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FIFTH EDITION



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VCE PHYSICAL EDUCATION | UNITS 3 AND 4

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SALLY NELSON

KIRSTY WALSH

PAUL STOCKDALE

ANDREW HAMILTON

JAMES GUTHRIE

SAM MILLAR

achper VICTORIA

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The Publisher acknowledges ongoing discussions related to gender-based population data. At the time of publishing, there was insufficient data available to allow for the meaningful analysis of trends and patterns to broaden our discussion of demographics beyond male and female gender identification.

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Meet our author team

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Sally has completed a Master of Education in Health and Physical Education and has an intense interest in HPE curriculum development. She has had over 20 years' experience teaching HPE to Years 7–12 students in a variety of educational settings. She is also currently Head of Integrated and Immersive Learning at Carey Baptist Grammar School and is an Australian Education Excellence Awardee for innovation in curriculum design. Sally has been a representative on VCAA and ACHPER discussion panels and a member of the Learning Creates Australia Social Lab team; has presented at Adolescent Success and ACHPER conferences and been involved with the New Metrics collaborative research with Melbourne University. She has also authored for several past Jacaranda titles.

Kirsty Walsh

Kirsty has 20 years' experience as a Health and Physical Education teacher. Currently the Head of HPE at Ballarat Clarendon College, Kirsty is also a VCAA examiner across HHD and PE and is the Assistant Chief Assessor for VET Health. Kirsty has also co-authored a number of Jacaranda titles, practice exams and resources, and presented and shared her expertise with ACHPER and other HPE professional learning organisations.

Paul Stockdale

Paul is currently Head of HPE at Mentone Girls Grammar and has over 25 years' experience teaching VCE Physical Education at various schools. Paul has held multiple roles at VCAA including an exam setting panel member and Assistant Chief Assessor. He has presented at the ACHPER Conference and in 2020 started abcPE – a business that specialises in supporting VCE Physical Education teachers and students with high quality resources and presentations.

Andrew Hamilton

Andrew has taught VCE Physical Education within state, select entry and independent school settings for over a decade and has also been a VCAA Physical Education assessor. He is currently the Leader of Learning for HPE at Carey Baptist Grammar School. He previously worked in training and education roles at some of the world's major sporting events including the Australian Open, French Open and China Open tennis tournaments.

James Guthrie

James is a long-serving teacher in the Health and Physical Education faculty at Melbourne High School, where he has held a number of leadership positions, including rowing coordinator and Head of Senior School. James has frequently contributed to teacher professional development via ACHPER and has served as a VCAA assessor on multiple occasions. This is James' second time contributing to the Jacaranda *Live It Up* series.

Sam Millar

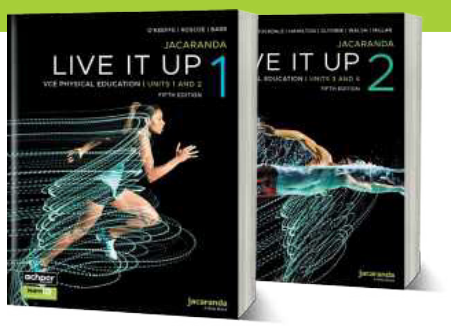
Sam is currently the Head of Physical Education at Scotch College. He has been a VCAA assessor and VCE PE teacher for 15 years and has been a Head of Department in both government and non-government schools. Sam has Master Degrees in Education and Sports Biomechanics, a Graduate Diploma of Education, and a Bachelor of Science Exercise and Sport Science. Prior to teaching, Sam was a full-time Strength and Conditioning Coach for the AFL.

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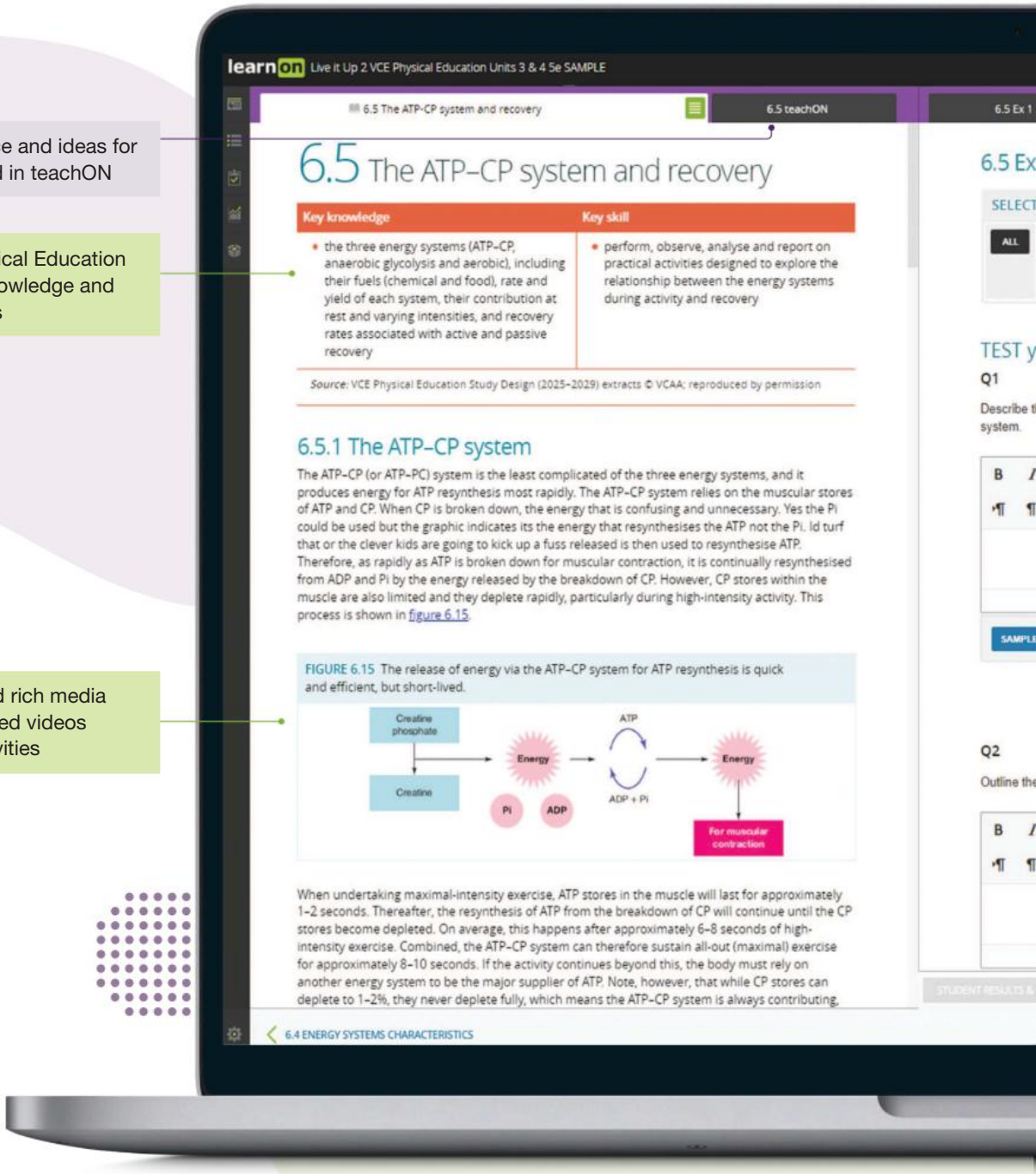
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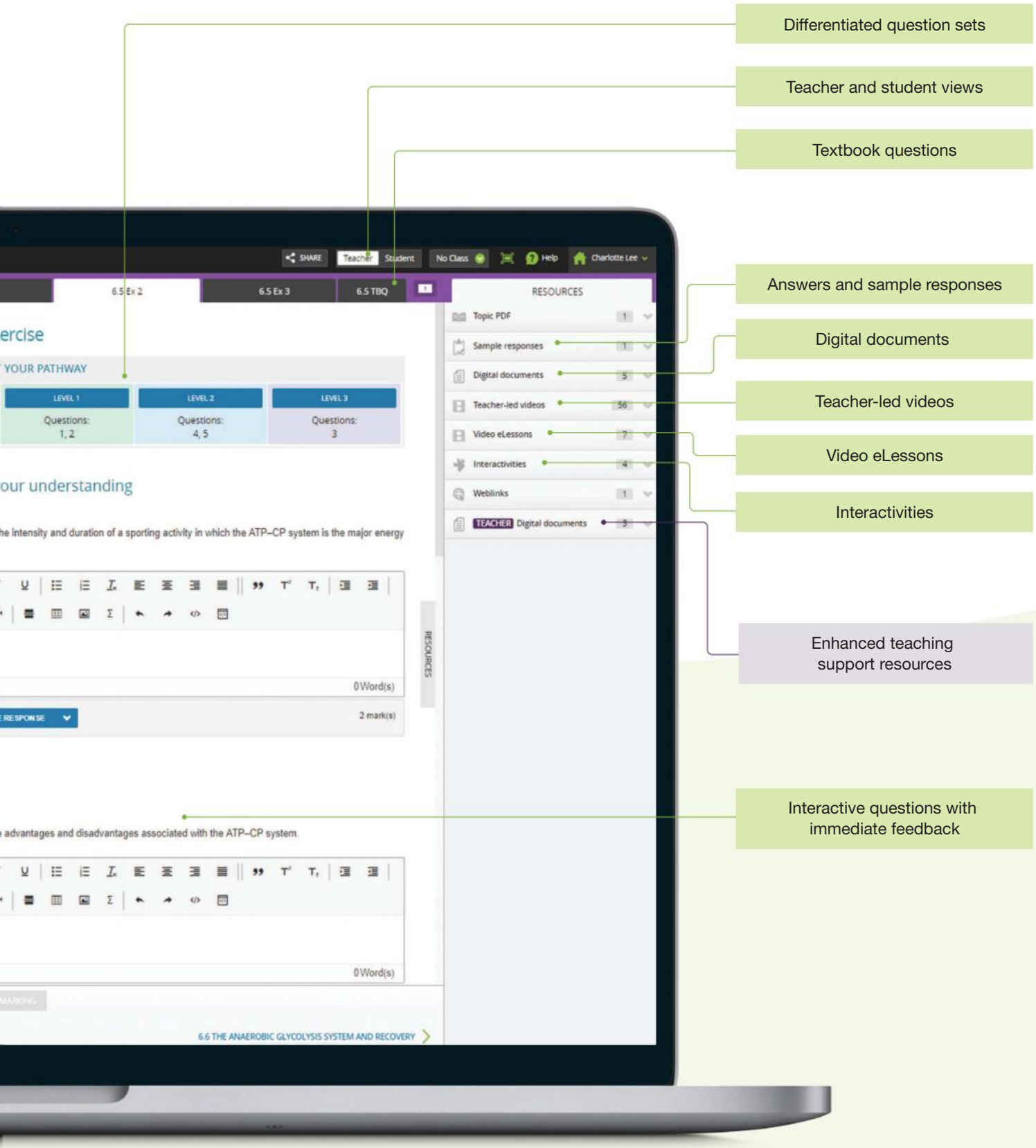
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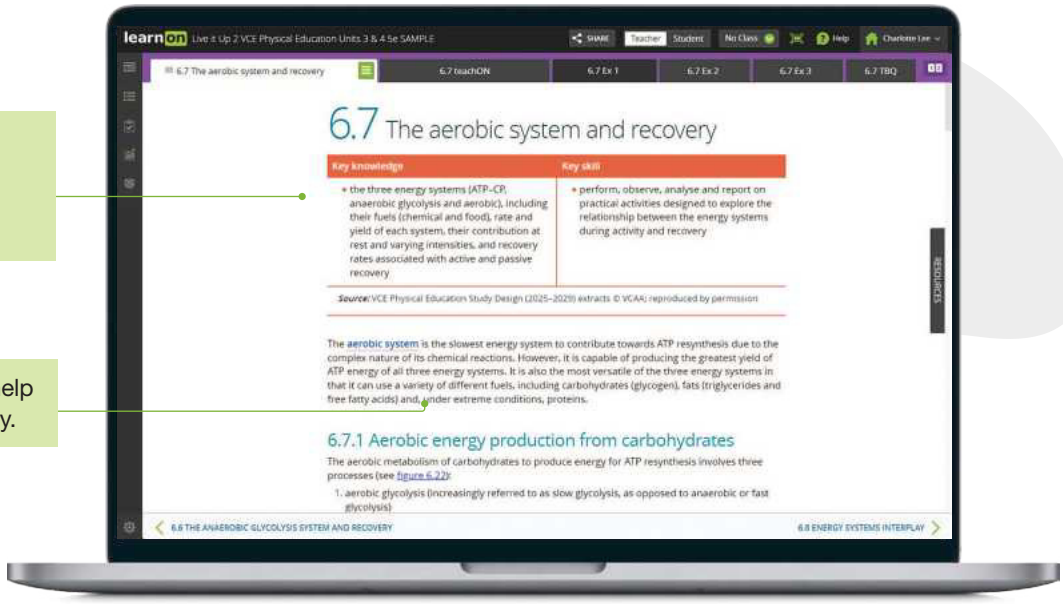


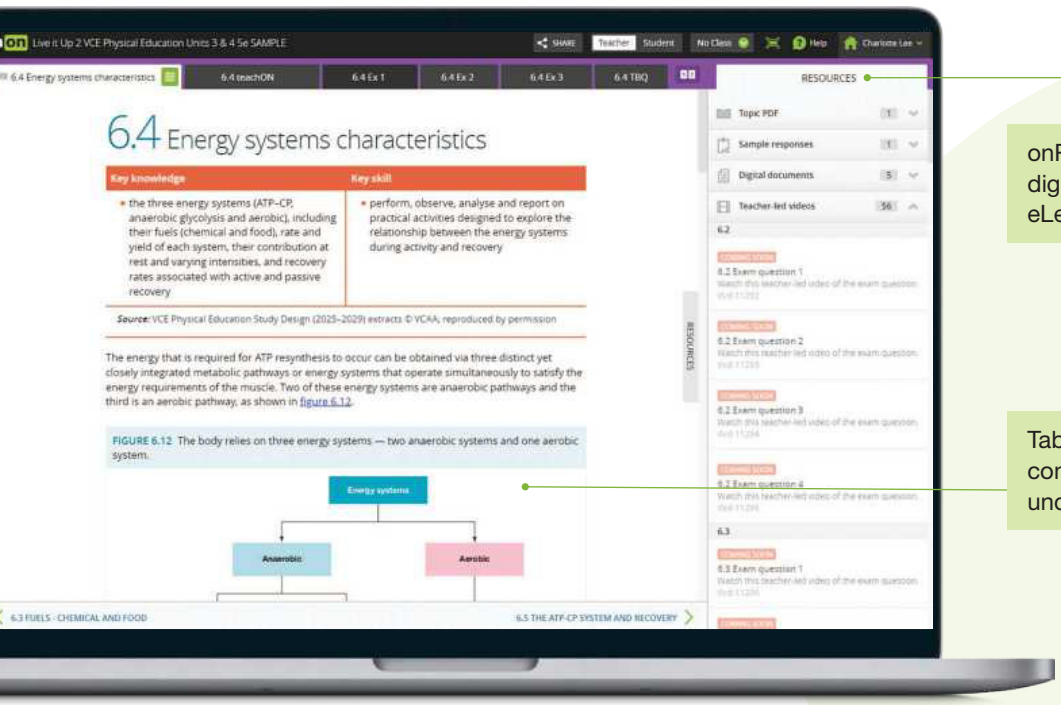
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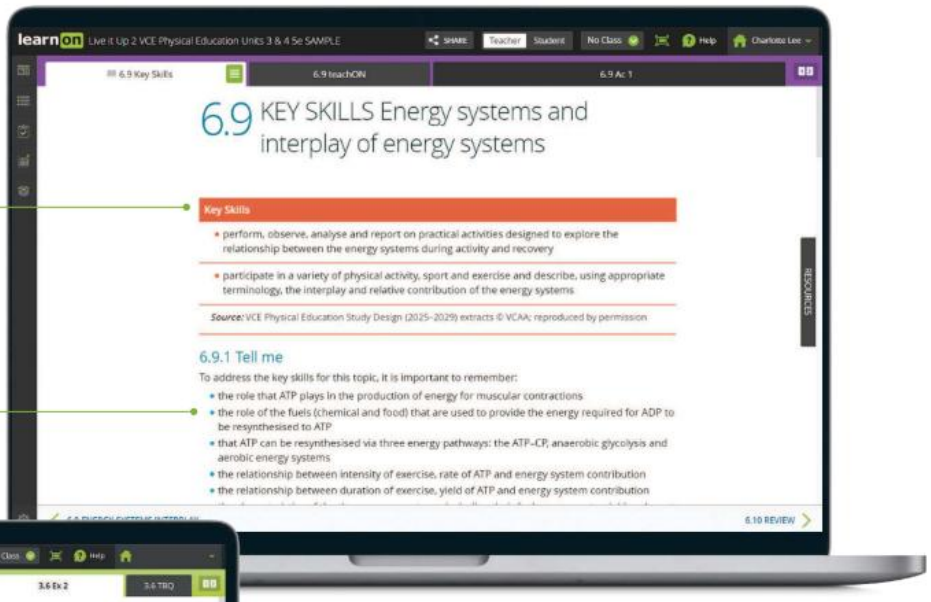


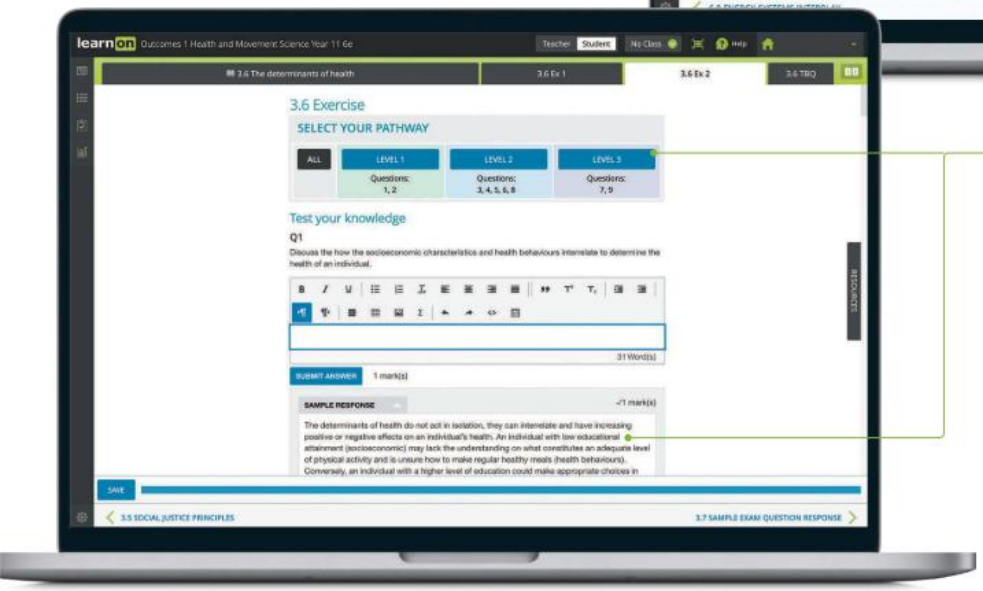
onResources link to targeted digital resources including video eLessons and weblinks.

Tables and images break down content, allowing students to understand complex concepts.

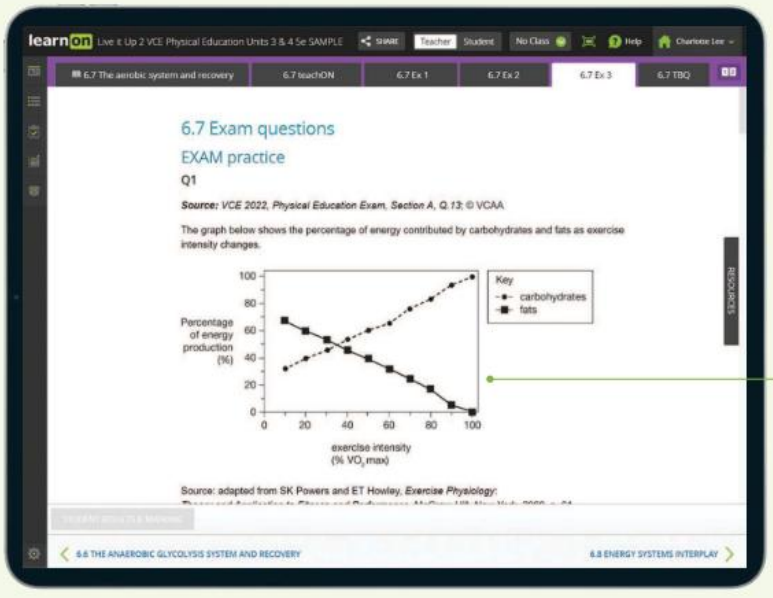
Breakdown and practice of Key skills.

