Rozario stated, 'I definitely lost it for a little bit there.' What do you believe she was referring to, and how could this be avoided in future performances?
- 3 **Propose** how de Rozario's recovery from the 1,500 metres would be different, from a physiological and dietary perspective, from her recovery following the marathon.
- 4 Even though de Rozario thought she had recovered from her previous event, she had not. **Outline** two signs or symptoms that de Rozario might have recorded in her training log before the 1,500-metre event that might have indicated more recovery was required.



Adam Pretty/Getty Images Sport/Getty Images

**FIGURE 15.42** One of the closest Olympic triathlon finishes on record – is it high LIP or high lactate tolerance that contributes to the win?

**15.6 CHECK-IN QUESTIONS**

- 1 **Propose** a reason why it is impossible to improve LIP at the same time as improving lactate tolerance.
- 2 Two endurance swimmers have the same  $VO_2$  max but different LIP readings, as shown in the table below.

	$VO_2$ max	LIP
Swimmer A	75 mL/kg/min	75% $VO_2$ max
Swimmer B	75 mL/kg/min	78% $VO_2$ max

- a Which one is likely to do a faster 20-kilometre ocean swim?
  - b Briefly **justify** your choice.
- 3 As a result of intermediate-interval training, a 400-metre runner is able to improve their lactate tolerance over a period of 12 months.
    - a **Discuss** how this would result in faster 400-metre sprint times.
    - b After 12 months of lactate tolerance training, the 400-metre runner records significantly higher blood lactate levels than before. **Propose** a reason for this increase.
  - 4 Megan and Stevie are arguing about training intensities and improving LIP for a triathlete who has recorded a LIP that occurs at 90% max HR. Megan thinks the triathlete should train at 80–85% max HR, whereas Stevie believes training at 85–90% max HR would lead to greater improvements in LIP. Who do you agree with? Briefly **justify** why you believe they are correct.



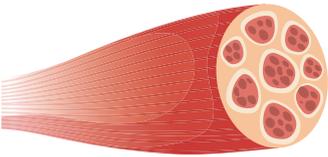
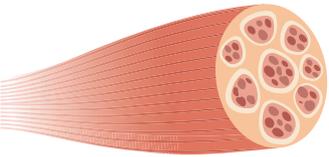
**Assessment**  
15.6 Check-in questions



## The three different fibre type classifications and their characteristics

Even though most skeletal muscle is a mixture of all three types of fibre, all the skeletal muscle fibres of any one motor unit are all the same. In addition, the different skeletal muscle fibres in a muscle may be used in various ways, depending on need. For example, if a fine motor skill is being performed, only Type I fibres and their motor units are recruited. If a stronger contraction is needed, the motor units of Type IIa fibres are activated. If a maximal contraction is required to perform a gross motor skill, motor units of Type IIb fibres are activated as well.

**TABLE 15.05** The three different fibre type classifications and their characteristics

	Slow oxidative Type I Slow-twitch	Fast oxidative Type IIa Hybrid fast-twitch*	Fast glycolytic Type IIb Fast-twitch
			
Contraction time	Slow	Fast	Very fast
Size of motor neuron	Small	Large	Very Large
Resistance to fatigue	High	Intermediate	Low
Activity used for	Aerobic	Long-term anaerobic	Short-term anaerobic
Force production	Low	High	Very high
Mitochondrial density	High	Intermediate	Low
Capillary density	High	Intermediate	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	Low	High
Major storage fuel	Triglycerides, glycogen	Glycogen	Glycogen, CP

\* Fast-twitch fibre with some slow-twitch characteristics

### Type I fibres

Slow-twitch, or slow oxidative, fibres contain large amounts of myoglobin, many mitochondria and blood capillaries, and are able to supply large amounts of oxygen for energy production. Type I fibres are red, split ATP at a slow rate, have a slow contraction velocity, are very resistant to fatigue and have a high capacity to generate ATP aerobically.

## Type IIa fibres

These fast-twitch fibres are also known as fast oxidative fibres. They contain moderate amounts of myoglobin, mitochondria and blood capillaries. Type IIa fibres are pink, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.

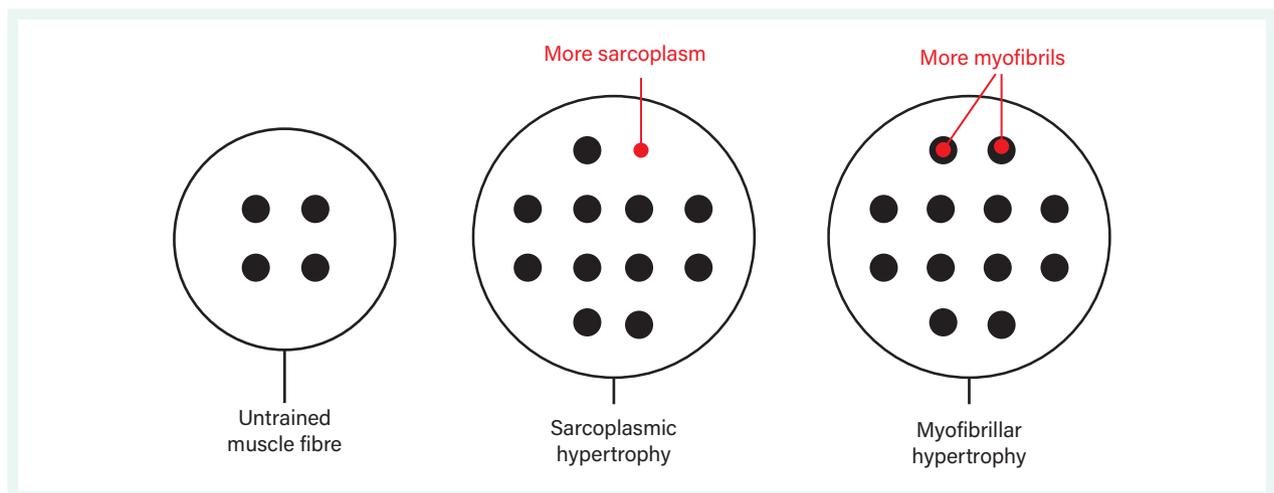
## Type IIb fibres

These fast-twitch fibres are sometimes referred to as fast glycolytic fibres. They are purely anaerobic, and contain low amounts of myoglobin, relatively few mitochondria and relatively few blood capillaries but very large amounts of glycogen. Type IIb fibres are white, generate ATP by anaerobic metabolic processes, fatigue easily, split ATP at a fast rate and have a fast contraction velocity.