Application of Key skills in each topic.





Online and offline differentiated question sets, with immediate feedback, help students to overcome misconceptions as they occur and to challenge themselves at their own level.

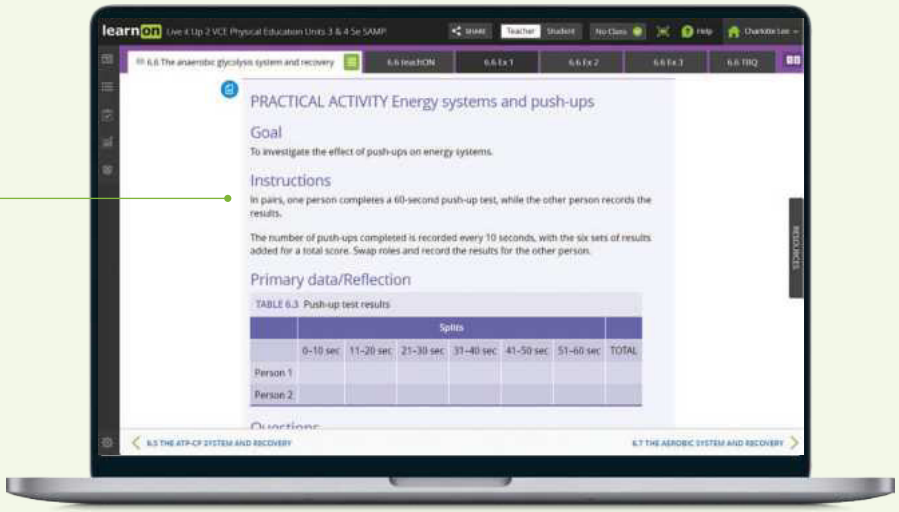


Online and offline exam questions with immediate feedback are available in each subtopic.

Practical activities and reflective folio

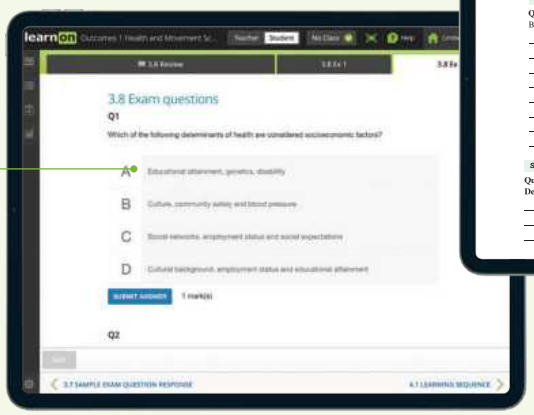
Practical activities in each topic to develop theoretical skills in a practical way.

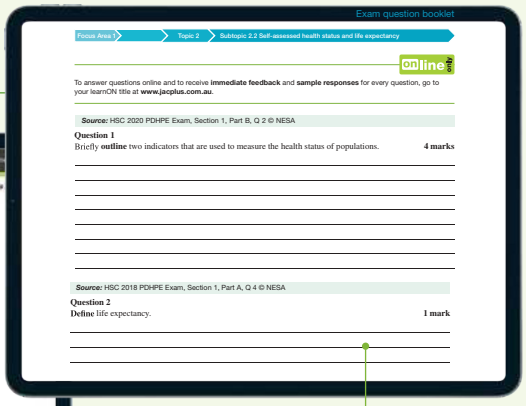
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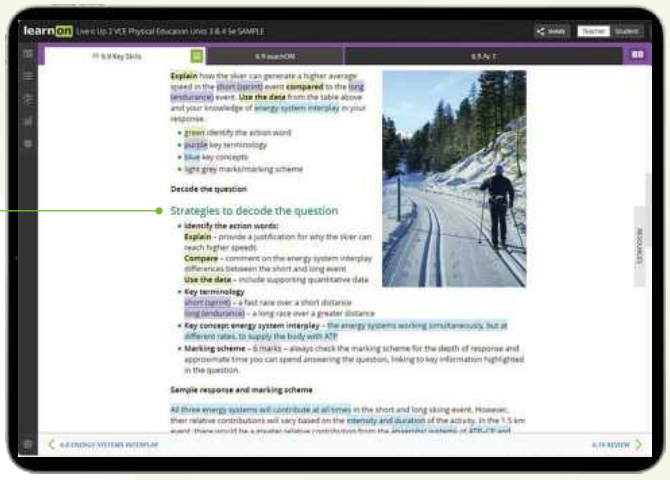




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Area of Study Review

- For each Area of Study, students can practice Extended Response questions.
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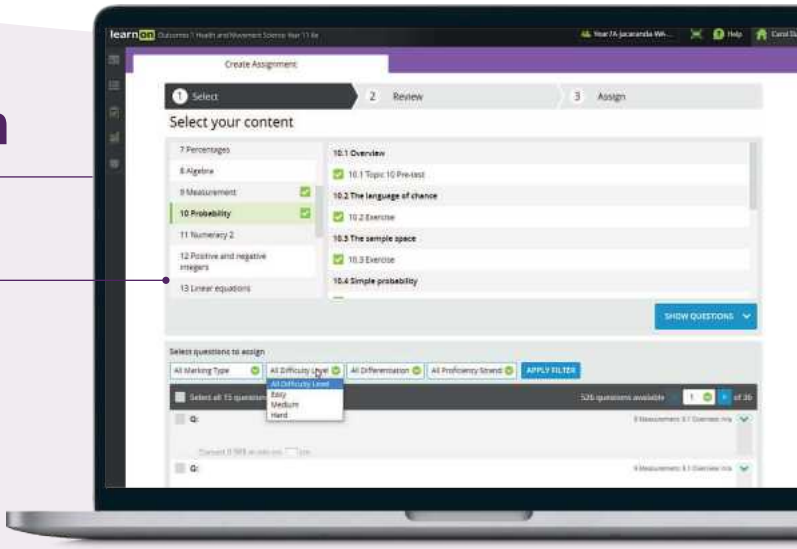


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- teaching advice and additional activities
- quarantined topic tests (with solutions)
- custom exam-builder with question filters

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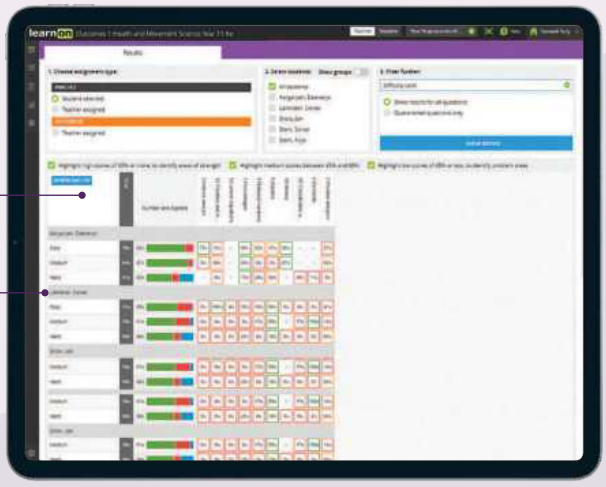
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Data analytics and instant reports provide data-driven insights into performance across the entire course.

Show students (and their parents or carers) their own assessment data in fine detail. You can filter their results to identify areas of strength and areas for improvement.



Acknowledgements

ACHPER Acknowledgement

The Jacaranda *Live It Up* series is an exciting and valuable resource for teachers, students, and the broader educational environment. It has been created to meet the modern school environment, curriculum and pedagogical models while providing a platform for multi-model learning.

The author team for the Jacaranda *Live It Up* series represents highly experienced, knowledgeable and leading educational experts. The Australian Council for Health, Physical Education and Recreation (ACHPER) Victorian Branch acknowledges Sally Nelson, Kirsty Walsh, Paul Stockdale, Andrew Hamilton, James Guthrie and Sam Millar for their contribution to the development of this learning resource.

ACHPER Victoria's purpose is to enable all people to lead active and healthy lives. We are the association that unites health and physical education professionals, including but not limited to sports, recreation, physical activity and education technology. We do this by combining to share knowledge, skills, research and understanding and bring these benefits to the broader community.

Kate Simpson

President ACHPER Victoria

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Exam terminology

The following terms are often used in the VCE Physical Education exam. Refer back to this list when answering the activities, practice exam questions and extended response to ensure you understand what each question is asking you to do.

Key term	What does it mean?
Analyse	Examine the components of; look for links, patterns, relationships and anomalies
Apply	Use your knowledge and relate it to the given case study/scenario
Assess	Weigh up the value of outcomes, results, significance, nature or extent of something
Comment	Make relevant remarks about
Compare	Show similarities and/or differences
Contrast	Show differences
Critique	Evaluate in a detailed and analytical way, judge the strengths/weaknesses and suggest improvements
Define	Give the precise meaning of a key term or concept
Describe	Provide a general description
Discuss	Give an overall account of all aspects of a concept
Draw conclusions	Make reasoned decisions or judgements
Evaluate	Make a judgement, weigh up the positives/negatives, strengths and limitations
Explain	Make plain, make clear (may require reasons), give additional detail
How	The way in which something happens
Identify	List, state
Illustrate	Use examples to show understanding
Justify	Give reasons and/or evidence to support a point of view
List	Provide single word responses, or very brief points
Outline	Provide an overview or brief summary, usually within a sentence
Suggest	State ideas
To what extent	Describe the degree or level to which a statement, opinion or contention is correct or valid
What	Provide information about something
Why	Give the reason for something

UNIT 3

AREA OF STUDY 1

How are movement skills improved?

OUTCOME 1

On completion of this unit, the student should be able to analyse primary data collected from participation in physical activity, sport and exercise to develop and refine movement skills from an individual and coaching perspective, by applying biomechanical and skill-acquisition principles.

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TOPIC SEQUENCE

1 Movement skills 2

2 Coaching to enhance participation and performance 25

3 Practice, feedback and psychological skills 64

4 Biomechanical principles 120

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Extended response — Build your exam skills 183

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1 Movement skills

1.1 Overview

Hey students! Bring these pages to life online

Watch videos

Engage with interactivities

Answer questions and check results

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LEARNING SEQUENCE

1.1 Overview
1.2 Classification of movement skills
1.3 The link between motor skill development, participation and performance
1.4 Key skills
1.5 Review

1.1.1 Introduction

Movement skills are required to successfully participate in sport. You are not born with these skills; they must be learned or acquired. This is known as skill acquisition.

Skills are classified in ways that help to inform coaches how best to teach them to young athletes. Specifically, skills are classified according to movement type, movement precision and the predictability of the environment the skill is performed in. You will need to know how this is done.

The physical education industry recognises that early skill development is important. There is a clear link between motor skill development and high performance in sport, and successful performance motivates continued participation in sport. We all like doing things we are good at!

FIGURE 1.1 How can movement skills be analysed?

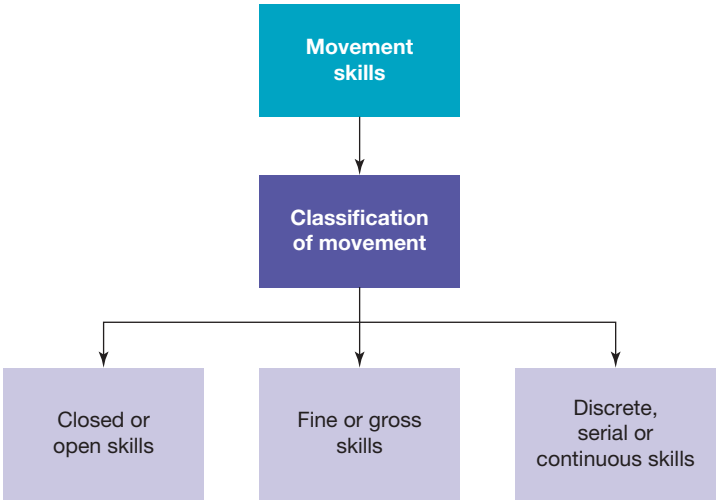


1.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• 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	• analyse primary data • analyse and classify movement skills	**1.2**
• the link between motor skill development, participation and performance	• analyse the link between motor skill development and participation and performance	**1.3**

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1.1.3 Topic preview



1.2 Classification of movement skills

Key knowledge	Key skills
• 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	• analyse primary data • analyse and classify movement skills

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Skill acquisition teaches us how best to teach and learn the skills to be performed when playing sport. Athletes and coaches use a number of criteria to classify skills. This helps them to identify the best teaching and learning approaches to acquire these skills.

It is important to identify the classification of skills before teaching them, because the different types of skills are best taught in different ways. For example, it is often best to practice a fine skill such as archery in a closed environment to limit distractions and promote accuracy. Serial skills with multiple parts, such as the triple jump (hop, step and jump), may be best taught initially in individual parts (part practice) rather than all together (whole practice).

1.2.1 Movement skills

Skill is required for all movement, but not all movements are the same. Some movement skills require small muscle groups and others require the coordination of large muscles. For example, throwing a dart uses only a few small muscle groups, making it a more precise movement compared to a kick in soccer, which requires more and larger muscle groups for more power. The external environment (e.g. opposition players, moving teammates and the location of the ball) affects the execution of some skills, while others are performed in relatively stable or closed environments, where the performer has full control of the outcome (see figure 1.2).

Movement skills can be classified as open, closed, gross, fine, discrete, serial or continuous. The classification of a skill is based on:

- the predictability of the environment (open, closed)
- the precision of the movement (fine, gross)
- the type of movement (discrete, serial, continuous).

FIGURE 1.2 Elite archers practise their delivery action using small muscle groups in a relatively controlled (closed) environment.



1.2.2 Fundamental movement skills and sport-specific skills

Fundamental movement skills (FMS) are the basis of all movements in sport. They are basic learned movement patterns and form the foundation for the development of further sport-specific skills. There is no single universally recognised list of fundamental movement skills. The skills that are identified as fundamental movement skills can vary, depending on the institution/researcher that is identifying the skills or the context in which the skills are performed. For example, the fundamental movement skills identified in the Canadian education system include some skills that are performed on ice and in snow, whereas the fundamental movement skills recognised in Australia do not typically include these skills. Figure 1.3 shows the list of skills that the Australian Sports Commission has identified as fundamental movement skills.

These skills are often the priority in primary school physical education programs and the coaching of primary school–aged children. Fundamental movement skills are sometimes categorised for the purposes of teaching, research or professional discussion.

fundamental movement skills (FMS) movement patterns that involve different body parts. They are the foundational movements for more specialised sport-specific skills.

FIGURE 1.3 The fundamental movement skills according to the Australian Sports Commission



Sport-specific skills often use a range of fundamental movement skills in a sequence of movement. For example, a high mark in Australian Rules football requires running, jumping and catching, as well as balance to land. For this reason, successful skill execution in sports requires well-developed fundamental movement skills and a knowledge of the specific requirements and techniques associated with the particular sporting skill (see figure 1.4).

Fundamental movement skills form the basis of sport-specific skills. *Can you think of a sport-specific skill and identify the fundamental movement skills that are used for it?*

sport-specific skills use a range of fundamental movement skills in a sequence

FIGURE 1.4 (a) The young girl on a trampoline is learning to jump and land with balance. These fundamental skills must be mastered before being able to **(b)** take a high mark in AFLW, like Taylah Harris.



1.2.3 Predictability of the environment — closed and open skills

Three criteria are used when determining if a skill is more open or more closed:

1. stability of the environment (is the environment stable or unstable)
2. pacing of the skill (internally or externally paced)
3. inter-trial variability (low or high).

Closed motor skills are performed in a relatively predictable unchanging environment (stable), where the performer determines when they perform the skills (internally paced) and the skills are relatively the same each time they are performed (low inter-trial variability). An example is a free throw in basketball. Play is stopped (stable environment), the basketballer throws from the same spot on the court each time (low inter-trial variability), and they determine when they move to shoot the ball (internally paced). Other skills that can be considered more closed than open are a golf drive, a gymnastics routine or batting in T-ball.

closed motor skills are performed in a predictable, self-paced environment with low inter-trial variability

open motor skills are performed in a constantly changing, externally paced environment with high inter-trial variability

Open motor skills are performed in a constantly changing unpredictable environment (unstable), where defenders, teammates or other external factors influence when skills can be performed (externally paced) and the skills are different each time they are performed (high inter-trial variability). For example, a field goal in basketball can only be scored when a player gains possession of the ball (via a pass, steal, rebound or gather) and can be heavily influenced if they have a defender on them (externally paced). This is constantly changing as the game evolves and players continually move (unstable environment). When the time is right for the basketballer to take the shot, it could be a jump shot, a slam dunk or be performed from any part of the court (high inter-trial variability). Other skills that can be considered more open than closed are surfing (see figure 1.5), passing a hockey ball in open play and kicking a goal on the run in AFL.

FIGURE 1.5 A spectacular manoeuvre gives Taj Burrow a win at the Billabong Pipe Masters in Hawaii — a reward for adapting his surfing skills to the variable wave conditions.



1.2.4 Closed/open skill continuum

Not all sports skills, whether classified as closed or open, are identical in their ease or difficulty of execution. Some skills can be classed as more closed than others. For example, tenpin bowling is more closed than outdoor archery as there are no external wind conditions to contend with. Likewise, netball is much more open than trap shooting, as the netballer must contend with the unpredictability of both opponents and teammates. The shooter on the other hand, has no one else to consider, but must respond to the variable wind conditions and moving clay target.

It is clear that the different sports and skills lie along a continuum, with the classically closed and open skills at either end (see figure 1.6). However, it is important to note that the same skill can vary in its position along the continuum depending on the particular circumstances in which it is performed. For example, practising batting using a T-stand is a more closed skill than facing a pitched ball from a ball machine, which, in turn, is more closed than facing a pitcher on the mound.

FIGURE 1.6 The closed/open skill continuum



Closed ——— Open

Closed skills are simpler to learn as they are practised under predictable conditions and lack the external pacing of open skills. This means that the learner can concentrate on the skill components or subroutines themselves, without having to worry about where their teammates or opponents are. In addition to this, the learner can perform the skill in their own time, learning the correct sequence and timing of the motor program. Open skills should be 'closed down' as much as possible for beginners (cognitive learners) so that they have more control over the skill they are practising.

As skill development progresses, the learner should practise the skill in situations that more closely resemble the game situation (see figure 1.7). This is called 'opening up' the skill and is essential if the athlete is to correctly and effectively apply the skills in the real game. For example:

- The beginner tennis player should first drop the ball and hit it over the net.
- Once this skill is mastered, the coach can hit the ball to the learner while they practise their forehand.
- The next stage would be to practise forehands using a tennis ball machine.
- The final stage of learning would involve the athlete hitting forehands randomly to a variety of positions from all corners of the court.

In this way, they are mimicking the demands of the real game.

FIGURE 1.7 Performers exhibiting open and closed skills



EXAM TIP

Always consider the three criteria when determining if a skill is open or closed:

	Closed	Open
Stability of the environment	stable	unstable
Pacing of skill	internal	external
Inter-trial variability	low	high

1.2.5 Precision of movement — fine and gross motor skills

Skills can also be classified according to the number and size of muscles or muscle groups involved in the activity. The two major classifications are fine and gross motor skills (see figure 1.8).

Fine motor skills involve the cooperative use of small muscle groups to produce precise and accurate movements. Examples include shooting in archery, darts throwing or the precise movement of the fingers in leg spin bowling.

Gross motor skills involve a combination of large muscle actions that result in a coordinated and often powerful movement. Examples include throwing, hitting and kicking.

Many sporting activities combine fine and gross motor skills, so fine motor skills may indirectly improve. Spin bowling, for example, requires both gross movements of the legs and arm, as well as the precise manipulation of the ball by the spinning fingers.

FIGURE 1.8 These skills can be placed on a continuum. Throwing darts is a fine motor skill, while a somersault in gymnastics is a gross motor skill.



Fine motor skills — Gross motor skills

on Resources

Interactivity Gross and fine motor skills (int-1837)

1.2.6 Type of movement — discrete, serial and continuous motor skills

Another method of classifying skills is by whether the movements are discrete, serial or continuous.

- **Discrete motor skills** involve movements of brief duration, and they are easily defined by a distinct beginning and end; for example, a throw, kick or catch.
- **Serial motor skills** are a series or group of discrete skills strung together to create a more complicated, skilled action. The duration of the activities is prolonged, but each individual movement in the series has a definite beginning and end. Examples include performing a gymnastics routine or the triple jump, which includes the run-up, followed by the hop, step and jump, in sequence.
- **Continuous motor skills** have no distinct beginning or end. These movements may continue for several minutes, often involving repetitive movements. Examples include swimming, running and pedalling a bicycle (see figure 1.9).

fine motor skills delicate, precise movements that engage the use of small muscle groups

gross motor skills movements involving the use of large muscle groups, resulting in a coordinated action

discrete motor skills involve movements of brief duration that are easily defined by a distinct beginning and end

serial motor skills a series or group of discrete skills strung together to create a more complicated, skilled action

continuous motor skills have no distinct beginning or end

EXAM TIP

Always use specific sporting examples when classifying skills in sport.