## The two ways the cross-sectional area of myofibrils increases

The cross-sectional area of myofibrils can increase through:

- myofibrillar hypertrophy – when the myofibrils inside muscle fibres grow in number, allowing muscles to produce more force
- sarcoplasmic hypertrophy – when the sarcoplasm surrounding the myofibrils expands, giving more fuel and growth potential.



**FIGURE 15.44** Muscle fibres experience hypertrophy when the number of myofibrils or the amount of sarcoplasm increases.

### DID YOU KNOW?

Fast-twitch (Type IIa) muscle fibres move five times faster than slow-twitch (Type I) fibres, and fast-twitch (Type IIb) fibres contract 10 times faster than slow-twitch fibres.

# CHAPTER SUMMARY



### Resource

Self-assessment checklist

### Video

Masterclass: Chapter 15

In this chapter you have looked at long-term or chronic adaptations to training. In summary:

- Chronic adaptations occur as a physiological response to the increased demands placed on the body through training.
- Adaptations due to training can occur at the respiratory, cardiovascular and muscular systems. There are close links between the respiratory and cardiovascular systems in how they manage oxygen flow throughout the body.
- Training can be categorised as either aerobic or anaerobic. Aerobic training will elicit training responses specific to the aerobic energy system and slow-twitch muscle fibres. Anaerobic training predominantly utilises the ATP-CP and anaerobic glycolysis systems, and chronic adaptations will occur in these systems and in fast-twitch fibres.
- Adaptations are reversible and, when training ceases, will be lost at a faster rate than that at which they were achieved.

## 15.1 Respiratory adaptations

- The lungs increase their efficiency by being able to take in larger amounts of oxygen with less cost (energy), and there is an associated decrease in resting and submaximal respiratory rates.
- Tidal volume and stroke volume both have finite capacities, which means they can only increase by a certain amount, to a point at which no further increases are possible.
- Chronic adaptations that occur in the respiratory system as a result of aerobic training include increases in tidal volume, gaseous diffusion, surface area of the alveolar-capillary interface and ventilator efficiency.

## 15.2 Cardiovascular adaptations

- The heart muscle responds to training. Aerobic training increases ventricle size and anaerobic training leads to an increase in ventricle wall thickness.
- Vasodilation allows more blood to flow to areas that need more oxygen and fuels; simultaneously, vasoconstriction reduces blood flow to areas less in need during exercise, such as the stomach and other internal organs.
- Aerobic training increases the efficiency of the heart muscle. The increase in ventricle size, decrease in heart rate and increase in stroke volume are the result of the heart not needing to work as hard or beat as often to meet the body's oxygen demands at rest and during submaximal exercise.
- Increased capillarisation occurs, in both the heart muscle and skeletal muscles, as a result of aerobic training.
- Blood volume increases as a result of increases in plasma levels, number of red blood cells and haemoglobin levels.

## 15.3 Muscular adaptations: aerobic-based training

- The chronic adaptations to skeletal muscles that result from aerobic training increase oxygen consumption. These changes occur in the slow-twitch fibres and include increases in fibre size (due to increased capillarisation); capillary density; myoglobin, mitochondria, glycogen and triglyceride stores; oxidative enzymes; oxidation of fat; glycogen sparing; and  $a-vO_2$  difference.

### 15.4 Muscular adaptations: anaerobic-based training

- Chronic adaptations to skeletal muscle as a result of anaerobic-based training occur mainly in the fast-twitch fibres. These adaptations include increases in motor unit recruitment, fibre size (hypertrophy), fuel stores (ATP and CP), glycolytic enzymes and ATPase, and improved lactate tolerance.
- Resistance and plyometric training results initially in neural adaptations, followed by hypertrophy. These adaptations increase the force of contraction and the frequency and synchronisation of force development, resulting in increased speed, power and strength. Decreased neural inhibition also allows more powerful contractions to occur.

### 15.5 Combining respiratory, cardiovascular and slow-twitch adaptations to increase $VO_2$ max

- Aerobic training increases the body's ability to take up, transport and use oxygen, which increases the capacity of the aerobic energy system as well as increasing  $VO_2$  max.
- A high LIP is associated with a high  $VO_2$  max.

### 15.6 Improving LIP or lactate tolerance?

- Aerobic-based training increases the body's ability to remove lactate. This allows endurance athletes to work at higher intensities for longer before lactate accumulates, leading to an increased lactate inflection point (LIP).
- Improving LIP focuses on aerobic-based adaptations and the aerobic energy system whereas improving lactate tolerance focuses on anaerobic adaptations and the anaerobic glycolysis system.

## CHAPTER REVIEW

### 1 ©VCAA Exam 2018, Section A, Q2

Tua, Caleb and Rocky all have a  $VO_2$  max. of 3.8 L/min. If Tua weighs 58 kg, Caleb weighs 98 kg and Rocky weighs 125 kg, who would be the most suited to running a 10 km race?

- A Tua
- B Caleb
- C Rocky and Tua
- D Caleb and Tua

### 2 ©VCAA Exam 2021, Section A, Q6

The table below shows the effect of aerobic training on cardiovascular responses after eight weeks.

Cardiovascular response	Response 1	Response 2	Response 3	Response 4
Pre-training	120	195	23	55
Post-training	160	195	31	42



**Assessment**  
Chapter 15 Review

Which of the following most accurately identifies the cardiovascular responses shown in the table on the previous page?

	Response 1	Response 2	Response 3	Response 4
A	maximal cardiac output (L/min)	resting heart rate (bpm)	maximal stroke volume (mL/beat)	maximal heart rate (bpm)
B	maximal stroke volume (mL/beat)	maximal heart rate (bpm)	maximal cardiac output (L/min)	resting heart rate (bpm)
C	maximal cardiac output (L/min)	maximal heart rate (bpm)	maximal stroke volume (mL/beat)	resting heart rate (bpm)
D	maximal heart rate (bpm)	maximal stroke volume (mL/beat)	maximal cardiac output (L/min)	resting heart rate (bpm)

3 ©VCAA Exam 2020, Section B, Q3 b

Students in a Physical Education class took part in the following long-interval training session for running.