FIGURE 1.9 Skills can be classified according to the type of movements involved. **(a)** Goal shooting is an example of a discrete skill, **(b)** a gymnastics routine is a serial skill and **(c)** track cycling is a continuous skill. It is helpful to compare these skills using a continuum, just as we do for closed/open and fine/gross skills.



on Resources

Interactivity Discrete motor skills (int-1838)

doc-41825

PRACTICAL ACTIVITY Classification of skills

Goal

To participate in a variety of activities so that you can classify each activity as being either closed or open.

Instructions

Participate in each activity with your class and then use the three criteria of environmental stability, pacing and inter-trial variability to classify each activity on the closed/open continuum. (Is it more open or more closed?)

Station 1: 3 on 3 basketball

Station 2: Free throws

Station 3: Skipping single ropes

Station 4: Skipping long rope (person catches and throws a ball or bounces while skipping)

Station 5: Basketball 3-man weave

Primary data/Reflection

Draw up a table allocating a column to each station and each of the classifications. Decide whether the station was closed or open.

In small groups, reflect on and discuss after each station whether the activity:

- was performed in a relatively stable or unstable environment
- was internally or externally paced
- had low or high inter-trial variability.

Questions

1. Draw a horizontal line and label one end 'closed' and the other end 'open'. This is your closed/open continuum. Now place each station on the continuum.



2. Justify, using each of the three criteria, which station was the most closed.
3. Justify, using each of the three criteria, which station was the most open.
4. Explain how the same skill of skipping can be classified differently.
5. Coaches often manipulate training to make skills more open or more closed to suit the learner. Discuss an advantage and a disadvantage of making skills more open, using an example from basketball.

doc-41826

PRACTICAL ACTIVITY Basketball throw

Goal

To shoot a basketball through a hoop as the environment changes.

Instructions

1. In the gym, break into small groups (3–4 people) and collect a hoop and a basketball.
2. In each group, one person will be the thrower and one person will hold the hoop as a target 5 metres from the thrower. The other group members can collect the ball and record the scores.
   - Trial 1 – The thrower has 5 attempts to get the ball through the hoop held stationary by their partner.
   - Trial 2 – The thrower has 5 attempts to get the ball through the hoop while their partner is walking with the hoop at a constant pace.
   - Trial 3 – The thrower has 5 attempts to get the ball through the hoop while their partner moves the hoop randomly at any time.

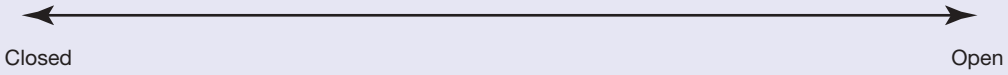
Primary data/Reflection

	Number of successful throws
Trial 1	
Trial 2	
Trial 3	

- How confident were you before and after performing each trial?
- Describe how easy or difficult it was to complete the different trials.
- What adjustments did you make as the environment changed?

Questions

1. Which trial was the most successful and why?
2. Draw a closed/open continuum and label it to show the position on the continuum of the three trials.



3. With reference to the three criteria used for open and closed skills, justify the positioning of trial 3 on the continuum.

on Resources

Video eLesson Classification of movement skills (eles-6617)

1.2 Activity

1.2 Quick quiz on | **1.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 4, 5, 6	1, 7, 8	3, 9

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TEST your understanding

1. **Provide** examples of one fine and one gross motor skill and **compare** the characteristics of these skills.
2. **Identify** the difference between a discrete and a continuous motor skill.
3. **Identify** which type of skill would be easier to develop: discrete or serial. **Explain** your answer.
4. **Identify** the type of skill that you perform most regularly while walking to class.
5. Choose a team sport and **identify** eight skills that it requires. **Categorise** each of the skills you have identified as discrete, serial or continuous.
6. **Identify** two sports in which gross motor skills are important for performance and describe the specific skills.
7. Choose two sports and **provide** examples of how fine motor skills are important for performance in those sports.

APPLY your understanding

8. **Create** a table to categorise the sports or actions according to whether they:
   - are more open or closed
   - use mainly fine or gross movements
   - are mostly discrete, serial or continuous.

   a. Archery
   b. Table tennis
   c. Darts
   d. Tennis doubles
   e. Tennis singles
   f. Squash
   g. Springboard diving
   h. Platform diving, inside
   i. Platform diving, outside
   j. Netball
   k. Netball training
   l. Track cycling
   m. Tour de France
   n. Gymnastics, uneven bars
   o. Gymnastics, horizontal bar
9. Examine the photographs in figure 1.7.
   a. **Suggest** which of the activities shown are open skills and which are closed skills.
   b. For each activity, use the characteristics of the movements involved to **justify** your classification in part a.
   c. A continuum is a line with two open ends, like a number line. The most 'closed' and the most 'open' examples would be positioned at either end of the continuum. For example, delivering a lawn bowl would be towards the closed end of the continuum, whereas making a save in water polo would be towards the open end.



Construct a closed/open continuum (as shown in the figure above), and label it with some closed and open skills.

1.2 Exam questions

Question 1 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.4;* © VCAA

Open skills

A. are self-paced.
B. allow a person to repeat the same movement pattern.
C. are performed when the conditions remain unchanged.
D. vary depending on the requirements of the activity or game.

Question 2 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.2.a;* © VCAA

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.

i. Is batting in baseball **classified** as an open skill or a closed skill? **(1 mark)**
ii. Give two **reasons** to support your response in **part a.i.** **(2 marks)**

Question 3 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.6;* © VCAA

A kick in soccer could be classified as an open skill or a closed skill.

Classify the soccer kick as an open skill or a closed skill and **justify** your response.

Question 4 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.1;* © VCAA

A free throw in basketball is classified as a discrete skill.

Provide one characteristic of a discrete skill and **outline** why a free throw in basketball is **classified** as a discrete skill.

Question 5 (3 marks)

Using the sport of hockey, **outline** how a particular skill would be taught in a closed environment before progressing to an open environment.

More exam questions are available in your learnON title.

1.3 The link between motor skill development, participation and performance

Key knowledge	Key skill
• the link between motor skill development, participation and performance	• analyse the link between motor skill development and participation and performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

1.3.1 Motor skills, participation and performance

Motor skills, participation and performance are interrelated. Central to this relationship is the fact that motor skills can be an **enabler** or a **barrier** to movement.

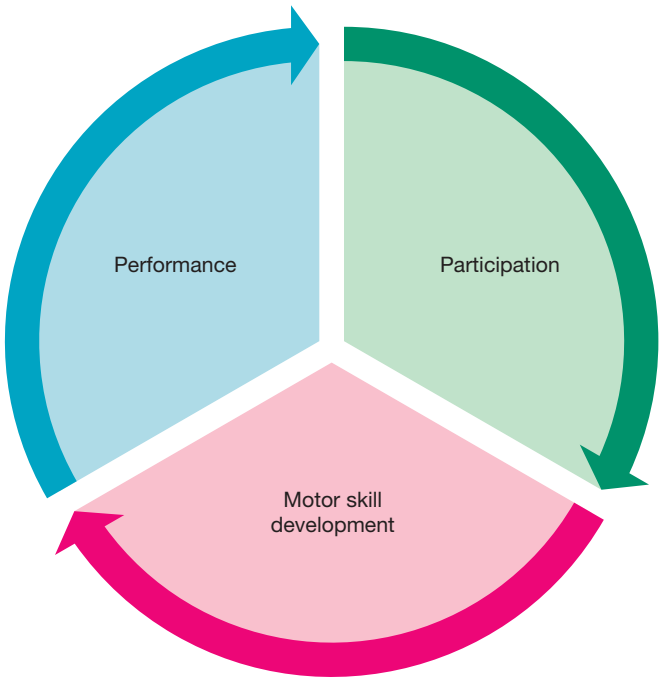
enabler something or someone that has a positive effect on a person's movement skills
barrier something or someone that has a negative effect on a person's movement skills

Motor skills as an enabler of movement

Early development of motor skills can lead to better performance in sports. Given that most people enjoy doing things they are good at, better performance in a sport or activity will lead to even more participation in that sport or activity. The more a person participates, the more they practice and develop their motor skills, and the better their performance becomes. This creates a positive

feedback loop, where better performance leads to more participation, which leads to better performance, and so on (see figure 1.10). However, the reverse can also be true.

FIGURE 1.10 The development of motor skills enables a person to participate in sports. Participation leads to greater development of skills and better performance, which can lead to increased participation.



Motor skills as a barrier to movement

A person who has not developed their skills, perhaps due to lack of encouragement from peers, school or parents, may choose not to participate in sport and develop habits associated with a sedentary lifestyle from a young age. They may choose to play sport at some point, but due to a lack of skill, they may perform poorly and quickly become discouraged and demotivated from further participation.

Examples of enablers and barriers related to motor skills, participation and performance can be seen in table 1.1.

TABLE 1.1 Examples of enablers and barriers to movement – the javelin throw

	Enabler	Barrier
Motor skill development	Using a lighter javelin (such as the plastic javelins used by Little Athletics) allows children to focus on developing the correct technique, which develops their motor skills faster. There are also fewer safety concerns, allowing for more practice opportunities.	Using a standard javelin prevents children from focusing on their technique, since they cannot produce enough force to throw the heavy javelin. The result is very little motor skill development and low participation.
Performance	Children experience success and their performance improves. They are motivated to train further, and their performance gets better with practice.	Children often only manage to throw short distances. They experience a lack of success and little improvement in their technique. They decide not to continue participating in a sport that they experience little success in.
Participation	The plastic javelins are not viewed as dangerous, so parents are happy for their children to participate. The accessibility of the sport increases participation.	The heavy javelin can pose a risk of injury. This can intimidate potential participants and may cause parents to discourage their children from participating in javelin.

1.3.2 The role of schools

Primary and secondary school students who develop their fundamental motor skills — for example, running, kicking and throwing — are most likely to increase their performance and participation in physical activity, sport and exercise. This fact has been supported by many recent studies that have shown that participation in physical activity is most likely by students who have been taught by Physical Education teachers who are skilled at increasing the fundamental motor skills of students (see figure 1.11).

The quotes below are taken from Australian and international studies into the relationship between the development of motor skills in Physical Education classes and participation in physical activity.

- 'We contend that the development of motor skill competence is a primary underlying mechanism that promotes engagement in physical activity' (Stodden, 2008).
- 'Youth with better motor abilities may find it easier to be physically active and may be more likely to engage in physical activity, compared with peers with poorer motor competence' (Wrotniak, 2006).
- 'It is clear from this review and other research that movement skill development needs to remain a key focus of PE curriculum for children and adolescents to acquire the movement skills necessary to lead physically active lives' (Sallis & McKenzie, 1991; Pate et al., 1995).

FIGURE 1.11 The improvement of motor skills in Physical Education classes has an impact on performance and participation.



on Resources

Weblink The relationship between movement skills, enjoyment and lifelong physical activity

1.3.3 Modified sports

Many mainstream sports such as tennis, netball and soccer have modified sports programs to encourage young people to participate in their sport (e.g. Tennis Hot Shots, Netta Netball and Miniroos). Each sport recognises the importance of overcoming the barriers that many children face in developing motor skills and performing and participating in their sport. To address this, they bring children of the same age together to play with modified rules (task constraints), which can include:

- shorter games
- no contact or tackling
- fewer players on smaller pitches or courts
- modified equipment, such as shorter goalposts in netball
- smaller and more colourful balls in soccer.

These sports acknowledge the link between motor skill development, performance and participation. They aim to encourage participation, fast track the development of children's motor skills and thus increase their performance. It is understood that if children can perform well, they may develop a love of the sport that could lead to lifelong participation. This is a win-win for both the participant and the sport itself!

Resources

Weblinks Family support for sporting success
Modified sports

1.3 Activity

1.3 Quick quiz | **1.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3	2, 4	1, 5

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TEST your understanding

1. In your own words, **explain** the relationship between movement skills, participation and performance.
2. Your school has asked you to complete a literature review for a paper on the relationship between movement skills and participation in physical activity. Use the statements made in section 1.3 to develop this review of the literature. As an extension task, you could do further research using the papers quoted in this section.
3. **Outline** the possible limitations of physical education programs that focus solely on participation at the expense of motor skill development.

APPLY your understanding

4. Use **Family support for sporting success**, available in the weblink section of the Resources panel, to **research** sporting families within Australia and internationally and **explain** how parents and siblings can influence skill development. **Discuss** the relationship between motor skills development, participation and performance among sporting and non-sporting families.
5. Access **Modified sports** in the weblink section of the Resources panel. Choose one modified sport from the list and **research** how it is modified from the adult version of the sport. **Explain** how these modifications affect motor skill development, performance and participation in the sport. Present your findings to the class.

1.3 Exam questions

Question 1 (4 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.9;* © VCAA

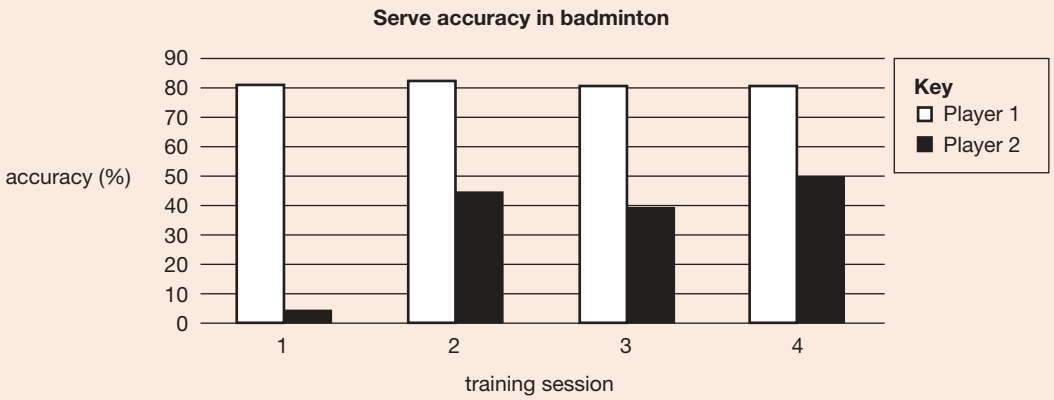
Little Athletics Australia is a modified athletics program for children aged five to 15 years. Children aged five years learn to throw a discus using a lighter, 350 g discus and they learn to throw a javelin using a light, foam javelin.

a. What type of constraint is being modified in the Little Athletics Australia program above?
b. **Discuss** the impact one modification from the Little Athletics Australia program could have on the motor skill development, participation and performance of children aged five years.

Question 2 (3 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.7.c;* © VCAA

The graph below shows the serve accuracy data of two badminton players over four training sessions.



After training session 1, Player 2 reported that they were uninterested in attending another session; however, following training session 2, Player 2 was excited to come back.

Referencing the data and stages of learning, **analyse** the link between motor skill development, participation and performance.

Question 3 (4 marks)

Pickleball (pictured) is a modified version of tennis that is hugely popular all over the world. Players use shorter racquets (paddles) to hit lightweight balls over the net in an attempt to win the point. The court is also much smaller than a normal tennis court. Pickleball was invented in the United States and is said to be 'much easier to learn to play than tennis'.



Explain how one of the game modifications of Pickleball identified in the stimulus can make it 'easier to learn to play than tennis'. In your answer refer to the link between motor skill development, performance and participation.

Question 4 (1 mark)

Define what is meant by an enabler.

Question 5 (2 marks)

Suggest how siblings can act as enablers or barriers.

More exam questions are available in your learnON title.

1.4 Key skills

Key skills

- analyse primary data
- analyse and classify movement skills
- analyse the link between motor skill development and participation and performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

1.4.1 Tell me

To address the key skills for this topic, it is important to remember:

- movements can be discrete, serial or continuous
- a discrete skill has a distinct beginning and end, such as a forehand in tennis
- a serial skill contains several discrete skills in sequence or as part of a routine (e.g. triple jump — hop, step and jump)
- a continuous skill has no clear beginning or end, and includes activities such as running, swimming or cycling
- movement precision can be fine or gross
- a fine motor skill involves the use of small muscle groups for more precise and accurate movements, such as in a darts throw
- a gross motor skill involves the coordinated use of larger muscle groups, such as in a soccer kick
- the environment in which a skill is performed can be closed or open
- a closed skill takes place in a stable environment (e.g. no defenders, indoors), is self-paced (i.e. the performer determines when the skill starts and finishes) and has low inter-trial variability (i.e. the skill is performed the same way each time). An example of a closed skill is a free throw in basketball
- an open skill is performed in an unstable or constantly changing environment, is externally paced (e.g. due to the movements of defenders and teammates) and has high inter-trial variability (i.e. the skill is performed differently each time)
- there is an interrelationship between motor skill development, participation and performance
- primary data, which includes photos, video recordings, journal entries, statistics or observations collected while completing practical activities, should be included in a reflective journal throughout Unit 3 and Unit 4.

1.4.2 Show me

Practice question (10 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

a. Place an 'x' on the continuum below to **classify** the cricket shot in figure 1.12 according to the movement precision it requires. (1 mark)

FIGURE 1.12 To come



Fine — Gross

b. The cricketer hits the ball and immediately takes off for a run to the other end of the pitch. **Identify** what type of movement the running would be **classified** as, and **explain** why. (2 marks)

c. **Justify** why batting in cricket is an open skill. (3 marks)

d. Referring to figure 1.13 and using your understanding of the link between motor skill development, performance and participation, **discuss** how *modifying* the child's equipment might *impact* their participation in cricket. (4 marks)

FIGURE 1.13 To come



Decode the question

Strategies to decode the question

- **Identify the action words:**
  Classify — arrange into categories

Identify — determine the key characteristics or features
Explain — provide detail to show the relationship between concepts
Justify — prove with reasoning why an option chosen is the best
Discuss — presents a clear, considered and balanced argument

- **Key terminology** — *modifying*, *impact*
- **Key concepts** — movement precision, type of movement, open skill, motor skill development, performance and participation
- **Marking scheme** — 10 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a.



Fine Gross

Award 1 mark for marking the continuum towards the gross motor skill end, as hitting the ball with the bat requires the use of large muscles.

b. Running would be **classified** as a continuous movement as it does not have a *distinct beginning or end point.*
Award 1 mark for identifying running as a continuous movement.
Award 1 mark for explaining that running has no distinct beginning or end point.

c. Batting is an open skill as the environment is relatively *unstable* because the *ball moves, as do fielders*. It is externally paced because the *timing of the skill* is determined by the bowler and *how fast they bowl the ball*. Finally, there is high inter-trial variability because each shot is *slightly different* depending on where the *ball is pitched*.
Award 1 mark for identifying batting as unstable, with an example.
Award 1 mark for identifying cricket as externally paced, with an example.
Award 1 mark for identifying cricket as having high inter-trial variability, with an example.

d. In the image, the bat is too big for the child so *modifying the bat to be smaller and lighter* would mean it is easier for them to hit the ball and *develop* their motor skills faster. This would lead to *better performance* in cricket and *motivate the child to continue* participating in cricket or participate *more often*.
Award 1 mark for identifying how the equipment could be modified to be easier to use for the child.
Award 1 mark for discussing the impact the modified equipment has on motor skill development.
Award 1 mark for discussing the impact the modified equipment has on performance.
Award 1 mark for discussing the impact the modified equipment has on participation.

1.4.3 Let me do it

Question 1 (9 marks)

Auskick is an introduction for young kids to try Australian Rules football. It uses non-contact drills and different sized footballs and grounds to allow for greater participation for children of all ages and sizes. Kids can develop fundamental motor skills and team tactics and strategies, while learning the basics of Australian Rules football. All Auskick participants are grouped according to their age and all age groups are facilitated by volunteers at local football clubs around Australia.