Repetitions	Sets	Distance (m)	Recovery time (s)	Intensity (% HR max)
3	2	500	90	80

Two students in the class, Sarah and Mark, debated the benefits of long-interval training. Sarah believed that long-interval training would improve lactate inflection point (LIP). Mark disagreed and claimed that long-interval training would increase lactate tolerance. Who is correct – Sarah or Mark? **Justify** your response with reference to the long interval training session above.

- 4 Two 10,000-metre runners have been swapping the lead throughout the race and find themselves next to each other, out in front of the rest of the competitors, with 200 metres left to run before the finish. Who do you believe will win the race?
- Runner A – high LIP (90% max HR) and moderate lactate tolerance
  - Runner B – moderate LIP (85% max HR) and high lactate tolerance
- Briefly **justify** your selection.

5 ©VCAA Exam 2018, Section B, Q3 b

Three male subjects, all 20 years of age, participated in a three-month training program. Physiological data was collected for each subject prior to commencing the program and at the end of the program. This data is shown in the results table below.

Factor	Subject 1		Subject 2		Subject 3	
	Pre-program	Post-program	Pre-program	Post-program	Pre-program	Post-program
resting heart rate (bpm)	60	55	63	65	50	45
maximum heart rate (predicted) (bpm)	200	200	200	200	200	200
sub-maximal heart rate (bpm)	140	130	160	160	130	125
stroke volume (sub-maximal) (mL/beat)	110	135	110	115	140	155
maximum a-vO <sub>2</sub> diff. (mL of O <sub>2</sub> /100 mL of blood)	12	16	12	12	16	18

**Explain** how the changes reflected in the pre-program and post-program physiological data for Subject 1 and Subject 3 may lead to improvements in performance.

6 ©VCAA Exam 2023, Section B, Q5 d

A long jump requires an athlete to run up and apply an explosive force to propel themselves into the air. **Identify** and **describe** one chronic adaptation of the muscular system that you would expect the long jumper to experience from completing plyometric training, and **explain** how that adaptation would lead to an improved performance.

- 7 The following table shows fuel usage for a soccer referee running on a treadmill at 60%  $\text{VO}_2$  max before and after 6 months of aerobic-based training.

Fuel	Percentage of fuel usage at 60% $\text{VO}_2$ max (%)	
	Pre-training	Post-training
Muscle triglycerides	22	45
Free fatty acids	18	15
Muscle glycogen	60	40

By referring to this data, **explain** how the changes in fuel use will improve the soccer referee's performance.

8 ©VCAA Exam 2021, Section B, Q11

In 2019, marathon runner Eliud Kipchoge became the first athlete to complete the 42.195 km distance in under two hours (1:59.40). His average pace was 2 minutes 50 seconds per kilometre throughout the run. A well-trained 800 m track runner attempted to hold Kipchoge's average pace. They had to run at maximal intensity and, due to fatigue, they were unable to continue after 1 km.

- a With reference to the lactate inflection point (LIP), **explain** how Kipchoge could maintain an average pace of 2 minutes 50 seconds per kilometre for 42.195 km, whereas the 800 m track runner could only run at this pace for 1 km.
- b i **State** one chronic muscular adaptation that leads directly to an improvement in LIP.
- ii **Describe** the role that the chronic muscular adaptation stated in part b.i. plays in improving LIP.
- 9 Sarah has been training to improve her performances as a netball centre.
- a Other than increased tidal volume, **state** two respiratory adaptations that would have led to improved aerobic power and increases in her  $\text{VO}_2$  max.
- b Select one of the above adaptations and clearly **state** how it would allow Sarah to produce more aerobic ATP.
- c By improving her  $\text{VO}_2$  max, Sarah has also found that she is able to recover more quickly during breaks in play and after training sessions. **State** how having a higher  $\text{VO}_2$  max contributes to faster recoveries such as these.
- 10 Brin has badly injured her ankle during a basketball training drill and needs to have her foot in a 'moon boot' for 12 weeks. **Identify** a muscular adaptation that she would see rapidly deteriorate as a result of detraining. Clearly **discuss** how this adaptation reversal would impact her performance in the first week she returns to training after the 12-week lay-off in the 'moon boot'.

### Command terms

#### explain

Give a detailed account of why and/or how with reference to causes, effects, continuity, change, reasons or mechanisms; make the relationships between things evident

#### describe

Provide characteristics, features and qualities of a given concept, opinion, situation, event, process, effect, argument, narrative, text, experiment, artwork, performance piece or other artefact in an accurate way

## UNIT 4 REVIEW

### INTEGRATED EXTENDED-RESPONSE QUESTIONS

These questions have been developed to allow you to draw on the knowledge and skills that you have developed across both areas of study in Unit 4. The responses require you to incorporate the concepts found in each area of study, draw on practical examples and integrate theoretical and practical concepts.

- 1 (17 marks) The Australian women's national field hockey team is nicknamed the Hockeyroos. Before travelling to the Olympic Games, they underwent extensive analysis and testing to ensure training programs were tailored to each individual player. In three lead-up international games, six cameras were stationed around the field to capture all player movements; lactate testing was conducted at various stages of the game; GPS units provided valuable information on intensities; and skill frequencies were also captured from the video. The tables below contain a summary of the findings.

**TABLE 1** Percentage of game spent working at different intensities based on field position

	% at 0–70% max HR	% at 71–79% max HR	% at 80–85% max HR	% at 85–90% max HR	% at 91–95% max HR	% at 96+% max HR
Player 1	2.9	2.8	5.6	18	41.7	28.6
Player 2	5.3	5.0	15.2	29.8	32.8	11.9
Player 3	7.7	15.6	22.5	24.8	28.6	0.7
Player 4	12.2	8.7	17.4	25.1	24.7	11.7
Player 5	39.4	21.1	17.6	12.5	4.3	5.1

**TABLE 2** Blood lactate at various stages of the game for different players

Time of game (min)	0 (pre-game)		20		35 (half-time)		60		80 (post-game)	
Player	1	2	1	2	1	2	1	2	1	2
Lactate (mmol/L)	1.3	1.4	6.2	4.3	5.7	3.1	7.4	3.8	4.2	2.7

**TABLE 3** Locomotor patterns for Player 1

Activity	% of game	Frequency	Duration (seconds)	
			Average time	Longest time
Stationary	9	123	2.5	23.7
Walking	41	362	4.2	34.5
Jogging	29	413	2.9	18.2
Moving sideways	3	58	1.2	4.1
Shuffling	5	115	1.1	5.3
Striding/sprinting	13	184	2.6	8.7

- a Explain why using six different positional cameras provides more useful data than relying on direct observation and note-taking. 3 marks
- b After considering the data presented in Tables 1 and 2 above, justify which player – 1 or 2 – is more likely to be a midfielder for the team. 3 marks
- c i Suggest how data from the analysis (Table 3) can be used to select appropriate fitness tests for Player 1. 2 marks

- ii State the most appropriate fitness test for speed in this instance, and justify why this is your choice instead of other tests for the same fitness component. 3 marks
  - d It was suggested that Player 2 could improve their anaerobic capacity.
    - i Discuss how improving this component would lead to performance improvements during a hockey match. 2 marks
    - ii Suggest a suitable training method that might be considered to improve their anaerobic capacity and provide specific details about a training session using this method. 4 marks
- 2 (17 marks) The following entry was taken from the training diary of a national-level rower who was a member of the crew that won a silver medal in the double sculls at the last Olympic Games. The training was conducted on an indoor rowing ergometer.

Day	Oct 20	Oct 23	Oct 25	Oct 28	Oct 29
mins	50	50	50	50	50
strokes	888	892	896	900	904
Dist	12,524	12,541	12,548	12,566	12,576
Predicted	12,464	12,481	12,499	12,516	12,534
Diff	60	60	49	50	42
avq watts	204	205	206	206	206
avq pace	01:59.7	01:59.6	01:59.5	01:59.4	01:59.2
avq spm	17.76	17.84	17.92	18.00	18.08

Day	Nov 23	Nov 27	Dec 1	Dec 5	Dec 9
mins	40	50	50	50	50
strokes	768	960	968	972	976
Dist	10,100	12,837	12,875	12,883	12,926
Predicted	10,100	12,778	12,830	12,850	12,869
Diff	0	59	45	33	57
avq watts		219	221	222	224
avq pace		01:56.6	01:56.5	01:56.4	01:56.0
avq spm	19.20	19.20	19.36	19.44	19.52

**spm** = strokes per minute, referring to the number of rowing strokes taken in 1 minute while using a rowing machine

- a Describe what an effective warm-up for the above training session/method would include, making specific reference to the activities undertaken. 3 marks
- b Explain how and why each of the following training principles would be applied to the above training program:
  - progression
  - tapering. 4 marks
- c Monitoring and recording of psychological and sociological variables is often overlooked throughout a training program. Provide an example of each of these types of data, and explain how tracking them during training can contribute to improved training outcomes. 4 marks
- d It is likely that the training method outlined above will lead to improvements in the athlete's lactate inflection point (LIP). Identify one cardiovascular and one respiratory adaptation and discuss how each contributes to improved rowing performances. 6 marks

- 3 (24 marks) The following data sets were collected during the first 10 minutes of an AFL game using GPS monitors worn by a midfielder and 10 different positional cameras located around the playing field.

**TABLE 1** Locomotor summaries for AFL midfielder player

Zone	Lower speed (km/h)	Upper speed (km/h)	Distance (m)	% of quarter	Entries
1 (walk)	0.0	6.0	822.9	24	88
2 (light jog)	6.0	10.0	434.6	13	101
3 (easy running)	10.0	14.0	680.5	20	125
4 (3/4 pace running)	14.0	18.0	656.2	19	66
5 (very fast sprint)	18.0	22.0	399.4	11	37
6 (max sprint)	22.0	40.0	395.2	13	18
		<b>Total zonal distance</b>	3388.8	100	

**TABLE 2** Midfielder player possessions during first 10 minutes of game

<b>Kicks</b>	< 30 m	31–40 m	41–50 m	50+ m
	0	2	2	3
<b>Handballs</b>	< 5 m	6–10 m	11–15 m	16–20 m
	0	3	0	1

Tackles	3
Directional changes	79
Loose ball gets	6
Hard ball gets	2
Overhead marks	3
Chest marks	4

Coaching staff can use the information above to better determine the physiological requirements for the midfielder player.

- a** Discuss how the above data informs the selection of fitness tests and how the results are used to plan a training program. Your discussion should include how training goals are determined and why they need to be recorded and monitored throughout the training program. 4 marks
- b** Select two different training methods that might be considered to improve  $VO_2$  maximum and two different training methods that might be used to maintain muscular power. Identify and discuss two key differences in the methods you have chosen to improve  $VO_2$  maximum. Summarise a key similarity between the two methods targeting muscular power. 6 marks

**c** Use the table below to demonstrate your understanding of:

- specificity
- intensity
- frequency
- progression
- tapering.

Summarise the training activities undertaken in three different weeks of training leading up to competition in Week 9.

10 marks

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Week 1							
Week 5							
Week 8							
<b>Week 9 = COMPETITION</b>							

**d** Identify two muscular chronic adaptations that are likely to occur if your suggested program is continued for 12 months. For each, clearly state how this leads to improved performance for the AFL midfield player.