Paul is the local Auskick program coordinator but has run out of the softer, smaller balls designed for 5–8 year olds. He runs the 5-8-year-old program with full-sized footballs instead.

a. **Identify** one fundamental motor skill required to play football and provide a sport-specific example of where it is required in a game. **(2 marks)**

b. **Explain** the impact that using full-sized balls could have on motor skill development, participation and performance for the 5–8 year olds. **(3 marks)**

c. Paul wants to design a drill to improve the kicking skills of the 5 year olds. **Justify** whether a closed environment would be better than an open environment to teach 5 year olds and **suggest** one drill that Paul could use. **(4 marks)**

1.5 Review

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1.5.1 Summary

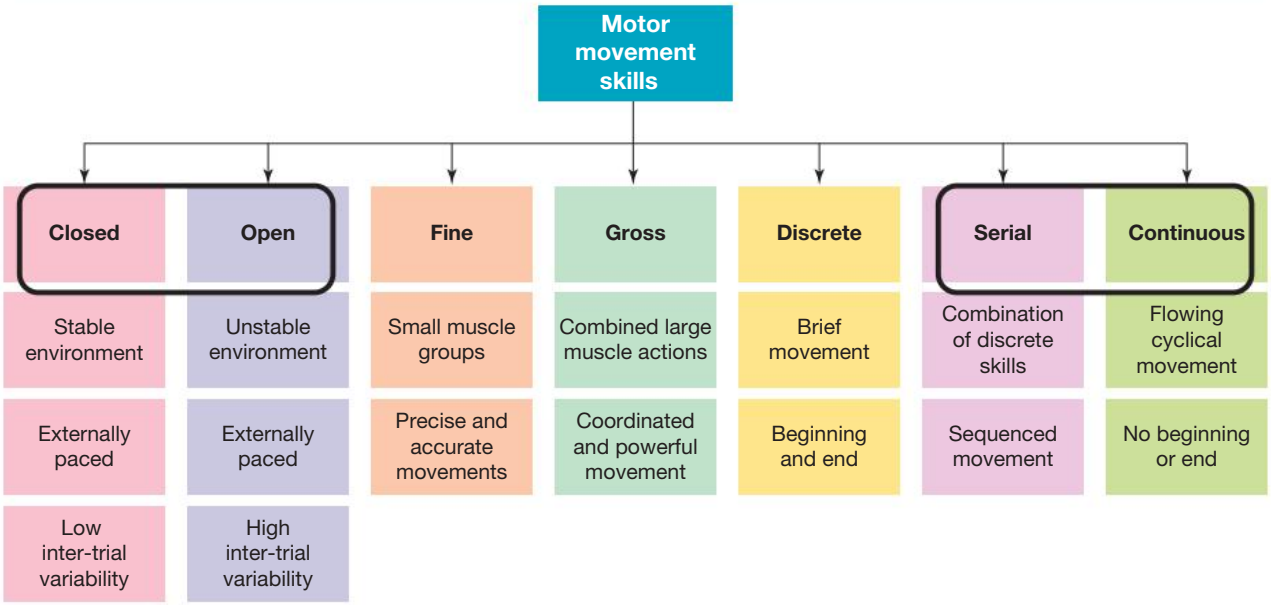
Classification of movement skills

- A motor skill involves specific movements of the body's muscles to perform a certain task.
- The predictability of the environment determines if a skill is more open or closed.
  - Closed skills are performed in a stable (predictable) environment (e.g. gymnastics moves). They are internally paced (determined by the performer) and have low inter-trial variability (the skill is relatively the same each time it is performed).
  - Open skills are performed in an environment that is unstable (unpredictable) (e.g. a sport in which the speed of the ball varies). The skills are externally paced (influenced by external factors, such as other players) and have high inter-trial variability (skills are performed differently each time).
- The precision of a movement relates to fine and gross motor skills.
  - Fine motor skills involve the cooperative use of small muscle groups for precise and accurate movements (e.g. putting in golf).
  - Gross motor skills involve a combination of large muscle actions, which result in a coordinated movement (e.g. skipping and throwing).
- The type of movement relates to discrete, serial and continuous motor skills.
  - Discrete motor skills are of a short duration and have a distinct beginning and end.
  - Serial motor skills are a series or group of discrete skills joined together to create a more complicated action (e.g. a gymnastics routine) or, in other words, fundamental movement skills combining to form a sport-specific skill.
  - Continuous motor skills are repetitive movements with no distinct beginning or end that may flow on for several minutes (e.g. swimming or running).

Link between motor skill development, participation and performance

- Motor skill development is related to participation and performance.
- Factors such as family can influence participation and skill development, with implications for performance.
- Motor skill development is an important factor in determining lifelong participation in physical activity.

FIGURE 1.14 Summary of skill classifications



1.5.2 Key terms

barrier something or someone that has a negative effect on a person's movement skills
closed motor skills are performed in a predictable, self-paced environment with low inter-trial variability
continuous motor skills have no distinct beginning or end
discrete motor skills involve movements of brief duration that are easily defined by a distinct beginning and end
enabler something or someone that has a positive effect on a person's movement skills
fine motor skills delicate, precise movements that engage the use of small muscle groups
fundamental movement skills (FMS) movement patterns that involve different body parts. They are the foundational movements for more specialised sport-specific skills.
gross motor skills movements involving the use of large muscle groups, resulting in a coordinated action
open motor skills are performed in a constantly changing, externally paced environment with high inter-trial variability
serial motor skills a series or group of discrete skills strung together to create a more complicated, skilled action
sport-specific skills use a range of fundamental movement skills in a sequence

1.5 Exam questions

1.5 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.1;* © VCAA

Which one of the following is an example of a discrete skill?

A. handball in Australian Rules football (AFL)
B. gymnastics routine
C. triple jump
D. cycling

Question 2 (1 mark)

Which of the following best classifies the release action of shooting an arrow in archery?

A. Closed, fine, serial
B. Open, fine, discrete
C. Closed, gross, discrete
D. Closed, fine, discrete

Question 3 (1 mark)

Which of the following best classifies the skill of an overhead 'smash' shot in tennis?

A. Open, fine, serial
B. Open, gross, discrete
C. Closed, fine, discrete
D. Closed, gross, serial

Question 4 (1 mark)

Which of the following best classifies the skill of a skateboarding routine in the Tokyo Olympics involving many different tricks?

A. Open, gross, discrete
B. Open, fine, serial
C. Closed, gross, serial
D. Closed, fine, discrete

Question 5 (1 mark)

Which of the following skills would be the most open?

A. A basketball free throw
B. Surfing
C. Kicking for goal in football in general play (not from a free kick)
D. Spiking a ball in a volleyball match

Question 6 (1 mark)

Which of the following is a continuous skill?

A. A soccer penalty
B. Swimming backstroke
C. Catching a cricket ball
D. A 3-minute dance routine

Question 7 (1 mark)

A Physical Education teacher teaching a 6-year-old student how to hop is an example of teaching:

A. a serial skill.
B. an open skill.
C. a sport-specific skill.
D. a fundamental motor skill.

Question 8 (1 mark)

The skill of running in a 100-metre race is considered a:

A. continuous skill.
B. serial skill.
C. autonomous skill.
D. discrete skill.

Question 9 (1 mark)

Use the following information to answer questions 9 and 10.

Auskick is a program developed by the Australian Football League to introduce children to the game of Australian Rules football. Children are grouped according to age and expert coaches are provided to teach the skills of the game in small groups with modified equipment, such as small and light footballs. To avoid injury, Auskick games have modified rules so that no one gets tackled and players can't kick off the ground. Playing fields are also smaller.

The no tackle rule to avoid injuries is designed to:

A. increase anxiety.
B. decrease participation.
C. increase fitness.
D. increase participation.

Question 10 (1 mark)

Motor skill development and performance are likely to increase in Auskick due to:

A. smaller balls.
B. smaller playing fields.
C. expert coaches.
D. all of the above.

More exam questions are available in your learnON title.

1.5 Section B – Short answer questions

Question 1 (2 marks)

Explain why the triple jump is considered a serial skill.

Question 2 (1 mark)

Provide an example of a fundamental motor skill required to perform a tennis serve.

Question 3 (2 marks)

Provide one characteristic of a discrete skill, and **outline** why a tennis serve is classified as a discrete skill.

Question 4 (3 marks)

The class debates the classification of the tennis serve. Bruno thinks that the serve is a closed skill, but his classmate Tilly thinks it is an open skill. **Justify** who is correct, and why.

Question 5 (8 marks)

Jennifer just served an ace (the opposing team were unable to pass her serve) in her volleyball match.

a. **Classify** the skill of serving in volleyball by marking a point on the closed/open continuum. **Explain** your reasoning. **(2 marks)**

b. **Classify** a volleyball serve as a discrete, continuous or serial movement, **explaining** why. **(2 marks)**

c. Primary school children often play volleyball using a low net and a soft ball. Use your understanding of the link between skill development, performance and participation to **explain** how these modifications can impact performance in volleyball. **(4 marks)**

Continue to build your exam skills

Access the Unit 3 Area of Study 1 Review at the end of Topic 4. This includes:

- Practice extended response
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2 Coaching to enhance participation and performance

2.1 Overview

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LEARNING SEQUENCE

2.1 Overview
2.2 Stages of learning
2.3 Sociocultural influences on skill development
2.4 The direct approach to coaching
2.5 The constraint-based approach to coaching
2.6 Key skills
2.7 Review

2.1.1 Introduction

In this topic, we examine the most effective means of coaching movement skills. There are two main approaches to coaching movement skills: the traditional, instructor-centred approach to coaching and the indirect, learner-centred approach to coaching.

FIGURE 2.1 How should coaches change their instruction to cater for individuals with varying skill levels and for different types of movement skills?



Choosing the most effective approach depends largely on the needs of the learner, in particular their relative stage of learning: cognitive (beginner), associative (intermediate) or autonomous (advanced). Learners' skill development and attitudes towards learning new skills is also shaped by their environment and sociocultural influences, such as family, peers, cultural norms and sociocultural status.

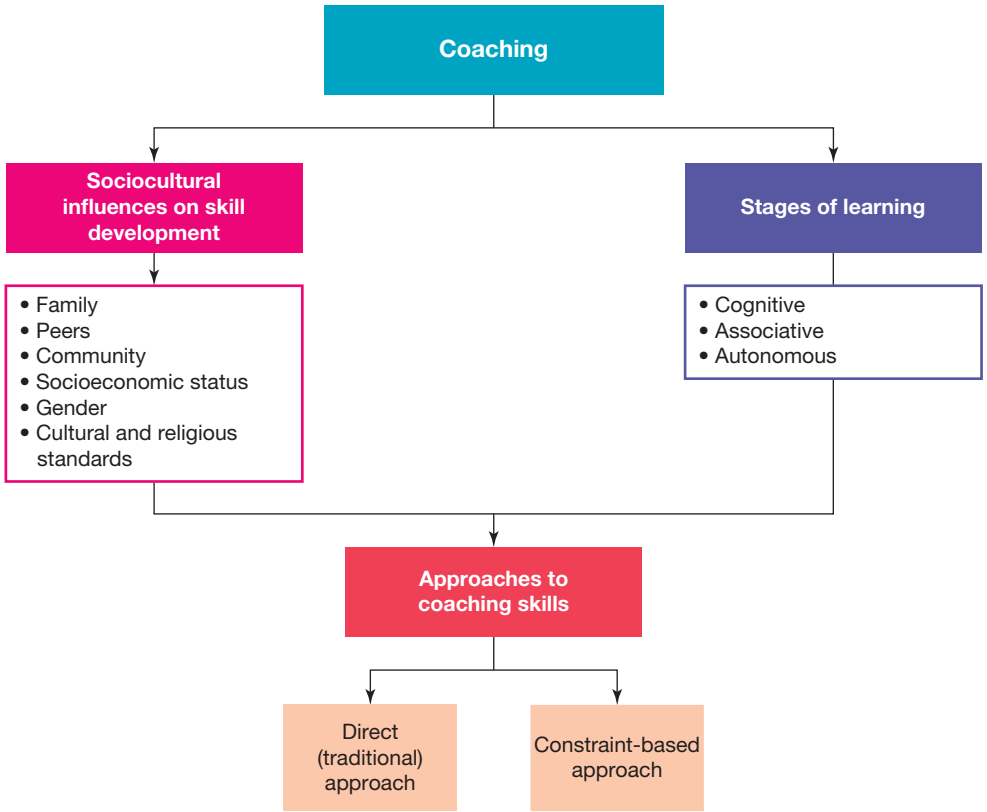
Therefore, to successfully develop and refine new movement skills, a coach must have a solid grasp of multiple coaching strategies as well as an appreciation of the learner and their specific needs. A learner who experiences a positive learning environment in which their individual needs are met is more likely to persist with, and continue to participate in, the sport or physical activity.

2.1.2 Key knowledge and Key skills

Key knowledge	Key skill	Subtopic
• considerations when coaching to enhance participation and performance: – characteristics of the three stages of learning	• analyse primary data • 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	**2.2**
– sociocultural factors that affect skill development		**2.3**
– theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches		**2.4** **2.5**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

2.1.3 Topic preview



2.2 Stages of learning

Key knowledge	Key skill
• considerations when coaching to enhance participation and performance: – characteristics of the three stages of learning	• analyse primary data • 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

To design an effective skills training session, a coach needs to take into account the skill level of the learners. The coach must be able to successfully match the learning needs of the performers with the appropriate learning environment (see table 2.1). For example, the level and type of coaching given to a novice (beginner) will be significantly different to the coaching given to an elite athlete.

The stages of learning model identifies three distinct learning stages:

1. cognitive (*understanding stage*)
2. associative (*practice stage*)
3. autonomous (*automatic stage*)

These stages describe the characteristics of the learner as they progress from novice performer (cognitive stage) to an intermediate level (associative) and finally to skill mastery (autonomous).

Understanding a performer's stage of learning helps the coach to decide on the most appropriate type of coaching and the most effective way to structure the practice session. (This is covered in more detail in topic 3.)

While the model describes three distinct stages, it's best to think of the stages of learning as a continuum, where learners transition gradually from one stage to the next.

How quickly a performer moves through these stages of learning will depend on the skill being taught, the characteristics of the learner and the type of coaching and practice environment. It should be noted that not all performers will reach the autonomous stage. The demands of the skill may surpass the relative ability of the learner and/or the learner may not be exposed to appropriate practice or suitable coaching.

FIGURE 2.2 Learners progress along a continuum from novice to skill mastery.



2.2.1 Cognitive (understanding) stage

The first stage of learning, the beginner phase, is known as the **cognitive (understanding) stage of learning** (see figure 2.3). In the cognitive stage of learning, the majority of the learner's attention is directed to trying to understand the new skill. The performer makes many skill errors and struggles to understand why the errors occur or how to correct them.

Learning in the cognitive stage takes place largely through 'trial and error'. The cognitive stage is usually the shortest of the three stages, as improvements in skill performance is rapid early in the learning process.

Coaching the cognitive stage

- It's important that the coach keeps feedback simple and does not overload the beginner with too much information.
- Performers in the cognitive stage of learning benefit from watching repeated demonstrations of effective technique.
- Verbal instruction should be clear and concise.
- The coach should provide feedback on the relative success of the performance, and provide the learner with strategies to correct faults.

FIGURE 2.3 In the cognitive stage, the new skill is learned.



2.2.2 Associative (practice) stage

Once a learner is able to understand and refine the basic mechanics of the skill (indicating improvement), they are said to be in the **associative (practice) stage of learning**. In the associative stage, the performer moves away from the trial-and-error style of learning towards refining and replicating the required movement pattern (see figure 2.4). The associative stage is often referred to as the practice stage; the learner can successfully perform the skill but needs regular practice to eliminate minor errors.

FIGURE 2.4 In the associative stage, the learner is exposed to the game environment.



In the associative stage, the learner begins to understand why they make errors and starts to comprehend and adopt strategies to correct these errors. The learner is directing less attention towards performing the skill, so more attention can be given to the game environment. The learner begins to interpret relevant cues in the game environment and selects the appropriate skill to perform. For example, in basketball, the learner is able to decide when it is appropriate to pass and when it is best to dribble.

Coaching the associative stage

- Coaches must provide regular practice opportunities.
- The learner should be exposed to a more 'open' competition environment, where they learn to recognise important cues and develop their decision-making capabilities.
- Coaches should continue to assist the learners to recognise why they have made an error and develop their ability to self-correct the error.

cognitive (understanding) stage of learning the initial phase of learning of a motor skill where the emphasis is on conscious understanding of the task requirements

associative (practice) stage of learning the second phase in the learning of a new skill, in which movement patterns become more refined and consistent through practice

2.2.3 Autonomous (automatic) stage

In the **autonomous (automatic) stage of learning**, the learner can perform the skill almost automatically. The skill becomes ingrained, so that very little attention is required for skill execution. A performer in the autonomous stage is able to multitask. For example, a NBL-level basketballer can dribble the ball while simultaneously assessing where their teammates and opponents are, and deciding on the most effective play in the situation: to pass, shoot or dribble (see figure 2.5).

Performers in the autonomous stage of learning become more attuned to important cues and information in the competition environment and develop greater tactical awareness and decision-making capabilities.

FIGURE 2.5 The autonomous performer can simultaneously execute movement skills and scan the environment to decide on the next play: pass, dribble or shoot.



Coaching the autonomous stage

- The coach should provide precise feedback to further improve skill execution. Small improvements can make a significant difference at an elite/high level of sport.
- Performers need to be kept motivated to further improve and refine their skill level.
- Match simulation should be used to enhance performers' tactical knowledge and decision-making skills.

EXAM TIP

The study design stresses the importance of considering the needs of the learner when developing coaching strategies. Don't forget to familiarise yourself with the coaching strategies that are applicable to each of the three stages of learning.

autonomous (automatic) stage of learning the final stage of learning in which the performer's skill execution is almost automatic and requires very little of their attention

on Resources

Interactivity Characteristics of the stages of learning (int-6783)

TABLE 2.1 Summary of coaching the stages of learning

Stages of learning	Cognitive	Associative	Autonomous
Characteristics of learner	• Complete beginner – Frequent errors – Large errors – Unable to detect own errors • Learner's attention is given to understanding the skill • Trial-and-error learning style • Unable to correct performance errors	• Skill refinement and becomes more consistent (improving) – Less frequent errors – Small errors as skills are refined – Beginning to detect their own errors • The learner concentrates on skill refinement • Improved ability to correct errors • Some perception of important cues/information in the game environment	• Performance almost automatic • Highly skilled – Few errors – Very small errors – Can detect errors • Multitasking evident • Able to adjust skills to game environment • Greater tactical and strategic awareness • Highly developed ability to correct errors
Considerations for coaches	• 'Keep it simple' • Don't overload the learner with information • Verbal instructions should be clear and concise • Learner benefits from skill demonstrations • Learner should be taught how to detect and correct errors • Skills may be simplified or broken into smaller skill components	• Provide opportunity to practise • Learners continue to work on error detection and correction • Assist learner to recognise important cues/information in the game environment	• Precise feedback • Match practice • Ensure learner motivation is high through varied and engaging practice • Continue to challenge the learner

doc-41827

PRACTICAL ACTIVITY Stages of learning

Goal

To observe the characteristics of a novice performer and identify the most effective way to coach individuals in the cognitive stage of learning.

Equipment

- Class set of footbags (hacky sacks)

Instructions

1. Use **Footbag**, found in the weblinks section of the Resources panel, to choose one or two skills you'd like to learn; for example, juggling the bag with consecutive inside kicks.
2. Working in pairs, one person attempts to practise the skill while the other observes and provides instruction. Each person should spend approximately half the lesson time in each of the roles of coach and learner.

Primary data/Reflection

- What were the most challenging aspects of learning the hacky sack skill?
- How did you overcome obstacles or setbacks during the learning process?
- What strategies were most effective in improving your skill?

- How do you plan to continue developing your hacky sack skills beyond this activity?
- How has learning a hacky sack skill contributed to your overall understanding of the stages of learning?

Questions

1. Use your observation of your partner's performance to describe the characteristics of the cognitive stage of learning.
2. As the learner, discuss where the majority of your attention was focused.
3. As the coach, reflect on the most effective and least effective means of teaching the new skill.
4. From the learner's perspective, what was your partner's most effective coaching strategy?

on Resources

Weblink Footbag

2.2 Activity

2.2 Quick quiz on

2.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2	1, 5	3, 4

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TEST your understanding

1. **Name** and briefly **summarise** the characteristics of each of the three stages of learning.
2. **Outline** why it is important for a coach to understand their performer's stage of learning.
3. **Explain** the difference in learning styles between the cognitive stage and the associative stage.
4. a. **Define** the term *attention*.
   b. **Explain** how the amount of attention given to executing a skill changes as the learner progresses through the three stages of learning: cognitive, associative and autonomous.
   c. **Identify** the implications of your answer to **part b** regarding coaching an autonomous performer.

APPLY your understanding

5. Imagine you're a hockey coach. You've been asked to run two very different training sessions: one for a group of under-10 beginners and one for an elite senior State League club side.
   a. **Identify** the most likely stage of learning for the players in the under-10 group.
   b. **Identify** the most likely stage of learning for the players in the senior team.
   c. **List** some coaching strategies appropriate for the under-10s.
   d. **List** some coaching strategies appropriate for the senior team.