4 marks

- 4 (17 marks) A training program aimed at improving muscular power for volleyball players is outlined in the table below:

	Mon	Tue	Wed	Thu	Fri
Plyometrics	<ul style="list-style-type: none"> <li>Lateral bounds 2 × 6/side</li> <li>Cone hops 2 × 8/side</li> <li>Squat jumps 2 × 6</li> </ul>	<ul style="list-style-type: none"> <li>Tuck jumps 5 × 10</li> <li>Single-leg box jumps 3 × 15</li> <li>Weighted squat jumps 3 × 5</li> </ul>		<ul style="list-style-type: none"> <li>30 cm depth jumps 3 × 6</li> <li>Ankle hops 4 × 15</li> <li>Split squat jumps 3 × 6</li> </ul>	<ul style="list-style-type: none"> <li>Weighted squat jumps 3 × 10</li> <li>Cone hops 2 × 10/side</li> <li>Double-leg box jumps 4 × 10</li> </ul>
Resistance		<ul style="list-style-type: none"> <li>Bent-over bench row 40% 1RM × 8</li> <li>Triceps extension 70% 1RM × 4</li> <li>Biceps curls 40% 1RM × 20</li> </ul>	<ul style="list-style-type: none"> <li>Wide grip pull-ups × 6</li> <li>Bent-over plate row 70% 1RM × 5</li> <li>Bench press 50% 1RM × 8</li> </ul>		<ul style="list-style-type: none"> <li>Weighted closed-grip pull-ups × 6</li> <li>Bent-over DB flies × 12</li> <li>DB lateral raises 40% 1RM × 15</li> </ul>

- a Assess the effectiveness of this program in improving the volleyball players' performance through the development of muscular power. Your response should make specific reference to the FITT principles. 7 marks
- b Discuss why this training program needs to be adapted if it is to be individualised to the different players on the volleyball team. 3 marks
- c Fitness testing plays a vital role in determining the main focus areas or goals for any training program.
- i List two other ways in which coaches/players can use fitness test results. 2 marks
- ii Explain two benefits of conducting regular (e.g. monthly) fitness testing during a period/block of training lasting 2–3 months. 3 marks
- iii 'In order for fitness tests to be useful, they need to be reliable.' In your own words, what does this mean? 2 marks
- d Many elite-level performers use wearable technologies during their training. Select two of these technologies and demonstrate your understanding of how they can improve the quality of training by describing how they are used within a training program. 4 marks

# GLOSSARY

## **abduction**

Moving a body part away from the midline of the body

## **absolute VO<sub>2</sub> max**

See also VO<sub>2</sub> max; the VO<sub>2</sub> max of a person expressed as L/min; lighter subjects with the same absolute VO<sub>2</sub> max as heavier subjects will have a higher relative reading and should perform better in endurance-based activities

## **acceleration**

The rate of change in velocity, measured in metres per second per second, or metres per second squared (m/s<sup>2</sup>)

## **accumulate**

To build up in the body

## **actin and myosin filaments**

Protein-based filaments, located within muscles, that are responsible for muscle contractions and production of movement

## **acute responses**

The body's immediate changes to exercise; these are short-term – that is, they last for the duration of exercise or training and while returning to pre-exercise levels (recovery)

## **adduction**

Bringing a body part towards the midline of the body

## **aerobic ATP resynthesis**

Reactions that resynthesise ATP with oxygen

## **aerobic training zone**

Also known as the continuous training zone; between 70 and 85 per cent of maximum heart rate (70–85% max HR)

## **agility**

The ability to perform a rapid, whole-body movement with change in velocity or direction in response to a stimulus

## **alveoli**

The very small air sacs, found in the lungs, where exchange of oxygen and carbon dioxide (gaseous exchange) takes place

## **ambient**

Relating to the immediate surroundings

## **anabolic effect**

The rebuilding of muscle after training

## **anaerobic ATP resynthesis**

Reactions that resynthesise ATP without oxygen

## **anaerobic capacity**

The total amount of energy available via the ATP–CP and anaerobic glycolysis systems

## **angle of release**

The angle at which a body or object is projected into the air in relation to the horizontal

## **angular motion**

Movement of a body part around an axis of rotation

## **apps**

See software applications

## **arteriovenous oxygen difference**

A measure of the amount of oxygen taken up from the blood by the tissues, as indicated by the difference in oxygen concentration between arterial blood and venous blood; measured per 100 mL of blood

## **atrophy**

A reduction in size of an organ or tissue due to an increase in size of its cells; in particular, a reduction in the cross-sectional area of muscle or muscle fibres

## **augmented feedback**

Information about a performance that comes from an external source

## **balance**

The ability to control equilibrium while stationary or moving

## **ballistic muscle contractions**

Muscle contractions exhibiting maximum velocities and accelerations over an extremely short period of time

## **ballistic stretching**

Using momentum of body parts to force a joint beyond its normal range of motion; characterised by 'bouncy' actions

## **baseline**

A performance result/outcome against which future performances are compared; or a standard of performance excellence against which current performances are measured or that they aim to achieve

## **blocked practice**

Practice of a skill where the learner practices the same skill over and over again

## **bradycardia**

An abnormally slow heartbeat

## **cardiac output**

The amount of blood squeezed/pumped out of the left ventricle, measured in litres per minute (L/min)

## **catabolic effect**

The breakdown of muscle from training

## **Chanbara**

A Japanese term for adapting the fighting arts to film

## **centre of gravity**

The point at which the whole weight of an object can be considered to act

## **checklist**

A list of items required, things to be done or points to be considered that can be used by the person who makes the list, or by others, for future reference

## **chronic adaptations**

Long-term improvements occurring in multiple body systems in response to sustained training and correct application of training principles

## **circuit training**

Training that involves performing a variety of different exercises (between five and 15), with recovery/transition periods between each, that target different muscle groups and fitness components. The completion of all these exercises makes up a single circuit, which may be repeated one or more times.

## **circumduction**

A combination of flexion, extension, adduction and abduction, in which the end of the limb being circumducted draws a circle

## **closed environment**

A setting where the learner has full control over the timing and execution of skills being performed; characterised by being in a familiar and stable place where skills can be repeated with high levels of consistency

### **closed motor skill**

A motor skill that is more internally paced, and has higher predictability and lower variability

### **compound exercise**

A movement that uses several muscle groups collaboratively to perform movements of multiple joints

### **concentration**

The action of focusing all of one's attention

### **concentric**

A muscle action in which a muscle shortens as force is developed

### **concentric contraction**

When muscle tension is developed while a muscle is shortening

### **conditioning**

Increasing the capacity of the body to produce energy and do work through training

### **confidence**

The belief or degree of certainty that an individual possesses about their ability

### **constraint-based approach**

An indirect instruction approach that allows the learner to explore movement skills and to find solutions to movement problems with less input from the coach and greater interaction with other learners

### **constraints**

Limitations or restrictions; the boundaries that influence the movement capabilities of individuals

### **continuous motor skill**

A motor skill with arbitrary beginning and end points, usually involving repetitive movements

### **coordination**

The ability to use the body's senses to execute motor skills smoothly and accurately

### **criterion-referenced results**

In fitness assessment, results that are not based on a comparison to a reference group and that typically identify an acceptable standard

### **detraining**

What happens when training ceases or the training load is less than that required to maintain a certain level of fitness

### **diaphragm**

A thin, dome-shaped muscle, located below the lungs, that assists us to inhale and exhale

### **diastolic blood pressure**

The lower of the two blood-pressure values, which represents the force of blood against arterial walls as the heart relaxes and the ventricles refill with blood – in the period of time when your heart relaxes between beats

### **diminishing returns**

The slowing of improvement over time, even in response to an appropriate training program, after initial rapid improvements on commencing training

### **discrete motor skill**

A motor skill with clearly defined beginning and end points, usually requiring a simple movement

### **displacement**

A change in the position of a body

### **distance**

The path travelled by a body from point A to point B

### **distributed practice**

Practice of a skill, or each part of a skill, with rest between activities or as shorter sessions throughout the week

### **duration**

See *also* time; how long training lasts or takes to complete; also the minimum length of time for which a training program needs to be performed before chronic adaptations become evident

### **dynamic flexibility**

The ability to move a joint quickly through its range of motion with little resistance

### **dynamic stretching**

Actively moving joints and muscles through a range of movement, usually with sports-specific motions

### **eccentric force**

A force that does not act through an object's centre of gravity

### **eccentric**

A muscle action in which tension is developed while a muscle is lengthening

### **eccentric contraction**

When muscle tension is developed while a muscle is lengthening

### **environmental constraints**

Characteristics of the physical and social environments that influence movement

### **enzymes**

Protein-based structures that help to speed up chemical reactions in our bodies that build some substances and break others down

### **equilibrium**

The state of motion the body is in when all forces and torques are balanced

### **error correction stage**

The fourth and final stage in a qualitative movement analysis; involves implementing improvement strategies to address weaknesses and errors in technique

### **e-textiles**

Fabrics that enable electronic components such as batteries, lights, sensors and microcontrollers to be embedded in them

### **evaluation stage**

The third step in a qualitative movement analysis; involves judgements about the quality of movements. Typically, it also involves identifying strengths and weaknesses in the technique and considering how improvements can be made.

### **excess post-exercise oxygen consumption (EPOC)**

The volume of oxygen used during recovery from exercise that is in excess of resting oxygen consumption

### **exercise prescription**

A specific plan consisting of fitness-related exercises and activities that are designed for a particular purpose and are usually summarised within a training program

### **explicit learning**

Learning through direct instruction on how to perform the skill

### **extension**

Movement that increases the angle of the joint

### **extrinsic motivation**

Participating in an activity for an external reason such as a reward, and not for the activity itself

**fartlek**

From the Swedish word meaning 'speed play'; a training method that uses alternating low- and medium-intensity efforts, working the aerobic energy system, with high-intensity efforts, activating the anaerobic energy systems

**fatigue**

The inability to maintain a given force production or power output

**feedback**

Information a learner receives about their performance

**fine motor skill**

A motor skill that requires control of small muscles to achieve the goal of the skill. Typically it involves eye-hand coordination and requires a high degree of precision of hand and finger movement.

**finite**

Having a limit. The ATP-CP system is finite due to limited fuel, and the anaerobic glycolysis system is limited due to the accumulation of metabolic by-products.

**finite capacity**

The limiting value of a variable, beyond which it is not capable of any further increase

**flexibility**

The ability to move the muscles and joints through a full range of motion

**flexion**

Movement that decreases the angle of the joint

**force**

A push or a pull

**force arm**

In a lever system, the distance from the axis to the force

**free fatty acid (FFA)**

The broken-down and transportable form of fats

**frequency**

How often training occurs; also the minimum number of weekly training sessions required to elicit chronic adaptations for a specific fitness component

**friction**

A force that acts in the opposite direction to motion when two surfaces are in contact with one another

**fundamental movement skills (FMS)**

Basic learnt patterns that do not occur naturally, and that form the basis of more complex sport-specific skills

**gaseous exchange**

The process of swapping oxygen and carbon dioxide. These gases move passively by diffusion across different surfaces – for example, between the blood and either the lungs or muscles.

**global positioning system (GPS)**

A satellite-based navigation system that can use body sensors to locate and track performers' position and movements

**glycogen**

An important energy store in the muscles and liver. When the body requires energy, glycogen is broken down to glucose to be released into the bloodstream.

**glycogen sparing**

The process whereby triglycerides are used instead of glycogen as fuel in the early stages of an endurance performance

**Golgi tendon organs**

Proprioceptors, located in the tendons, that are responsible for moderating muscle tension

**gross motor skill**

A motor skill that requires the use of large musculature to achieve the goal of the skill

**haemoglobin**

An oxygen-binding structure found in red blood cells, used to carry oxygen from the lungs to the rest of the body

**headspace**

A person's state of mind, mindset or attitude

**hypertrophy**

The enlargement of an organ or tissue due to an increase in size of its cells

**imagery**

Using all of the senses to create/recreate a movement skill in the mind

**implicit learning**

Learning skills through practice tasks without direct instruction on how to complete the task

**impulse**

The change in momentum of an object. It is the product of force and the time over which the force is applied ( $I = F \times t$ ).