2.2 Exam questions

Question 1 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.1;* © VCAA

In the cognitive stage of learning, what is the learner trying to do?

A. understand the skill
B. refine their performance
C. make the actions automatic
D. organise a more efficient movement pattern

Question 2 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.8;* © VCAA

Which one of the following is a characteristic of an athlete in the autonomous stage of learning?

A. The athlete performs subroutines out of order.
B. The athlete is able to detect some of their errors on their own.
C. The athlete has difficulty anticipating what movement is needed.
D. The athlete can vary the accuracy, speed and uniformity of their movements.

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.1;* © VCAA

During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200 m and 400 m freestyle swimming events.

i. **Identify** the stage of learning Titmus was in at the 2020 Tokyo Olympic Games. **(1 mark)**
ii. **List** two characteristics of the stage of learning identified in **part a.i**. **(2 marks)**

Question 4 (3 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.7.a,b;* © ACHPER

Two VCE students, Bobby and Charlie, who regularly play representative basketball, have volunteered to coach a Year 2 basketball team. None of the primary school players have played basketball before. The first match is scheduled to be played in six weeks.

a. What stage of learning are the Year 2 players likely to be in? **(1 mark)**
b. **Identify** two characteristics of learners in this stage of learning. **(2 marks)**

Question 5 (3 marks)

Dale, a Year 9 student, is learning 3-ball juggling. Dale's best performance is seven complete cycles (21 catches) of 3-ball juggling before he makes a mistake and drops a ball.

a. **Identify** Dale's stage of learning. **(1 mark)**
b. **Describe** the defining characteristics of the learner in the stage of learning identified in **part a**. **(2 marks)**

More exam questions are available in your learnON title.

2.3 Sociocultural influences on skill development

Key knowledge	Key skill
• considerations when coaching to enhance participation and performance: – sociocultural factors that affect skill development	• analyse primary data • 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

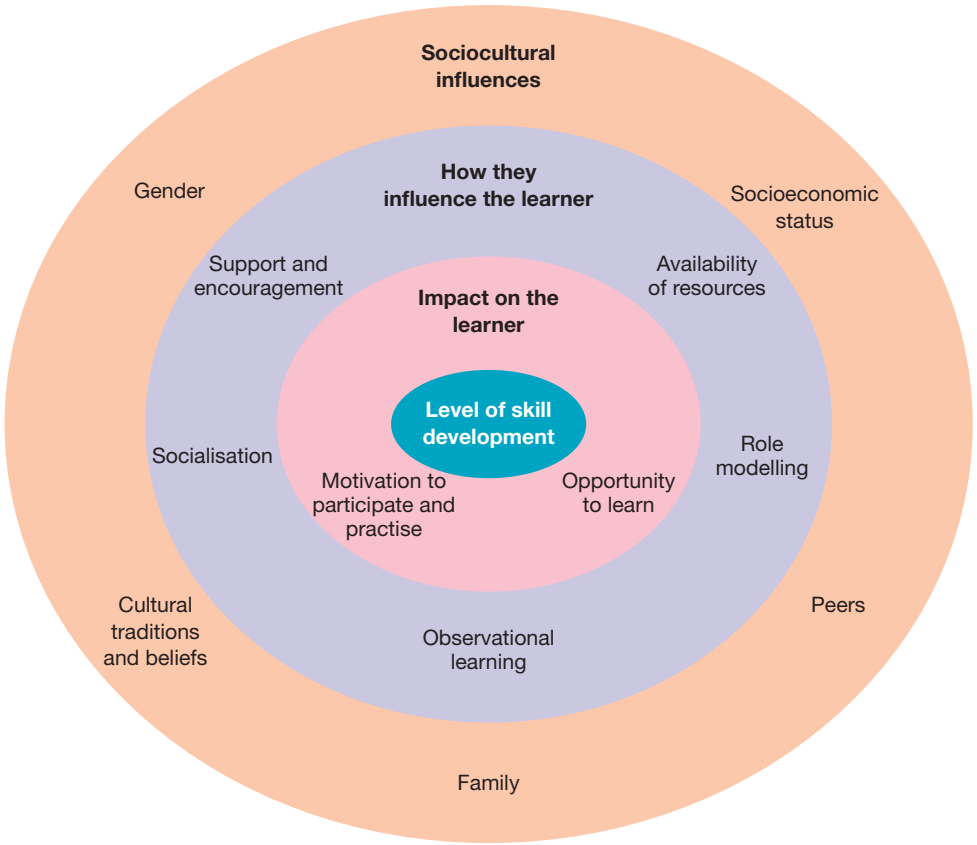
2.3.1 Sociocultural factors

We generally consider skill development to be the result of a combination of the learner's genetic traits, the amount of practice undertaken and the availability of expert coaching. However, it's also important to acknowledge the influence that society and cultural practices have on skill development. Sociocultural factors such as family, peers, cultural norms, local community and socioeconomic status play a significant role in determining the type and extent of skill development (see figures 2.6 and 2.7).

FIGURE 2.6 Skill development is influenced by the sports prevalent in the local community.



FIGURE 2.7 The impact of sociocultural influences on skill development



Sociocultural influences affect skill development in multiple ways, including through:

- the relative opportunity afforded to the learner to participate and practice in sporting activities
- the values and beliefs that underpin attitudes to learning
- the presence of influential role models.

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

These sociocultural factors influence what the learner values and who they aspire to be. For example, most young soccer players aspire to play with the attacking flare of international strikers such as Australia's Sam Kerr and France's Karim Benzema (see figure 2.8). Learners will be influenced by people in their immediate environment, such as family and friends, and by their country's bias towards particular sports and activities.

Significantly, an awareness of sociocultural factors enables a coach to better understand learners' specific needs and relative strengths and weaknesses, allowing them to design a more effective learning environment.

FIGURE 2.8 Young players look up to exciting role models such as **(a)** Sam Kerr and **(b)** Karim Benzema.



2.3.2 Family

Parents facilitate their children's involvement in sport by driving them to practice sessions, buying uniforms and sports equipment, and funding registration fees. But more than meeting costs and providing logistical support, parents encourage their children to get involved and to apply themselves to practice. Parents have a significant impact on their children's values and their attitude towards learning.

FIGURE 2.9 Families have a significant impact on children's sport and movement skill development.



2.3.3 Cultural norms, traditions and beliefs

Different nationalities identify with different sports. For example, Kenya is often associated with distance running, Canada with ice hockey, Japan with martial arts and Brazil with soccer (see figure 2.10).

FIGURE 2.10 (a) Canadians love their ice hockey, **(b)** distance running is popular in Kenya and **(c)** Japan is famous for its martial arts.



The prevalence of a particular sport in a community can have a significant impact on skill development. For example, swimming is a high-profile sport in Australia. Our national swimmers receive a high level of coverage in the media and are afforded celebrity status. These high-profile swimmers act as role models to Australian children and this, in turn, leads to greater participation in the sport of competitive swimming.

Barriers to involvement in sport and physical activity

Cultural and religious beliefs can also be a barrier to sports participation and potential skill development. For example, in some countries, the abiding beliefs and cultural norms may oppose women being involved in sport or particular types of sport. Likewise, opportunities to be involved in sport and recreational pursuits can be seriously compromised in countries that suffer from political instability and civil unrest.

The ethnic minorities in a society and/or recent refugees may encounter many barriers to involvement in sport and the opportunity to develop fundamental movement skills. These include:

- language barriers in accessing important information regarding organised sport
- lack of culturally appropriate venues and facilities
- encountering discrimination and racism
- cultural and religious standards of modesty may be at odds with a sport's dress code/uniform expectations
- lack of appropriate role models.

How barriers are being addressed

In Australia, to help address these barriers, programs, initiatives, resources and clubs have been created and changes have been implemented. This includes, but is not limited to:

- updates to sport dress codes/uniform expectations to be more inclusive
- the government-run Driving Social Inclusion through Sport and Physical Activity Grant Program
- Multicultural Active Sports Australia (MASports Australia) programs
- Welcoming Australia initiatives, including Welcome to the Game and Welcoming Clubs.

on Resources

Weblinks Multicultural Active Sports Australia Club
Welcoming Australia
Australian Sports Commission — Cultural, racial and linguistically diverse communities

2.3.4 Peers

Friends play an important role in influencing the types of sport children participate in and, therefore, the types of skills they develop. Younger athletes are generally motivated to play with their friends and will consequently choose and work on the sports popular with their social group. If a peer group has a tendency towards sedentary behaviour, such as playing computer games, this can present a barrier to physical activity and movement skill development.

2.3.5 Gender

Gender stereotypes

Children often choose sports that align with stereotypical views of masculinity and femininity. Sports such as netball, softball and gymnastics — sports that are non-contact and/or have an element of expression — are frequently considered more suitable for girls. Conversely, sports such as AFL, rugby and boxing — sports that involve higher levels of physicality and aggression — are considered more masculine and therefore more suitable for boys.

FIGURE 2.11 The introduction of the AFLW competition in 2017 not only challenged gender stereotypes, but has increased the number of females playing the game.



In recent times, many gender stereotypes regarding sports participation have been challenged, with an increasing number of women playing traditionally male-orientated sports (see figure 2.11). However, differences in the types of sports played by girls and boys still exist and this, in turn, leads to differences in skill development. For example, girls are more likely to develop the coordination, balance and flexibility associated with such sports as gymnastics and dance, whereas boys are more likely to develop the ball skills associated with traditional team sports.

Another important issue regarding gender, sexuality and sport concerns the opportunities afforded to transgender, intersex, non-binary and individuals from the LGBTIQA+ community who may face discrimination and stigma as barriers to involvement in sport.

'Many LGBTIQ+ people don't see sport as a safe space where they can participate because of the continued prevalence of discrimination and hostility. Recently, there has been increased effort to address these issues with programs and initiatives like Pride in Sport and Rainbow Roadmap.' (Australian Sports Commission, LGBTIQ+ communities)

on Resources

Weblinks Australian women in boxing
Australian Sports Commission — LGBTIQ+ communities
Rainbox ready roadmap

Barriers to involvement in sport and physical activity

Below are some gender-related issues that have been barriers to involvement in sport and subsequence skill development:

- a lack of appropriate, accessible, affordable and acceptable facilities; for example, lack of female or gender-neutral changerooms
- a lack of media coverage and visibility for women's sports and transgender athletes, reducing access to influential role models
- poor inclusion policies on the part of sporting organisations
- cultural norms that discourage involvement in sport
- uniforms
- stigma and discrimination, leading to unwelcoming environments in sports settings
- fewer opportunities for girls and transgender athletes to participate in sport
- not enough women sitting on managerial boards of sporting organisations, leading to a lack of advocacy for women's sporting issues
- negative peer pressure and a lack of confidence, affecting attitude towards involvement in sport.

How barriers are being addressed

To address these barriers, a number of programs, initiatives and opportunities have been created. This includes, but is not limited to:

- Change Our Game Community Activation Grants program
- Active Women and Girls Program by VicHealth
- This Girl Can
- Change our Game Initiative by the Victorian State Government
- Pride in Sport

on Resources

Weblinks Change our Game
Women in sport — Programs, policies and supporting structures
VicHealth — Active Women and Girls Program
This Girl Can
Pride in Sport
Sexist uniform rules
AFLW ditches white shorts from uniform policy to tackle period stigma

2.3.6 Socioeconomic status

A person's social and economic status is determined by family income, occupation and education levels. Socioeconomic status can have a strong influence on the types of sports people choose to play and, therefore, the skills they develop. A person from a lower socioeconomic background, for example, is more likely to take up rugby league than they are rowing. Rowing has prohibitively expensive equipment costs and is a sport more commonly available at elite schools and universities; rowing is a sport associated with high socioeconomic status.

A low socioeconomic background can also be associated with lower levels of physical activity and sporting participation. The cost of uniforms, transport and registration fees, for example, may be a deterrent to involvement in sport.

Certain communities, such as remote outback communities, may also lack adequate facilities for some organised sports. Lack of access to a heated pool, for example, can deter people from participating in competitive swimming.

FIGURE 2.12 Socioeconomic status can influence the types of sport in which an individual chooses to participate.



2.3.7 Local community

The local community plays a multifaceted role in shaping engagement with sports. Communities with well-maintained sportsgrounds and facilities, such as gyms, swimming pools and recreational centres, are more likely to have higher levels of active participation and attract people of all ages. Additionally, the presence of local sporting clubs and organisations can provide structured opportunities for individuals to engage in sports, fostering a sense of belonging and social connections within the community.

FIGURE 2.13 Kids growing up on the NSW Central Coast are more likely to take up surfing because of local role models such as pro surfer Molly Picklum.



The social and cultural dynamics of the local community can also influence the types of sports available. For instance, in some regions, there may be a strong tradition of certain sports like Australian Rules football or cricket, which are deeply ingrained in the local identity and heritage. As a result, individuals growing up in these communities are more likely to participate in these sports due to peer influence, familial traditions and the community events centred around them. Communities with diverse demographics may see a broader range of sports being played, reflecting the cultural diversity and preferences of the population.

EXAM TIP

Remember, sociocultural influences **do not** include geographical location. Essentially, sociocultural influence refers to people influencing people. These people could be family, peers or members of the local community and their influence manifests through role modelling, socialisation and the impact of traditions and beliefs.

on Resources

Weblink National sport and physical activity participation

doc-41828

PRACTICAL ACTIVITY Kabaddi

Goal

Participate in a game of Kabaddi.



Instructions

Research the rules of the game Kabaddi using **Rules of Kabaddi** in the weblinks section of the Resources panel. After learning the basic rules and moves, play a game on the oval or in the gym (using protective mats).

Primary data/Reflection

- Identify the challenges you faced during the game and think about how your understanding of this game could be improved.
- Reflect on your own cultural background and its influence on your experience of playing Kabaddi. How did your cultural perspective shape your approach to the game and your interactions with your teammates and opponents?

Questions

1. How could you make the game of Kabaddi more available in your local community?
2. What aspects of Kabaddi do you find unique or different?
3. Brainstorm strategies to foster cross-cultural exchange through sports events and workshops in your community. How can partnerships with cultural organisations and sports federations facilitate this initiative?
4. Explore the concept of cultural competency in sports education. How can educators and coaches facilitate learning about sports from diverse cultures in the curriculum?

on Resources

Weblink Rules of Kabaddi
Clearinghouse for sport

2.3 Activity

2.3 Quick quiz on | **2.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	4, 5	2, 6

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TEST your understanding

1. a. **List** the sociocultural influences that can impact movement skill development.
   b. **Draw** a two-column table. Label one column 'Barriers to skill development' and the other 'Enablers of skill development'. Using your list from **part a**, **identify** examples of sociocultural influences and **classify** them as either barriers or enablers.
2. **Outline** a sociocultural-based issue in sport that has recently been reported on in the media. **Discuss** the potential impact of this issue on sport/physical activity participation.
3. The state of the economy has placed an extremely high cost of living burden on families. **Outline** two ways in which the high cost of living may negatively affect a family's capacity to support participation in sport.

APPLY your understanding

4. At a local primary school, the sport coordinator asked the Year 6 students to speak to the Year 1 students about their favourite sport. **Identify** and **suggest** the sociocultural influence this would have on the younger students.
5. Analyse your own sporting achievements. **Name** the sociocultural influences that apply to your involvement in sport and **explain** how they impacted on your skill development and performance.
6. **Conduct** a statistical analysis of male and female participation rates in sport, using **Clearinghouse for sport**, which is available in the weblink section of the Resources panel. **Analyse** the data on the website to address the following points.
   a. **Identify** the most popular sports for female children aged 0–14 years.
   b. **Identify** the most popular sports for male children aged 0–14 years.
   c. **Identify** and **discuss** the potential sociocultural influences that may have led to these differences in sporting preferences between girls and boys.
   d. **Identify** the impact sociocultural influences have on skill development in both girls and boys.
   e. With your knowledge of the applicable sociocultural influences, **suggest** a strategy to increase girls' participation rates in organised sports.

2.3 Exam questions

Question 1 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.2;* © VCAA

Which one of the following is a sociocultural factor that could influence the development of motor skills?

A. arousal levels
B. parenting practices
C. geographical location
D. the physical size and shape of an individual

Question 2 (1 mark)

Which is **not** a sociocultural factor that affects skill development?

A. Family
B. Opportunity
C. Being naturally athletic
D. Availability of resources

Question 3 (1 mark)

Toby is an elite junior ice hockey player who has grown up in 'hockey-mad' Edmonton, Canada. Toby's father played ice hockey in college and Toby idolises Connor McDavid, the star centre for the Edmonton Oilers in the National Hockey league.

Which of the following most accurately **describes** the sociocultural influences that shaped Toby into an elite-level ice hockey player?

A. Canadian climate, gender and peers
B. Local community, family and cultural norms
C. Socioeconomic status, peers and geopolitical issues
D. Socioeconomic status, peers and family

Question 4 (2 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.1;* © VCAA

Dylan Alcott is a retired wheelchair tennis champion who won 15 Grand Slam singles titles and two Paralympic gold medals during his career.



Describe **one** sociocultural factor that could have influenced Alcott's participation in wheelchair tennis.

Question 5 (2 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.12;* © ACHPER

Many of Australia's best snowboard half pipe and aerial skiing athletes lived in suburban Melbourne during their childhood. The nearest ski fields to Melbourne are a three-hour drive away. From a sociocultural perspective, **discuss** how family could impact on the development of skills for these athletes.

More exam questions are available in your learnON title.

2.4 The direct approach to coaching

Key knowledge	Key skill
• considerations when coaching to enhance participation and performance: – theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches	• analyse primary data • 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

The direct approach, often referred to as the traditional approach, is a coach-orientated coaching model in which learners are given explicit instructions about skill execution and tactical awareness (see figure 2.14). In the direct approach, the learner is told what to do and when to do it.

FIGURE 2.14 The direct approach is instructor centred.



2.4.1 Breaking it down

In the direct approach to coaching, skills are initially learned in isolation, outside of the game environment. For example, the beginner tennis player learns individual skills such as the forehand, the backhand, volleys and the serve before applying them in a game.

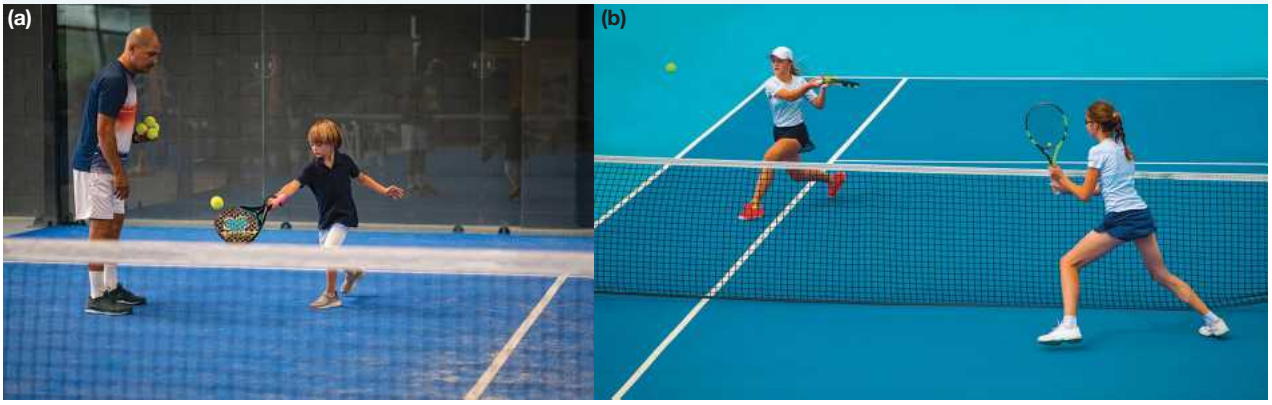
Through **explicit learning**, the emphasis is on continuous, repetitious practice of a skill to replicate a specific, predetermined movement pattern within a closed (low variability) learning environment. The coach, who is the source of all knowledge, controls the learning by giving explicit instructions, organising practice drills, providing skill demonstrations and giving prescriptive feedback.

FIGURE 2.15 Practicing the serve: one skill component of tennis



Learning is linear in the direct approach to coaching. The coach structures practice sequentially, increasing the complexity and difficulty of drills to match the relative progress in skill learning. For example, the beginner initially learns the service action in its simplest form before the coach introduces concepts of spin, speed and placement (see figure 2.15). In time, the coach will move the learner from the predictable closed environment, practising the serve in isolation, to the less predictable, open environment of serving to an opponent in a match environment (see figure 2.16).

FIGURE 2.16 (a) Skills are practiced in isolation before **(b)** executing them in a game.



In the direct approach to coaching, the emphasis is on learners replicating the appropriate 'textbook' technique. Once the learner is deemed suitably competent in these textbook techniques, they are considered ready for a competitive game.