**incremental**

Increasing in intensity over time

**inertia**

The tendency for a body to resist a change in its state of motion

**individual constraints**

Characteristics of the individual that influence movement

**individuality**

The characteristics that distinguish one performer from another; in the case of exercise, ensuring that training specifically addresses or targets the needs of the performer

**intensity**

How hard we are working during exercise, and therefore how quickly we require ATP resynthesis

**intercostal muscles**

Muscles, located between the ribs, that create and move the chest wall

**interval training**

Repeated periods of work that are followed by periods of rest/recovery

**intervention**

Implementing an action or a program in an attempt to bring about improvements

**intervention evaluation**

Understanding what impact an intervention has had and to what extent improvements have been made relative to goals

**intrinsic feedback**

Feedback from the performer's own senses; the internal information an athlete receives, based on the outcome of a particular movement or series of actions

**intrinsic motivation**

Motivation to participate in an activity for its own sake

**isoinertial**

A muscle contraction that maintains a constant inertia/load throughout the range of motion

**isometric**

The muscle length remains constant while force is developed

### **isometric muscle action**

Muscle action where there is no change in muscle length as force is developed

### **isolated exercise**

A movement that targets a specific muscle group and makes use of only one joint

### **kinetic chain**

A classification system that refers to interrelated parts of the body (i.e. joints and muscles) and how they work together to perform movements. The upper kinetic chain basically consists of the spinal column, shoulder blades, shoulders, upper arms, elbows, forearms, wrists and fingers. The lower kinetic chain basically includes the spine, pelvis, hips, upper legs, knees, lower legs, ankles, feet and toes.

### **kinetic energy**

Energy that is produced when an object is in motion

### **knowledge of performance**

Augmented feedback about the technique of skill performance

### **knowledge of results**

Augmented feedback about the outcome of skill performance

### **lactate inflection point (LIP)**

The final point that can be held where lactate production equals lactate removal

### **lactate tolerance**

The ability of muscles to buffer accumulating lactic acid so it does not interfere with muscle contractions and cause decreased force and frequency

### **lever**

A simple machine consisting of a rigid bar that can be made to rotate around an axis

### **ligaments**

Connective tissues that connect bone to bone

### **line of gravity**

A theoretical line that passes through the centre of gravity in the direction in which gravity acts

### **LIP**

See lactate inflection point (LIP)

### **location sensors**

Devices that track changes in a subject's position, speed and movements on a field or performance setting – for example, a GPS device

### **maintenance**

The minimum number of weekly training sessions required to keep a specific fitness component at current levels

### **mass**

The amount of matter that makes up an object, measured in kilograms (kg)

### **massed practice**

Practice that has fewer, but longer sessions, or shorter rest periods between practice trials within a session

### **maximum heart rate**

The highest number of beats your heart can pump per minute

### **mechanical advantage**

In a lever system, the ratio of the force arm to the resistance arm

### **mental practice**

Rehearsal of a skill, without movement, to learn the skill

### **mitochondria**

(singular: mitochondrion) Small structures found within muscle cells that produce adenosine triphosphate (ATP) in the presence of oxygen

### **moment of inertia**

The product of the distribution of the mass ( $m$ ) of the object and the axis about which it rotates

### **momentum**

The quantity of motion a body has; it is the product of a body's mass and its velocity ( $p = mv$ )

### **motivation**

The direction and intensity of effort

### **motor neuron**

A nerve cell responsible for carrying signals away from the central nervous system towards muscles to cause movement

### **motor skill**

A skill that requires voluntary body and/or limb movement to achieve its goal

### **motor unit**

A single motor neuron (nerve cell) and all the muscle fibres that neuron can potentially stimulate

### **muscle buffering**

The ability of muscles to neutralise accumulating lactic acid during high-intensity exercise, thus delaying the onset of fatigue

### **muscular endurance**

The ability of a muscle, or a group of muscles, to sustain repeated contractions against a resistance for an extended period

### **muscular hypertrophy**

See *also* hypertrophy; increasing the thickness of muscle fibres

### **muscular strength**

The ability of a muscle to develop maximal force in a single effort

### **myocardium**

The muscular tissue of the heart

### **myoglobin**

An oxygen-binding protein, mainly found in muscles, the main roles of which are storing oxygen and transporting it to the mitochondria, where aerobic ATP is produced

### **myotatic reflex**

A regulating reflex that increases muscle contractility provided a stretch is within physiological limits, ensuring muscles don't stretch too far or too fast

### **myosin filaments**

See actin and myosin filaments

### **neuromuscular**

Involving both the nervous and the muscular body systems

### **normative results**

In fitness assessment, results whose distribution is based on a particular reference group

### **objective data**

Information that can be observed or measured and that is highly verifiable and reliable

### **observation stage**

The second step in a qualitative movement analysis; involves either live or recorded vision of a subject performing a skill or movement pattern

### **open motor skill**

A motor skill that is more externally paced, and has lower predictability and higher variability

**overtraining**

When a person cannot consistently perform at a desired level of training, usually as a result of inadequate recovery or excessive training volume

**oxygen deficit**

A situation in which the body cannot fully meet its oxygen demands (oxygen demand is greater than oxygen supply). The shortfall in oxygen supply sees larger amounts of energy being produced by anaerobic pathways.

**part practice**

Practice of the individual parts of a skill

**peaking**

Demonstrating an optimal level of performance in competition as a result of successfully tapering before the event

**periodisation**

The planned variation in training methods, volume and intensity, designed to bring about optimal performance at a specified time

**personal reflection**

The process of taking time to evaluate and give serious thought to our own behaviours, thoughts, attitudes, motivations and desires

**physiological sensors**

Devices that measure physiological changes in various body parts, such as muscle contractions, heart rate and brain activity

**plasma**

The liquid portion of blood that transports fuels to cells, removes wastes from cells and helps maintain body temperature

**plateau**

A level or period where no change is observed; also, to reach such a level

**plyometric training**

Using the stretch-shortening muscle cycle to produce more powerful contractions than had no stretch occurred beforehand

**potential energy**

Stored energy in any object or system because of its position or the arrangement of its parts

**potentiate**

To select activities that make the warm-up effective or will improve the effectiveness of the performance

**practicality**

A measure of how conveniently an object can be set up and used

**preparation stage**

The first stage in a qualitative movement analysis, where prerequisite knowledge of the skill/movement is researched and consideration is given to how, where and when to conduct the next stage, which is observation

**primary data**

Information and data that is collected firsthand – either individually or as a team

**progression**

A planned increase in training stimulus to cause a positive long-term (chronic) adaptation

**projectile**

An airborne body that is only affected by the forces of gravity and air resistance

**projectile motion**

The movement of an object through the air

**proprioception**

Sensory information that comes from within the body about the body's movement and position in space

**psychology**

The study of the mind and behaviour

**qualitative analysis**

Collecting and analysing non-numerical data to understand and improve movement concepts

**quality**

The extent to which skills and movements can be performed in a controlled and optimal way, ensuring consistent and high levels of performance and reducing likelihood of injury

**quantitative analysis**

Referring to numerical and statistical data to understand performances

**quantitative data**

Any set of numerical data – typically, statistics – that can be analysed and measured objectively

**random practice**

Practice of different skills where the learner doesn't practise the same skill twice in a row

**rate**

How quickly energy can be provided to resynthesise ADP to ATP. Energy is required at the fastest rate when exercise intensity is maximal.