'The traditional (direct) approach teaches the skills isolated from the game before putting the skills and game back together' (*Play with Purpose,* ACHPER, 2009).

In a direct learning environment, learners receive explicit instruction on how to interpret visual cues in a game situation. The participants also receive explicit instruction about how to respond to these cues. In the sport of tennis, players are instructed to observe the service ball toss as a means of anticipating the type of serve they are about to receive (see figure 2.17). For example, a wide ball toss suggests a

explicit learning learning that takes place as a result of direct instruction, where the performer is told what to do and when to do it

wide swinging serve will be performed. For such a scenario, the receiver is explicitly instructed to adjust their court position to cover the swinging ball and look to strike the return down the sideline.

The direct approach is particularly effective at developing skills in the early stages of learning (see figure 2.18). This can be attributed to an emphasis on basic skills in a relatively 'predictable' environment, as well as a more regimented and instructor-driven approach that keeps the participants 'on task' and ensures the maximum use of practice time. In other words, prescribed learning goals are achieved through structured drills in an allotted period of time.

FIGURE 2.17 Alize Cornet's ball toss can be interpreted to anticipate the type of serve.



FIGURE 2.18 Line drills in junior soccer



2.4.2 Advantages and disadvantages of the direct approach

The direct approach has a number of advantages and disadvantages, as seen in table 2.2.

TABLE 2.2 The advantages and disadvantages of direct coaching

Emphasis	Advantages	Disadvantages
• Explicit learning • Coach/instructor-centred • The learner is a passive receiver of information • Skill and drill • Skills learned in isolation prior to game participation • Learner aspires to textbook technique	• Maximises practice time • Keeps learner 'on task' • Effective in the early stages of learning • Learning is immediately evident • Emphasis on developing sound technique • It provides a predictable/closed environment to assist the beginner skill learner	• Boring repetitious drills • Poor transfer of learning • Learners become overly dependent on coach's instructions for successful performance • Does not develop decision-making skills • The learner is more susceptible to skill errors in the competitive environment

doc-41829

PRACTICAL ACTIVITY Direct coaching

Goal

To assess the effectiveness of the direct style of coaching.

Instructions

Work in pairs or small groups to design, plan and execute a training session using the direct style of coaching for a sport of your choosing. The practicalities of the sport will have to be discussed with your teacher.

Your session should include the following:

- a structured warm up with moderate aerobic exercise and stretching and individual and/or pair skill work
- line drills
- a gradual progression of skill complexity
- a gradual introduction of competition to the practice session.
- a match to finish.

Primary data/Reflection

Reflect on what aspects of the direct coaching style went well and the areas for improvement.

Questions

1. How effective was your direct coaching session at facilitating skill learning in the practice drills?
2. How effective was your direct coaching session at transferring learning from practice drills to the competitive game?
3. If you were to repeat the exercise, what would you change about your coaching session to make it more effective?
4. Did the direct method of instruction help you to manage a relatively large class size? Explain.

2.4 Activity

2.4 Quick quiz on

2.4 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3	2	1, 4, 5

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TEST your understanding

1. **Explain** what is meant by *'textbook' technique*.
2. In the context of approaches to coaching, **suggest** what it means to be 'coach orientated'.
3. **List** two advantages and two disadvantages of the direct approach to instruction.

APPLY your understanding

4. With the use of a coaching example, **explain** what is meant by *explicit learning*.
5. **Explain** what is meant by linear learning with reference to a sport as an example.

2.4 Exam questions

Question 1 (1 mark)

Which of the following scenarios is most applicable to the direct approach to coaching in basketball?

A. Two teams of three players participating in a game of 'Keepings off'
B. A coach teaching and practising different passing techniques and dribbling skills before playing a game
C. A coach teaching tactical knowledge prior to teaching movement skills
D. A coach asking guiding questions rather than providing explicit instructions

Question 2 (1 mark)

The traditional approach to coaching involves:

A. implicit learning.
B. discovery-based learning.
C. more rest time than work time.
D. explicit learning.

Question 3 (2 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.6;* © VCAA

Swimming coaches often use a direct approach when coaching beginner swimmers.

Describe why this approach could be successful for beginner swimmers.

Question 4 (2 marks)

A basketball coach has only two training sessions to teach a middle-school basketball team multiple team strategies in preparation for an important school tournament.

Explain why the direct approach to coaching could be advantageous in this scenario.

Question 5 (2 marks)

A senior high school soccer team performs better during training than they perform on match day.

Explain why the team's poor match day performance could be the result of a direct approach to coaching.

More exam questions are available in your learnON title.

2.5 The constraint-based approach to coaching

Key knowledge	Key skill
• considerations when coaching to enhance participation and performance: – theories of skill acquisition (linear vs non-linear) applied through direct and constraint-based approaches	• analyse primary data • 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

2.5.1 Constraint-based coaching

Constraint-based coaching facilitates learning through manipulating constraints (task, individual and environment) to help the learner to find a movement skill solution. The learning style is discovery-based and guided by an experienced coach (see figure 2.19). In constraint-based instruction, the learning is **implicit learning**; that is, the players learn through participating in an activity rather than being explicitly instructed on what to do and when to do it.

implicit learning learning through doing. The participants learn through completing a task.

Using the constraint-based approach, the learner is supported to develop skills applicable to the specific demands of the game environment. A player who learns in this implicit way, whose skills are forged within a competitive environment, is less inclined to make mistakes or 'choke' under the pressure of competition.

FIGURE 2.19 Through participation in game-based learning, the players discover what is required for successful skill execution and effective decision making.



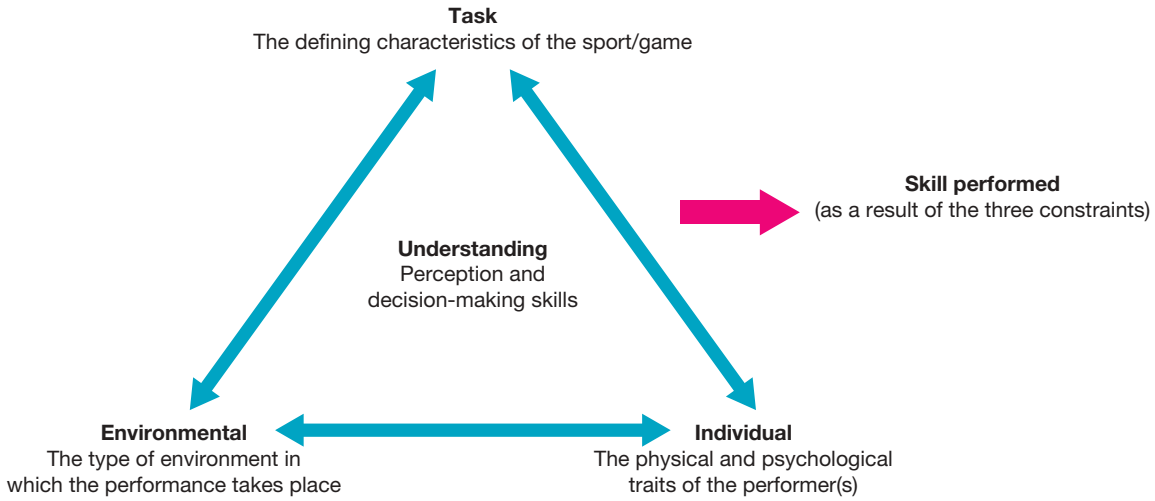
The constraint-based approach to coaching does not advocate learning 'textbook' or one-size-fits-all skill techniques; rather, it encourages the learner to discover effective and applicable movement skills for themselves and acknowledges that there are multiple ways to achieve the same outcome.

Whereas the traditional approach to skill learning is linear, with skills developed through progressively more complex practice, the constraint-based approach is considered non-linear. In the constraint-based approach to coaching, the learner's progress may initially be slow. However, skill development can shift and improve dramatically as the learner successfully meets the demands of game-based challenges.

Central to constraint-based learning is the understanding that all performance is influenced by three fundamental boundaries or constraints (see figure 2.20):

1. individual constraints
2. environmental constraints
3. task constraints.

FIGURE 2.20 Skill as a product of the three constraints: individual, environmental and task



Source: Adapted from Renshaw, Chow, Davids & Hammond, 2010.

2.5.2 Individual constraints

The individual constraints are the physical, psychological and behavioural characteristics of the individual performer (see figure 2.21). They include such things as height, weight, fitness, motivation, confidence, decision-making skills and learning style.

For example, the decision-making skills an individual has developed by playing a particular team sport may be transferrable to other team sports.

FIGURE 2.21 Individual constraints such as height and confidence can affect how successful someone will be in learning to perform the high jump.



2.5.3 Environmental constraints

The environmental constraints are the characteristics of the environment in which the performance takes place. This includes physical characteristics (e.g. climate, the playing surface and stadium lighting) as well as social factors (e.g. the influence of peers and cultural norms). For example, in India, cricket is extremely popular, which exposes the game to more people, increases participation and facilitates the development of skills such as throwing, catching, batting and bowling (see figure 2.22).

FIGURE 2.22 The popularity of cricket in India is an environmental constraint that facilitates the development of cricket-specific performance skills.



2.5.4 Task constraints

Task constraints relate to the defining characteristics of the activity or sport. Task constraints include the *goal* of the sport (e.g. kicking the soccer ball into the goal), the *rules* of the sport (e.g. soccer players other than the goalie may not use their hands) and the *equipment and facilities* used in the sport (e.g. the dimensions of a soccer field and the size of the soccer ball).

FIGURE 2.23 In archery, the task constraints include distance from the target and the goal of hitting the bullseye.



2.5.5 Manipulating constraints to develop movement skills

In the constraint-based approach, a coach will manipulate constraints, especially the task constraints (e.g. rules, scoring systems and space) to help the learner to develop the applicable movement skills and tactical awareness.

FIGURE 2.24 A small-sided modified game



For example, a coach might design a small-sided game to help junior soccer players discover and develop effective passing skills (see figure 2.24). In this example, the coach would manipulate constraints to encourage effective passing and deter the players' natural inclination to over-possess the ball and 'show off' their dribbling skills (an individual constraint). The goal of the game is for the team in possession to move the ball from one side of a defended area to the other. The coach can manipulate the game rules (a task constraint) to limit the players' capacity to dribble by enforcing the rule that players can only possess the ball for a maximum of three seconds. A team that successfully crosses the area also gains a bonus point if every member of their team makes contact with the ball (a task constraint) — that is, they are encouraged to share the ball.

The young players discover their best chance of success (moving the ball the length of the field) is to employ quick passes, using multiple teammates. Through this small-sided game, the players develop quick, one-touch passing skills and become aware of the tactical importance of sharing the ball with multiple teammates.

The passing game style is further entrenched and encouraged by the coach, generating a team culture (an environmental constraint) that rewards selfless play and sharing the ball.

In constraint-based coaching, such as the soccer example, participants become autonomous learners who are not overly reliant on a coach's instructions. Autonomous learners are better equipped to solve the unexpected problems and challenges they encounter in competition.

Another advantage of constraint-based instruction is that practice sessions are more varied and interesting compared to the repetitious drills associated with the direct approach to coaching. Constraint-based coaching can create an engaging and positive experience for the learner and, in doing so, has the capacity to enhance participation.

Concept connector

FIGURE 2.25 Children's capacity to learn is compromised if they are forced to use adult-sized sporting equipment.



Task constraints such as equipment, court size and competition rules should be modified to enhance skill acquisition in children. Lighter racquets and bats, smaller court sizes and rules that encourage maximum participation and reduced physical contact are all examples of modifications necessary to ensure children enjoy their sporting experience. These modifications enable children to learn the applicable movement skills as well as begin to understand game tactics. If children use equipment designed for adults, they are less likely to experience performance success. Heavy and/or oversized equipment can also lead to children developing skill techniques that compromise future development in their chosen sport. For example, a 7-year-old basketballer using an adult-sized basketball on a full-sized ring may be forced to shoot with two hands or adopt a throwing-like action in order to score. With a smaller ball and a lower ring, the young basketballer can experience success using a traditional shooting action – a technique they will rely on to have success in the sport at a more senior level.

Many sports have developed modified games that recognise the importance of changing task constraints to make the experience more fun for children and to facilitate skill development. Examples of these modified sports include Kanga Cricket, Netta Netball, Auskick (AFL) and Hot Shots (tennis).

In Hot Shots, children use a smaller court and larger, less-bouncy tennis balls. The modified tennis balls encourage the beginner to hit confidently and help to facilitate longer rallies. The smaller court size is more manageable and assists the young learner to develop tactical awareness.

Concept connector

Implicit instruction — use of metaphors

Metaphoric analogy is a useful implicit coaching strategy which gives the learner a simple focus and reduces the technical information they need to process. For example, a swim coach might tell his young swimmers to make their bodies into the shape of an 'arrow' as they push off the end of the pool. Long-winded, explicit technical instruction about arm, leg and body position is avoided — this is implicit in the analogy of the arrow.

FIGURE 2.26 Use of metaphor (make the shape of an arrow) to simplify skill performance is an implicit coaching strategy.



on Resources

Interactivity Constraint-based approach (int-6781)

2.5.6 Advantages and disadvantages of the constraint-based approach to coaching

The constraint-based approach to coaching has a number of advantages and disadvantages, as seen in table 2.3.

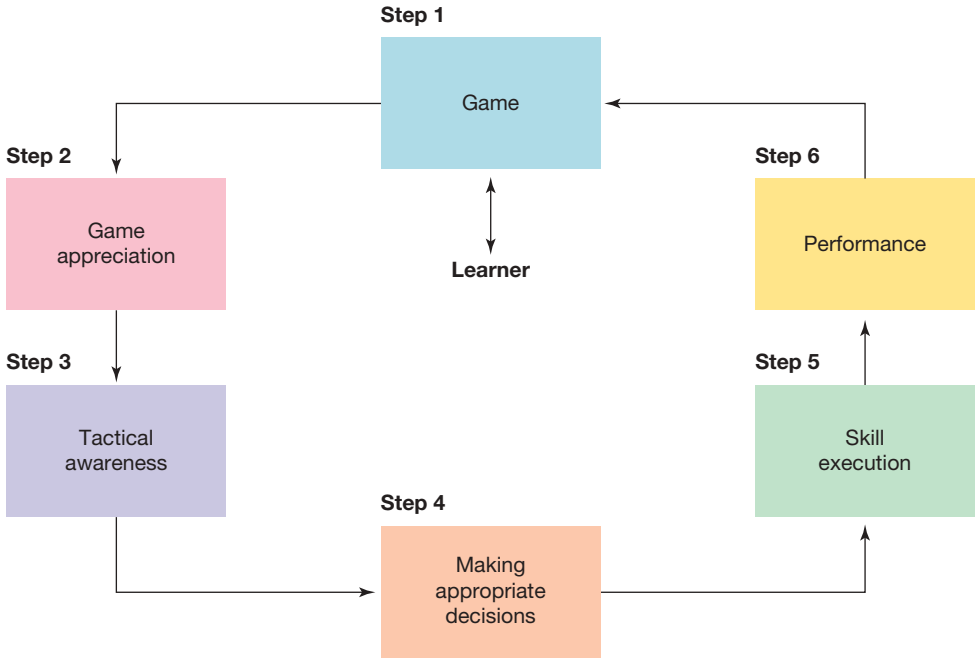
TABLE 2.3 Advantages and disadvantages of the constraint-based approach to coaching

Emphasis	Advantages	Disadvantages
• Implicit learning • Learner centred • Discovery-based learning • Learner solves problems • Small-sided modified games • Coach is a facilitator, not an instructor	• Practice sessions are more representative of game environment • Skills developed are applicable to the game environment • Development of tactical/strategic awareness and decision-making skills • Motivating — participants empowered to find solutions • Greater transfer of learning between practice and game environment. • Greater variability in practice • Skill performance is resilient to competitive pressure • Cultivates the independent/ autonomous learner	• The cognitive-stage learner may become overwhelmed with rules, tactics and new skills • Technical skills may lack refinement • Coaches are often less familiar with the constraint-based approach • A less regimented and structured approach — may not be appropriate for large groups or younger athletes • May take longer for skills to develop as individual feedback from the coach is more difficult to provide

2.5.7 A constraint-based approach to coaching

In Australia, the most commonly used constraint-based instruction model is game sense. Game sense is a means of coaching or teaching that uses small-sided modified games to develop tactical and strategic thinking, as well as movement skill performance (see figure 2.27). Game sense is an Australian adaptation of the Teaching Games for Understanding Model (TGFU) (Thorpe, 1996).

FIGURE 2.27 The game-sense approach seeks to teach game appreciation and tactical awareness prior to teaching movement skills.



One of the strengths of the game-sense approach to coaching is that there is a greater transfer of learning when using constraint-based coaching strategies. Transfer of learning refers to how well a skill learned in practice can be performed in a game setting, or how well a skill learned in one sport can be transferred to learning a skill in another sport.

All sports have their unique characteristics. However, sports grouped in the same games category share common principles of play. Hence, the tactical knowledge and decision-making skills developed in one sport are easily transferred and applied to other sports within the same category. For example, a modified game designed to encourage effective passing in soccer could easily be adapted for use in another game, such as netball.

on Resources

Interactivity Fundamental concepts for each game category (int-6782)

2.5.8 Comparing the direct and constraint-based approaches to coaching

Approaches to coaching can be classified on a direct–indirect continuum (see figure 2.28). The constraints-based approach to coaching and allows learners to discover effective skills and performance strategies for themselves. The direct approach, on the other hand, emphasises the learner following a coach's commands towards prescribed learning outcomes. It's important to note that effective coaches have the capacity to use both the constraint-based approach to coaching and the direct approach to coaching. The experienced and effective coach adopts a coaching approach to suit the needs of the learner, the demands of the relevant skills and the conditions of the learning environment.

FIGURE 2.28 A continuum of direct and indirect coaching



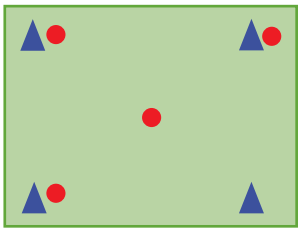
Comparing coaching approaches to the same sport

In table 2.4, we compare the direct (traditional) approach and a constraint-based (indirect) approach to teaching effective passing in junior basketball.

TABLE 2.4 Comparison between the direct approach and a constraint-based approach to coaching

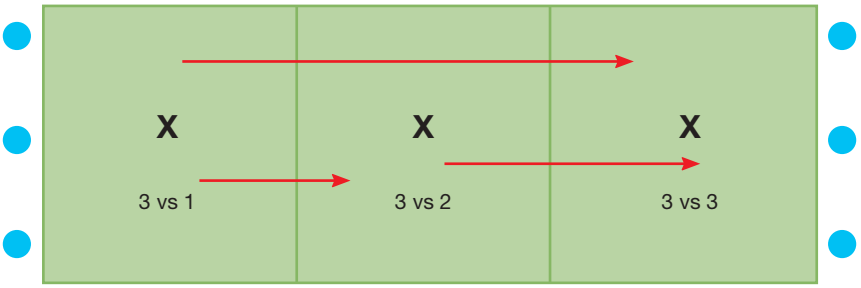
Direct (traditional) approach	Constraint-based (indirect) approach
Warm up 10-minute jog and stretching — Passing in pairs	**Warm up** 3 vs 3 small-sided game — 'Keepings Off'. The aim is to maintain possession for as long as possible.
Instruction and demonstration Coach provides instruction about how to perform different passing techniques. The coach uses the most accomplished players to demonstrate different passing techniques: bounce pass, overhead 'soccer' pass, chest pass and lob pass. Players return to passing in pairs. Coach provides feedback to the players on their passing technique, drawing attention to skill errors and encouraging the necessary modifications. Coaching is explicit and the feedback is prescriptive.	**Small-sided modified game 1 — 'Three Point Square'** See figure 2.29. The three players in possession of the ball must pass along the length of the square, not on the diagonal. Players in possession run between the cones to ensure the player with the ball always has two passing options. A single defender tries to intercept the passes. Freeze play for play analysis using a coach question, such as: What have you learned about making sure your pass hits its intended target? Continue 'Three Point Square' with a constraint modification Reduce the size of the square to make it easier for the defender to intercept the pass, placing more pressure on passing. In the small-sided, modified game, the players discover the most effective solution to the set task.