**rate coding**

The frequency with which motor units discharge action potentials/signals

**reaction time**

The time from the presentation of a stimulus to the onset of a response

**real-time data**

Information that is delivered as it is being collected

**redistribution of blood flow**

A physiological process that involves vessels widening (vasodilation) to increase blood flow to a particular site in the body and vessels narrowing (vasoconstriction) to decrease blood flow elsewhere

**relative height of release**

The difference between the height that a projectile is released from and the height at which it lands

**relative VO<sub>2</sub> max**

The VO<sub>2</sub> max of a person once their body weight is taken into consideration, expressed as mL/kg/min; makes it easier to compare between individuals

**reliable**

Able to be relied on; in the case of observations (performances), this depends on how often they can be replicated

**resistance arm**

In a lever system, the distance from the axis to the resistance

**resistance training**

Exercises that are performed against a resistance, including a person's own body weight, and that aim to develop muscular hypertrophy, power, strength or endurance

**resting heart rate**

The number of heartbeats per minute while the body is in a state of rest

**rotation**

Moving a body part inward or outward around its longitudinal axis

**secondary data**

Information or data that has been collected by others and that is used to increase understanding and application of existing knowledge

### **self-efficacy**

Confidence in one's own ability to perform a target behaviour (a movement skill)

### **serial motor skill**

A motor skill involving a series of discrete skills

### **shuttle run**

An exercise that consists of running back and forth between two points at a consistent pace

### **sociocultural**

Of, or relating to, the interaction of social and cultural factors such as family, peers, community, gender, socioeconomic status, and cultural beliefs and traditions

### **software applications**

Commonly referred to as 'apps'; computer software, or programs, most commonly small and specifically designed for mobile devices

### **specificity**

The kind of precision achieved by fitness testing and training that mimics the skills, movements and actions observed during competition and performances, and that enhances the physiological requirements (major muscle groups, fitness components and energy systems) of the sport or physical activity

### **speed**

The distance travelled divided by the change in time; the rate of motion or change in position

### **speed of release**

The speed at which an object is thrown, kicked or propelled into the air

### **stability**

The ability of a body to resist a change in its current state of equilibrium

### **static flexibility**

The ability to reach and hold a point in a joint's range of motion

### **steady state**

A situation that occurs when exercise intensity remains unchanged or within a small range, and variables such as oxygen uptake and heart rate remain stable, because almost all of the ATP is being produced aerobically

### **subjective**

Based on, or influenced by, personal feelings or opinions

### **subjective data**

Information that is derived from feelings, experiences, opinions and thoughts

### **submaximal heart rate**

A range of heart-rate responses between resting and maximal values. These can be further classified as low submaximal (< 50% max HR), moderate submaximal (50–75% max HR) or vigorous submaximal (75–99% max HR).

### **substrate**

A molecule that is broken down by enzymes

### **summation**

The process of adding together several of the same or different variables

### **summation of momentum**

The sequential and coordinated movement of each body segment to produce maximum velocity

### **systemic circuit**

Blood vessels that transport oxygenated blood from the left side of the heart to the tissues of the body

### **systematic observation**

A method of collecting data by watching and/or listening to the subject and recording their observations

### **systolic blood pressure**

The higher of the two blood-pressure values, which represents the force of blood against arterial walls while your ventricles contract and pump blood out of the heart

### **tachycardia**

An abnormally fast heartbeat

### **tapering**

Reducing training with the aim of significantly decreasing physiological and psychological fatigue and achieving optimal preparedness for competition

### **task constraints**

Characteristics of the task, such as rules, goals and equipment, that influence movement

### **taxonomy**

A scheme of classification

### **tempo training**

Aerobic-based training performed at competition or race pace, which is highly individualised based on training status

### **tendons**

Connective tissues that attach muscle to bone

### **testing battery**

A variety of different tests selected to assess multiple fitness components for an individual

### **thermoregulate**

To maintain a steady internal body temperature through a homeostatic process

### **thermoregulatory fatigue**

Fatigue that results from an inability to maintain a stable body temperature

### **time**

See *also* duration; how long training lasts or takes to complete; also the minimum length of time for which a training program needs to be performed before chronic adaptations become evident

### **torque**

The turning effect produced by a force

### **training adherence**

The extent to which a person acts in accordance with the intended exercise and/or training program

### **type**

A class of training that shares certain characteristics; also the particular training method being undertaken

### **variety**

A change – for example, to a regularly scheduled training session

### **vascular shunt**

The process of redistributing blood throughout the body through simultaneous vasoconstriction and vasodilation, depending on physiological needs

### **vasoconstriction**

A process whereby blood vessels narrow/constrict their internal diameter, thereby decreasing blood flow

### **vasodilation**

A process whereby blood vessels increase/expand their internal diameter, resulting in an increase in blood flow

### **velocity**

Speed of an object in a given direction ( $v = d/t$ )

### **venous return**

The rate of blood flow back to the heart, which can be increased by performing an active recovery

**ventilation**

The amount of air inspired and expired, measured in litres per minute (L/min)

**VO<sub>2</sub> max**

The maximum amount of oxygen that can be taken up (at the lungs), transported (by the cardiovascular

system) and used by muscles per minute; usually expressed in mL/kg/min when taking body weight into consideration

**weight**

The measure of gravitational force acting on a body ( $W = mg$ )

**whole practice**

Practice of the whole skill

**yield**

The amount of energy required for a task. Activities shorter in duration require a small yield, while endurance work requires a larger yield of energy.

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