FIGURE 2.29 Three Point Square



(continued)

TABLE 2.4 Comparison between the direct approach and a constraint-based approach to coaching *(continued)*

Direct (traditional) approach	Constraint-based (indirect) approach
Line drills focusing on passing Players are organised into opposing single file lines. The players dribble and pass the ball. The coach makes the line drill more challenging by 'criss-crossing' the lines. The coach makes the drill more challenging again by organising a 3-man weave. During each of the above drills, the coach provides explicit feedback to the players, encouraging them to throw the ball at chest height and to throw the ball in front of a moving teammate. **Half-court game** The coach introduces a competitive element to training via a simplified 2 x offensive players versus 3 x defensive players half-court game. The coach provides explicit instruction to the offensive team, encouraging the players to pass the ball 'early' and to maintain 'width'. The defensive team is instructed to close down 'space' and stay 'basket-side' of their opponent. The coach controls the learning and is the source of all information.	**Small-sided modified game 2 — 'Build the Pressure'** See figure 2.30. Teams of three attempt to move the ball through three designated areas. With each new area, another defender is added and the task becomes increasingly difficult. **FIGURE 2.30** Build the Pressure  Freeze play for play analysis using a coach question, such as: What's the best way to 'draw' a defensive player before passing to a teammate? Continue 'Build the Pressure' with a constraint modification: Reduce the width of the field to make the game more challenging and to encourage fast, decisive passing. Freeze play for play analysis using a coach question, such as: What type of pass worked best in particular game situations? This is discovery-based learning.
End game full court match	**End game** 3 vs 3 half-court game. The team that scores keeps possession. A bonus point is awarded for three or more passes before a successful shot or lay-up. (This is an implicit coaching strategy to encourage passing.) Task constraints are manipulated to teach effective passing.
Cool down The coach provides feedback on players' performance and outlines strategies for future development.	**Cool down** Players cool down. Both the coach and the players discuss what they have learned and where they can make future improvements.

EXAM TIP

Both the constraint-based approach to coaching and the direct approach to coaching have their relative strengths and weaknesses. It's important to recognise in a given learning scenario — defined by the type of movement skill, stage of learning of the participant/s and the type of environment — when it's most effective to use the direct approach and when it's best to use the constraint-based approach.

on Resources

Video eLesson Direct vs indirect approaches to coaching

Interactivity Direct versus indirect instruction (int-6780)

doc-41830

PRACTICAL ACTIVITY Constraint-based practice session

Goal

To design and run a Constraint-based practice session practice session with your peers.

Instructions

Work in pairs or small groups to design your session. Use **Designing and teaching a Constraint-based practice session** in the digital documents section of the Resources panel.

Remember, constraint-based coaching uses implicit learning. Your peers should learn the relevant skills through their involvement in your modified game rather than by receiving direct instruction.

For example, your session might consider the following:

Aim: improve basketball shooting

Modify game: team knockout competition

Guiding question from coach: What do you notice about the impact of your body's balance on your relative success in basketball shooting?

Modification: Give each team two balls to increase the speed of the game.

Primary data/Reflection

- Did you observe any noticeable improvements in the skill performance of your classmates throughout the practice session? If so, what specific skills showed improvement, and how did you measure progress?
- Reflect on the level of engagement displayed by your classmates during the practice session. Were they actively involved in the modified games? What factors influenced their level of engagement?
- Discuss how the modifications made to the games influenced the motivation levels of the students. Did adding constraints or altering the rules impact their enthusiasm and participation?

Questions

1. Did the participants' skill performance improve during the course of the session?
2. Were the participants actively engaged in this practice session? Outline the influences on the participants and how the modified games affected their motivation.
3. Speculate on whether this constraint-based coaching' session would be more or less likely to help participants' transfer their learning compared to a direct coaching session. Discuss.

on Resources

Digital document Designing and teaching a constraint-based practice session (doc-41831)

Weblink 3 essential small-sided game variations

2.5 Activity

2.5 Quick quiz on | **2.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	3, 6	2, 4, 5

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TEST your understanding

1. a. **Name** the three performance constraints.
   b. **Provide** an example for each of the three performance constraints identified in **part a**.
2. **Explain** the difference between *implicit learning* and *explicit learning*.
3. **Discuss** two advantages and two disadvantages of the constraints-based approach to coaching movement skills.
4. **Explain** how a coach uses questioning to guide the learning process when using a constraint-based approach.

APPLY your understanding

5. Watch footage of an elite team sport. Choose a position and **identify** the constraints and **suggest** how they affect your chosen player. For example:
   Sport: Soccer
   Position: Striker
   Task: The striker must time their forward runs carefully so as not to be off-side and taking a 'shot' on goal.
   Individual: The striker uses their agility to evade defenders.
   Environment: The striker takes account of the conditions when choosing the type of shot on goal. For example, they might choose a low 'skidding' shot at goal with a waterlogged ball, rather than unsuccessfully attempting to 'bend' the ball by imparting spin.
6. Watch the video **3 Essential Small Sided Game Variations,** found in the weblinks section of the Resources panel.
   Discuss two advantages of using the constraint-based coaching strategy of small-sided games.

2.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.12;* © VCAA

Which one of the following is most often associated with constraints-based approaches to coaching?

A. coach-led learning
B. prescriptive instruction
C. learners exploring movement solutions
D. a coach passing on knowledge to learners

Question 2 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.8;* © VCAA

A junior soccer player can confidently pass the ball to a teammate during a closed training drill but has varied success when completing the same pass during a game.

Which approach to coaching is likely to see the greatest improvement in a player's ability to pass the ball successfully to a teammate during a game?

A. constraints-based
B. closed drills
C. open drills
D. direct

Question 3 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.8.a;* © VCAA

The table below shows data resulting from a comparison of small-sided soccer games used as training for under-17s. Each small-sided game lasted three minutes, the pitch measured 40 m × 30 m and each team consisted of four players plus a goalkeeper. The coaches manipulated the constraints of each game, which influenced player movement and motor skill development. During 'unlimited touches' games, players were allowed unlimited ball touches per ball possession; during 'two touches' games, they were allowed a maximum of two ball touches per ball possession; and during 'one touch' games, they were allowed a maximum of one ball touch per ball possession.

	Small-sided soccer game constraints		
Mean per player (under-17)	**Unlimited touches**	**Two touches**	**One touch**
total distance covered (m)	428	418	407
distance walked (m)	36	39	40
distance jogged (m)	351	334	328
distance run (m)	41	45	39
number of successful passes	3.8	5.2	5.8
number of unsuccessful passes	1.1	1.6	1.8
number of shots on target	0.5	0.3	0.4
number of goals scored	0.3	0.2	0.2

Data: Adapted from D Coutinho et al., 'Exploring how limiting the number of ball touches during small-sided games affects youth football players' performance across different age groups', *International Journal of Sports Science & Coaching*, vol. 17, 2022, pp. 545–7

a. **What** type of constraint is being manipulated by changing the number of ball touches per ball possession during the small-sided soccer games? **(1 mark)**

b. **Explain** how manipulating the constraint identified in **part a.** influenced the skill performance and skill development during the small-sided soccer games. **(3 marks)**

Question 4

Source: *VCE 2018, Physical Education Exam, Section B, Q.6;* © VCAA

The size of a playing area for soccer can be manipulated using the constraints-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.

Question 5

Source: *VCE 2023, Physical Education Exam, Section B, Q.1.b;* © VCAA

In wheelchair tennis, the ball is permitted to bounce twice, whereas in able-bodied tennis, it is only allowed to bounce once.

a. **Explain** the relationship between individual and task constraints that led to this rule modification in wheelchair tennis and the impact this has on performance. **(3 marks)**

b. **Discuss** how this modification to the rules of wheelchair tennis could influence the motor skill development and participation of wheelchair tennis players. **(2 marks)**

More exam questions are available in your learnON title.

2.6 Key skills

Key skills

- analyse primary data
- 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

2.6.1 Tell me

To address these key skills, it is important to remember:

- a skill learner's stage of learning will determine the most appropriate and effective coaching strategies
- the constraint-based approach and the direct approach both have their relative strengths and weaknesses
- good coaches are versatile enough to use either approach to coaching; the choice will depend on the participant's stage of learning (individual) and the nature of the movement skill (task)
- manipulating task constraints can assist in learning applicable movement skills
- a range of sociocultural factors influence the types and extent of movement skill development
- sociocultural factors influence access to learning opportunities and learners' motivation to apply themselves to practice through a range of mechanisms including socialisation, role modelling, support and encouragement as well as socioeconomic status, which may (or may not) provide the opportunity for expert coaching and the availability of specialised equipment and resources.
- primary data, which includes photos, video recordings, journal entries, statistics or observations collected while completing practical activities, should be included in a reflective journal throughout Unit 3 and Unit 4.

2.6.2 Show me

Practice question (6 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Ben is an under-12 AFL footballer who demonstrates effective technique when executing a drop-punt kick during uncontested line drills. His kicks generally hit their intended targets but lack consistency and fluid skill execution. However, when Ben is involved in match practice, his kicking skills deteriorate significantly.

a. **Name** the stage of learning most *applicable* to Ben's kicking skills and **provide** two coaching strategies applicable to this stage of learning. (2 marks)

b. **Name** the coaching approach that would most likely *enhance* Ben's kicking skills in a *match*. **Explain** how this instructional approach facilitates the *execution of effective skills* under *match conditions*. **Provide** an example to support your answer. (4 marks)



Decode the question

Strategies to decode the question

- **Identify the action words:**
  Name — identify or state
  Provide — give or supply
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *applicable, coaching strategies, enhance, match, execution of effective skills, match conditions*
- **Key concepts** — stage of learning, coaching approach, coaching strategies
- **Marking scheme** — 6 marks — always check marking scheme for the depth of response required, linking to key information highlighted in the question

Sample response and marking scheme

a. Ben's kicking is in the associative stage of learning. Ben needs *regular supervised kicking practice*, and the coach should assist Ben to understand why he has made a *kicking error* and help Ben to develop strategies to correct skill errors.
Award 1 mark for naming the stage of learning.
Award 1 mark for providing two coaching strategies.

b. A constraint-based approach to coaching would enhance Ben's kicking skills in a match. The constraint-based approach places the learner in *small-sided games, modified to simulate match conditions*, through which they can *develop applicable* movement skills. For example, Ben and three other teammates might play a game of 'keepings off', in which two of the players try to maintain possession by kicking the ball to each other within a defined space, while trying to prevent the designated defenders from intercepting the ball. This game *implicitly teaches* important and applicable *kicking skills* that are generally *not developed in line drills*. For example:
- kicking the ball out 'in front' of the leading teammate
- being able to kick with either leg is an advantage
- attending to cues important to skill execution and blocking out distractions
- practising externally paced skills.

Award 1 mark for naming the coaching approach.
Award 1 mark for explaining the instructional approach and how it relates to the execution of the skill under match conditions.
Award 1 mark for using an example related to the instructional approach.
Award 1 mark for explaining how a game teaches skills not developed in a drill.

2.6.3 Let me do it

Question 1 (5 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.9;* © VCAA

Little Athletics Australia is a modified athletics program for children aged five to 15 years. Children aged five years learn to throw a discus using a lighter, 350 g discus and they learn to throw a javelin using a light, foam javelin.

a. What type of constraint is being modified in the Little Athletics Australia program above? **(1 mark)**

b. **Discuss** the impact one modification from the Little Athletics Australia program could have on the motor skill development, participation and performance of children aged five years. **(4 marks)**



2.7 Review

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2.7.1 Summary

Stages of learning

- There are three stages of learning. In order of novice learner to expert performer, the stages of learning are the cognitive stage, the associative stage and the autonomous stage.
- The cognitive (understanding) stage of learning is characterised by the novice learner directing most of their attention to understanding the relevant movement skill and making many skill execution errors. In the associative (practice) stage of learning, the learner successfully performs the fundamental components of the movement skill but requires regular practice to refine the skill and eliminate minor errors. In the autonomous (automatic) stage of learning, the learner has mastered the skill, directs very little attention to skill execution and is able to multitask.
- Knowing the stage of learning allows the coach to select more effective coaching and practice strategies.

Sociocultural influences on skill development

- Sociocultural factors include socioeconomic status, social and cultural practices, gender, peers and family, and beliefs and traditions. These factors can encourage or discourage involvement in sport and activity, and influence the types and extent of movement skill development.
- Sociocultural factors impact the learner's opportunity to be involved in sport, and their motivation to learn movement skills through a range of influences including socialisation, role modelling, and support and encouragement.
- For some groups in society, sociocultural factors can present a significant barrier to involvement in sport and the subsequent development of fundamental movement skills. Traditionally, there has been less access and fewer opportunities to be involved in sports for women, gender-diverse people, and people from lower socioeconomic status backgrounds (including those living in remote communities and recent migrants).

The direct approach to coaching

- The direct approach is a coach-orientated style of coaching where the learning outcomes are prescribed and the learner is given explicit instruction on how and when to perform movement skills.
- The direct approach encourages skill mastery in isolation prior to taking part in a game. The direct approach dictates that skill learning should first take place in a predictable/closed environment before the learner encounters the less predictable/open environment of a game.
- Explicit learning is the result of direct verbal instruction from a teacher or coach, where the learner is told how and when to perform a movement skill. We associate explicit learning with the direct approach to coaching.

The constraint-based approach to coaching

- The constraint-based approach is a discovery-based, learner-orientated model in which coaches guide the learner to technical competence and tactical awareness through the use of small-sided modified games.
- The constraint-based approach encourages early involvement in modified games. In the constraint-based approach, the coach modifies constraints, particularly task constraints, to enable the learner to discover applicable movement skills and tactical awareness.
- Implicit learning is the learning that takes place as a result of completing a task or, in the case of skill development, taking part in a game. We associate implicit learning with the constraint-based approach to instruction.

- The game-sense approach involves small-sided games in which constraints are modified to facilitate learning. In game-sense instruction, the coach uses guiding questions to facilitate a discovery-based learning environment.

2.7.2 Key terms

associative (practice) stage of learning the second phase in the learning of a new skill, in which movement patterns become more refined and consistent through practice
autonomous (automatic) stage of learning the final stage of learning in which the performer's skill execution is almost automatic and requires very little of their attention
cognitive (understanding) stage of learning the initial phase of learning of a motor skill where the emphasis is on conscious understanding of the task requirements
explicit learning learning that takes place as a result of direct instruction, where the performer is told what to do and when to do it
implicit learning learning through doing. The participants learn through completing a task.
sociocultural influences of, or relating to, the interaction of social and cultural elements such as family, peers, community, gender, socioeconomic status, cultural beliefs and traditions

2.7 Exam questions

2.7 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.1;* © VCAA

Improvements in skill development tend to be largest at which stage of learning?

A. gross
B. cognitive
C. associative
D. autonomous

Question 2 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.13;* © VCAA

When the noise level in a stadium influences performance, this would be classified as

A. a task constraint.
B. a direct constraint.
C. an individual constraint.
D. an environmental constraint.

Question 3 (1 mark)

A hockey player who successfully dribbles past several opponents while simultaneously monitoring the positions of their teammates and assessing where and when to pass the ball would be classified as in the:

A. cognitive stage of learning.
B. associative stage of learning.
C. autonomous stage of learning.
D. implicit stage of learning.

Question 4 (1 mark)

Skill development results from a combination of:

A. genetics and coaching.
B. psychological, biological and physiological traits, as well as the opportunity to learn.
C. socioeconomic status and the opportunities this affords the novice learner.
D. genetic traits, expert coaching and sociocultural factors that encourage and facilitate learning opportunities.

Question 5 (1 mark)

A consideration for coaching the autonomous performer is:

A. keep instruction simple.
B. provide precise feedback and game practice.
C. teach correctional strategies.
D. overload the performer with information.

Question 6 (1 mark)

Which of the following instructional characteristics is **not** associated with the direct approach?

A. Autocratic
B. Prescribed
C. Coach-orientated
D. Discovery-based

Question 7 (1 mark)

Canada has a relatively high number of outdoor ice rinks that are used by children to play ice hockey. This is an example of which kind of skill learning constraint?

A. Environment
B. Task
C. Individual
D. Performance

Question 8 (1 mark)

An example of a task constraint modification specifically designed to enhance skill learning in children is:

A. lighter racquets.
B. a tennis-specific fitness program.
C. senior role models.
D. video analysis of groundstrokes.

Question 9 (1 mark)

The basketball coaching analogy that compares the action of 'shooting' to 'putting your hand in the cookie jar' is an example of:

A. psychological imagery.
B. a coaching strategy that involves implicit learning, reducing the amount of information required to process and execute the skill.
C. a coaching strategy designed to provide detailed and precise instruction.
D. an explicit instructional strategy.

Question 10 (1 mark)

An advantage that the constraint-based approach has over a direct approach to coaching is that it:

A. is effective at quickly developing movement skills in the novice learner.
B. doesn't put the learner in a game until individual skills are mastered.
C. develops applicable movement skills, tactical awareness and decision-making skills.
D. has prescribed learning outcomes.

2.7 Section B – Short answer questions

Question 1 (6 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.8;* © ACHPER

The coach of the Dynamo's under 16 basketball team is disappointed one player constantly attempts to take the ball from one end of the court to the other without passing, then immediately attempts to take a shot.

The coach sets up two 2 v 2 half court basketball games at training and instigates the rule 'the ball must be passed at least three times before a shot can be taken'.

a. **Identify** two constraints the coach has manipulated and **classify** them as either individual, environmental or task constraints. **(4 marks)**
b. **Outline** two advantages of constraints-based coaching compared to direct coaching. **(2 marks)**

Question 2 (3 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.4;* © ACHPER

Making specific reference to constraints-based coaching, **discuss** the appropriateness of the following product for young children in their skill development for a two-hand strike.



Source: Author's own

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.2;* © VCAA

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.

For each skill acquisition principle in the table below, circle the option that would best suit practising batting with a ball projection machine.

Skill acquisition principle	Option 1	Option 2
coaching approach	direct	constraints-based
stage of learning	associative	cognitive
practice variation	random	blocked

Question 4 (6 marks)

Source: Adapted from *ACHPER 2015, Trial Exam Units 1 & 2, Section B, Q.7;* © ACHPER

a. **State** which stage of learning the players participating in the NBA would be in. **(1 mark)**

b. **Outline two** characteristics that the players display to support your choice in **part a.** **(2 marks)**



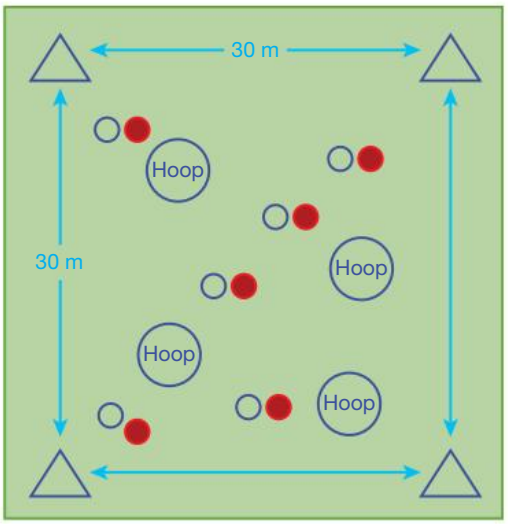
c. **State** the stage of learning most 5–10-year-olds would be in when they first begin the Aussie Hoops program. **(1 mark)**

d. **Outline two** strategies a coach or teacher would use to cater for the children in the stage identified in **part c.** **(2 marks)**

Question 5 (3 marks)

Examine the figure below that outlines Hoop Ball, a small-sided modified game suitable for use in constraint-based coaching.

The aim of the game is to keep possession of the ball and to score by passing to a teammate standing in one of the four available hoops. The defensive team attempts to intercept the offensive team's passes.



a. **Identify** what skills and tactics the game is designed to teach. **(1 mark)**

b. **Suggest** a modification you could make to this game to further develop the skills and tactics you identified in **part a**. **(2 marks)**

Continue to build your exam skills

Access the Unit 3 Area of Study 1 Review at the end of Topic 4. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

3 Practice, feedback and psychological skills

3.1 Overview

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LEARNING SEQUENCE

3.1 Overview
3.2 Types of practice
3.3 Practice distribution
3.4 Practice variability
3.5 Types of feedback
3.6 Feedback frequency
3.7 Psychological skills for enhanced performance
3.8 Key skills
3.9 Review

3.1.1 Introduction

In this topic, we examine the many factors that contribute towards developing and refining movement skills. It is evident that movement skill learning is a product of dedicated practice and expert feedback. However, there are different types of practice and feedback.

It is important to understand what kind of practice is most effective in meeting the specific needs of the learner and the demands of the sport/movement skill. Similarly, feedback should be tailored to optimise learning. For example, a beginner requires more frequent feedback than an elite performer, while the elite performer requires more precise and detailed feedback.

Finally, in keeping with the old adage, 'nighty per cent of sport is played between the ears', this chapter examines the significant impact that mindset has on skill performance. Specifically, it looks at the roles that the psychological skills of confidence, optimal arousal, motivation and concentration play in sport performance and the useful techniques that can be used to develop these skills.

FIGURE 3.1 What factors does a coach need to consider to provide the most effective type of feedback for their athletes?

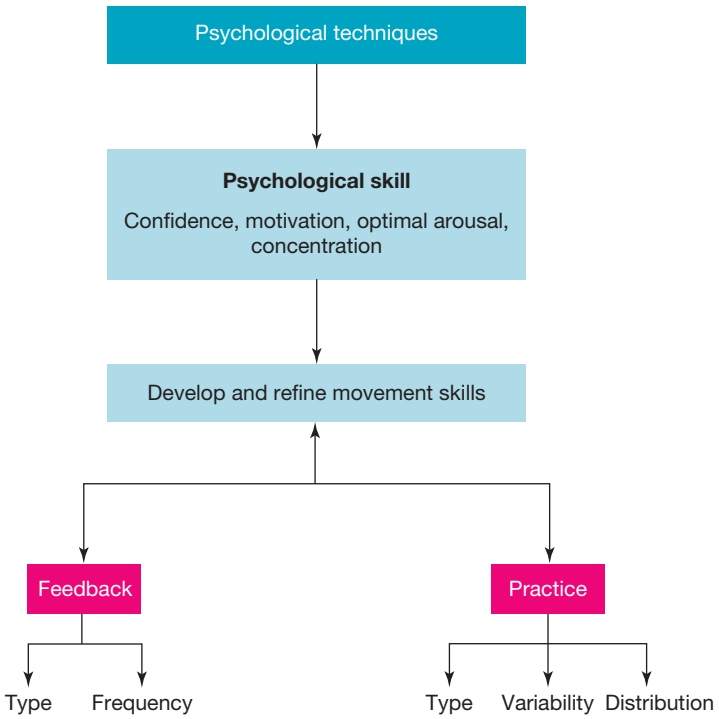


3.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• considerations when coaching to enhance participation and performance: – psychological skills (confidence, motivation, optimal arousal and concentration) and accompanying strategies	• 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 • analyse primary data	**3.7**
– scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)		**3.2** **3.3** **3.4**
– frequency and type of feedback including intrinsic and augmented (knowledge of results and knowledge of performance)		**3.5** **3.6**

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3.1.3 Topic preview



3.2 Types of practice

Key knowledge	Key skills
• considerations when coaching to enhance participation and performance: – scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)	• 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 • analyse primary data

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3.2.1 Effective practice

The most effective type of practice depends on the complexity of the movement skill being practiced and the learner's stage of learning. For effective practice to take place, a coach should design practice tasks that allow the learner to experience a reasonable amount of performance success. For example, if the learner is a novice and the movement skill is complex, the coach should design a practice task with a reduced level of difficulty. As the learner becomes more confident, the coach can progressively increase the difficulty of the practice tasks, from the relatively simple to the increasingly complex, to further enhance learning. The coach will also decide whether to use **whole practice** or **part practice**.

3.2.2 Part practice

Part practice refers to breaking the skill down into smaller parts. For example, a tennis serve is a complex skill that is very difficult for a beginner to learn. To make the serve more accessible for the beginner, the skill can be broken down into smaller parts and practised in isolation. For example, the beginner can practise the ball toss, the back swing and the follow-through separately. Once the individual parts have been mastered, the learner can attempt to put the parts together to perform the whole skill (see figure 3.2).

FIGURE 3.2 After practising the parts of a tennis serve in isolation, they can put it all together to perform the whole skill.



Part practice is effective when the learner is inexperienced, and the movement skill is complex and challenging. Part practice ensures early success, providing the learner with the confidence to progressively work towards mastering the whole skill. Part practice is also particularly effective when practicing serial skills. Serial skills are a collection of discrete skills that are easily isolated and practiced separately.

whole practice learning all of the skill

part practice learning smaller parts of a skill in isolation

However, not all movement skills are easily broken down. For example, it's difficult to breakdown skills of short duration, such as throwing, jumping (see figure 3.3) and hitting. For example, during the short time it takes to perform a golf swing, each body part movement, starting with the legs and hips and finishing with the arms and wrists, overlaps with, and builds on, the momentum of the previous body part movement. Therefore, it is not beneficial to practice the body part movements in isolation.

FIGURE 3.3 Training to jump the hurdles in athletics is a movement skill that is difficult to break down.



Furthermore, part practice is not always representative of performance. In the sport of swimming, the leg kick and the arm pull are often practiced in isolation. The kicking action is practiced separately with the aid of a kickboard and the arm action is practised with the aim of a pool buoy. However, while part practice may be advantageous for the beginner swimmer, it has the disadvantage of changing the nature of the skill being rehearsed. That is, part practice does not develop the necessary whole-body coordination (arms and lower body) and timing to swim efficiently.

3.3.3 Whole practice

Whole practice refers to practicing the whole skill. Whole practice is preferred when the learner is proficient, and the movement skill is relatively simple. In such circumstances, there is little benefit from breaking the skill into parts. Whole skill practice is well suited to continuous skills where the movement is relatively simple and the goal of the skill is sustained effort, such as in running and cycling.

FIGURE 3.4 Young children can practice whole skills with modified equipment, such as a larger ball and a lighter racquet for tennis.



Whole practice is also suitable for discrete skills that are short in duration and that involve elements of timing and coordination. For example, the golf swing discussed above.

In whole practice, the learner benefits from developing timing and coordination, and the movement skill learning is more representative of performance. However, the coach may still need to simplify practice tasks to support learning. For example, in Tennis Hot Shots, a modified version of tennis, junior participants can confidently practise whole skills using smaller, lighter racquets and bigger, brighter tennis balls. Coaches often use this kind of task modification in combination with whole skill practice to facilitate skill learning in novice participants.

3.2 Activity

3.2 Quick quiz on | **3.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	3	4, 5

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TEST your understanding

1. **Define** *part practice*.
2. **Identify** two factors that will influence whether a coach decides to use whole practice or part practice.
3. During a primary school class of circus skills, the instructor demonstrates three ball juggling and then tells the children to 'give it a go'. The children are complete beginners to juggling.
   Identify the type of practice being used in this class, and **predict** what will happen for most of the children when they attempt three ball juggling.

APPLY your understanding

4. Imagine you had to teach the following skills to a complete beginner. For both skills, **explain** whether it would be more beneficial to use part practice or whole practice.
   a. Cycling
   b. Tennis serve
5. Using sporting examples to support your answer, **explain** when it's appropriate to use whole practice and when it's appropriate to use part practice.

3.2 Exam questions

Question 1 (1 mark)

A novice swimmer who uses a kickboard to isolate and develop the freestyle leg kick and then to isolate and develop the freestyle arm draw is engaging in which kind of practice?

A. Part practice
B. Section practice
C. Whole practice
D. Beginner practice

Question 2 (1 mark)

When practising a complex dance routine for the first time, the learner should use:

A. massed practice to repetitively practice the dance steps.
B. whole practice to develop skills that are more representative of the performance.
C. part practice, by isolating and developing the individual steps that make up the routine.
D. massed practice because the dance routine is a discrete skill.

Question 3 (3 marks)

a. **Classify** the movement skill of a golf swing as continuous or discrete. **(1 mark)**
b. **Explain** whether a golf swing is better suited to part practice or whole practice. **(2 marks)**

Question 4 (3 marks)

A coach is teaching a group of beginner primary-school-aged students how to kick in AFL. They break the skill into four components: grip, ball drop, leg action and foot position. The coach has the students practice these skill components separately before attempting the whole skill.

a. **Name** the type of practice. **(1 mark)**
b. **Explain** why this type of practice can enhance learning in this scenario. **(2 marks)**

More exam questions are available in your learnON title.

3.3 Practice distribution

Key knowledge	Key skills
• considerations when coaching to enhance participation and performance: – scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)	• 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 • analyse primary data

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3.3.1 Practice distribution

Practice distribution refers to the relative spacing of practice time. For example, a coach will decide whether it is more beneficial for a team to have less frequent training sessions of longer duration (massed practice) or more frequent training sessions of shorter duration (distributed practice). Practice distribution also refers to the time spent resting within a single practice session.

practice distribution the ratio between time spent actively practising and time spent resting

massed practice a form of practice in which there is little or no rest between repeat performances of a skill

3.3.2 Massed practice

Massed practice involves fewer practice sessions of longer duration. For many sporting teams, this is not so much a choice as the reality of fitting practice times around other commitments, such as work and family. In this case, the longer practice sessions allow amateur sports participants to make the most of their limited time.

FIGURE 3.5 The physical and mental demands of massed practiced sessions may suit elite sports teams.



Massed training sessions tend to be longer in duration in which the majority of time is spent practicing and rehearsing with relatively few rests periods. In junior or club sport, movement skill learning may be hindered as participants become physically tired and struggle to concentrate during extended practice sessions. Conversely, for elite sportspeople, these sessions can offer an opportunity to rehearse complex movement skills in an environment more representative of a competitive game. As such, massed practice can be an effective strategy to extend and further develop the skills of autonomous learners.

Massed practice sessions are well suited to developing discrete skills (i.e. skills performed in a brief period of time). An example is a golfer hitting multiple shots on a practice fairway, with little recovery time between efforts. Practising discrete skills in one continuous training block allows the learner to replicate efficient movement patterns; through multiple and continuous practice trials, the learner can ingrain effective skill technique. Practising discrete skills, unlike continuous skills such as swimming or bike riding, is also less physically fatiguing and consequently does not require the long rest periods associated with distributed practice (see figure 3.6).

FIGURE 3.6 Little rest time is needed between shots when practising shots at the driving range.



3.3.3 Distributed practice

Distributed practice involves spreading practice out, where the practice time is relative short and the rest periods are reasonably long. Distributed practice can refer to the practice schedule in which there are more frequent practice sessions of shorter duration. Distributed practice can also describe the a practice session in which there are short work periods and frequent rest breaks. Research has shown that distributed practice is more effective than massed practice for learning a new movement skill. Distributed practice is particularly well suited to learning complex movement skills; that is, movement skills with multiple components. Learners develop and refine new movement skills more effectively through frequent, less demanding practice sessions compared to lengthy and less frequent practice sessions.

distributed practice a form of practice in which smaller practice time intervals are interspersed with rest periods. This applies equally to both the practice schedule and the individual practice session.

In a distributed practice session, there is either more rest time than work time or at least equal parts work and rest. The rest periods assist the learner to recover physically and mentally between efforts whilst also providing an opportunity to digest the coaches instructions and to consolidate their learning. The use of rest periods also makes distributed practice more suitable for learning continuous skills (e.g. running, swimming and cycling) as well as complex and fatiguing skills found in sports such as gymnastics. The varied nature of distributed practice can also be more motivating for the learner.

FIGURE 3.7 Complex, physical and fatiguing skills, are best suited to distributed practice.



FIGURE 3.8 A skill being learned for the first time is best rehearsed in a distributed format.



FIGURE 3.9 Complex skills are best practiced using distributed practice.



Distributed practice sessions are highly recommended when:

- learning a new skill (see figure 3.8)
- learning a complex skill (see figure 3.9)
- rehearsing a physically and mentally fatiguing skill
- the performer is young and/or lacks concentration
- the performer lacks motivation.

TABLE 3.1 Massed versus distributed practice

Practice distribution	Emphasis	Advantages	Weaknesses
Massed practice	• Continuous practice • Little or no rest between repeat rehearsal of skill • A training schedule with fewer but longer practice sessions	• Maximises practice time • Suits practising non-fatiguing, discrete skills • Suits an elite, highly motivated performer	• Physically and mentally fatiguing • Repetitious and monotonous
Distributed practice	• More or equal time spent resting between practising skills • Practice in shorter intervals, interspersed with recovery periods • A training schedule with more frequent but shorter sessions	• Greater learner engagement • Assists beginner or less motivated performer • Reduction of mental and physical fatigue during practice • Suitable when learning a complex skill • Recovery period allows for memory consolidation	• More time-consuming

on Resources

Interactivity Practice distribution (int-6786)

doc-41944

PRACTICAL ACTIVITY Massed vs distributed practice

Goal

Comparing the effect of different practice distributions with a hula hoop.

Instructions

Work in pairs. Each partner will attempt to master the hula hoop. If a student is already proficient in hula hoop, set them a more challenging task (e.g. use two or three hoops).

Trial conditions: In each trial, the student is pre- and post-tested; that is, time how long they can spin the hula hoop before the hoop falls.

Trial 1: The first student in your pair attempts to master the hula hoop action in one continuous practice session lasting for 15 minutes. The partner who watches can provide corrective feedback.

Trial 2: The second partner then attempts to master the hula hoop action. In this trial, the student rehearses the movement for three minutes and rests for two minutes. (Repeat this three times in the course of 15 minutes.) The observing partner can provide corrective feedback.

Repeat trials 1 and 2, but swap roles so that each partner gets to complete both trial conditions.

Record and analyse the results from each of the trials. Average the results for the entire class.

Primary data/Reflection

	Pre-test time (s)	Trial 1 Post-test time (s)	Trial 2 Post-test time (s)
Student 1			
Student 2			

	Pre-test time (s)	Trial 1 Post-test time (s)	Trial 2 Post-test time (s)
Class average			

- Reflecting on trial 1, how did the continuous practice session feel in terms of focus, fatigue and overall effectiveness?
- Considering trial 2, how did the practice sessions being broken up into shorter, spaced intervals impact your learning experience?
- How did the feedback from your partner influence your performance in each trial?

Questions

1. Classify the type of practice distribution in each trial.
2. Which type of practice distribution was more effective at facilitating skill learning?
3. Outline potential reasons for discrepancies in skill learning between the two types of practice distributions.

3.3 Activity

3.3 Quick quiz on | **3.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4	3	2, 5

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TEST your understanding

1. **List** three advantages of massed practice and three advantages of distributed practice.

2. **Contrast** the demands of darts and mountain biking. Suggest the ideal practice distribution for each sport.
3. **Discuss** the difference between massed practice and distributed practice. Using a coaching example, explain when it is appropriate to use massed practice and when it is appropriate to use distributed practice.
4. **List** three sport-specific skills suited to distributed practice and three sport-specific skills suited to massed practice.

APPLY your understanding

5. An elite AFLW football team uses a combination of distributed and massed practice to achieve their training goals. **Describe** a scenario where the AFLW team would benefit from distributed practice and one where the AFLW team would benefit from massed practice. In each case, **explain** why the team would benefit from that specific practice distribution.

3.3 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.10;* © ACHPER

A practice schedule where there are fewer practice sessions, and the sessions are of a longer duration, is

A. constraints led practice.
B. random practice.
C. massed practice.
D. distributed practice.

Question 2 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.8*; © VCAA

In relation to practice distribution, which one of the following practice schedules would be described as the most massed practice?

A. 2 × 90-minute sessions per week
B. 3 × 60-minute sessions per week
C. 1 × 180-minute session per week
D. 6 × 30-minute sessions per week

Question 3 (4 marks)

Source: Adapted from *ACHPER 2023, Trial Exam Units 3 & 4, Section B, Q.3.a,b;* © ACHPER



The image below shows an adult cognitive learner developing the movement patterns for the complex skill of volleyball digging.

a. Which type of skill best categorises the volleyball dig: discrete, serial or continuous?
Discrete Serial Continuous **(1 mark)**

b. The learner is highly motivated and wishes to participate in a local competition in two months. They allocate one two hour session per week to practise. **Evaluate** the use of this distribution of practice for developing volleyball skills. **(3 marks)**

More exam questions are available in your learnON title.

3.4 Practice variability

Key knowledge	Key skills
• considerations when coaching to enhance participation and performance: – scheduling of practice including type (part and whole), distribution (massed and distributed) and variability (blocked and random)	• 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 • analyse primary data

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

3.4.1 Practice variability

Practice **variability** refers to the extent to which a variety of skills are practiced, and the degree to which the same skill is practiced in different ways, under different conditions. For example, a practice session involving a golfer practising multiple types of shots (e.g. putts, chips and drives) has a high level of practice variability. Equally, practice variability can be added to putting practice by frequently changing the length of putts and the conditions under which the putts are performed (e.g. in isolation or in competition with other golfers).

FIGURE 3.10 Short-sided games force the participants to develop applicable and versatile skill sets.



High levels of practice variability often result in more skill errors during practice sessions. However, while skill performance during practice may suffer, research has shown that higher practice variability is advantageous for skill retention and beneficial for the development of versatile movement skills that can be applied in different situations (see figure 3.10). In other words, the skills learned with high practice variability transfer more effectively to competition. This makes sense, as high practice variability is more representative of competitive sport. **Random practice** is a form of practice in which the levels of practice variability are high.

Low practice variability can also play an important role in movement skill learning. Low practice variability is well suited to the early stages of learning. For example, to develop the basic skill mechanics of a golf swing, the beginner may benefit from repeatedly practicing the same shot, under the same practice conditions. **Blocked practice** is a form of practice in which the levels of practice variability are low.

variability the amount of change and uncertainty in an environment or in the performance of a skill

random practice a form of practice that involves rehearsing a number of different skills in an unpredictable sequence

blocked practice a type of practice in which each skill component is practised repetitively as an independent block

3.4.2 Blocked practice

Blocked practice sessions involve practising the same skill repetitively under the same practice conditions for a set period of time. For example, volleyball players repetitively practice performing a dig (shot) in isolation. The coach throws the ball to the same position and at the same velocity so that the volleyball player can comfortably and successfully repeat the basic skill movements. Blocked practice sessions have relatively low levels of practice variability.

Blocked practice is effective in the early stages of learning, particularly with complex movement skills. It enables the learner to become familiar with the basic mechanics of the skill, replicating and refining skill performance before having to link multiple skills within the less predictable game environment. Blocked practice generally results in significant improvements in skill performance during practice sessions. However, these improvements do not necessarily transfer to the match environment. As performers become more familiar with the new skill, the need for variability in practice becomes apparent.

FIGURE 3.11 Blocked practice: repetitively practising the same skill in isolation



3.4.3 Random practice

Random practice has a high level of practice variability. In random practice, a variety of skills are rehearsed within the same session. Unlike in blocked practice, no one skill is worked on for a defined period of time or in a repetitive manner. Rather, skills are practised in combination and rehearsed in random order (see figure 3.12). For example, a golfer working on their putting stroke might practise different length putts in random order. Random practice has a high level of what is known as contextual interference, the degree to which the repeat performance of a specific skill is interrupted by having to perform other movement skills.

During practice sessions with high levels of practice variability and a high degree of contextual interference, it is not uncommon for there to be a relatively large number of skill performance errors. However, variable practice ultimately leads to greater transfer of learning (the retention of skills learned in practice) and more substantial improvements in competition performance.

FIGURE 3.12 Multiple skills practised in an unpredictable sequence improves transfer of learning to game situations.



FIGURE 3.13 Random practice prepares athletes for competition.



TABLE 3.2 Blocked and random practice

	Blocked practice	Both blocked and random practice	Random practice
Suitability for stage of learning	Cognitive	Associative	Autonomous
Emphasis	• Very little or no practice variability • The learner's attention is predominantly on executing and replicating ideal skill technique	• A number of skills are practised in the same practice session • Different skills are practised in a predictable sequence • The learner's attention is divided equally between executing skill technique and decision making	• Multiple skills are practised in the same practice session • Skills are practised in random order • More representative of the game environment • The learner's attention is predominantly taken up with decision making

Advantages	• The novice learner is able to concentrate on one skill at a time, free from distractions • The learner replicates the basic mechanics of skill technique • Facilitates significant improvement in skill execution during practice sessions • Helps the learner to develop confidence in their skill performance	• Enables a moderate degree of practice variability for the intermediate or associative learner • Is an important progression towards skill mastery and game preparedness	• Most effective at preparing the learner for the game environment: – more closely replicates and mimics the physical and cognitive demands of a game – enables the learner to develop more applicable skills – helps the learner to improve applicable decision-making skills • Greater transfer of learning • Encourages participants to be active learners

3.4.4 Considerations for varying practice for skill learning

There are a number of factors a coach must consider when designing the appropriate level of variability for practice.

- Practice variability can be added to training sessions by changing the practice conditions. For example, a netballer can choose to rehearse their goal shooting by themselves or under the pressure of an opposing goalkeeper. Practice variability can also be added by changing the skills being rehearsed. This kind of practice is particularly applicable to random practice.
- As a general rule, there should be less variability of practice in the early stages of learning and more variability of practice in the later stages of learning. In the early stages, a more predictable/closed environment helps to establish basic skill performance. However, as the learner becomes more competent in skill execution, they will benefit from more practice variability.
- There should be a higher degree of practice variability for open sports than closed sports.
- The physical and cognitive demands of variable practice should mirror the physical and cognitive demands of the relevant game environment. Variable practice ensures the skills learned in training can be successfully applied in competition.
- Constraints-based instruction, the process of varying game constraints to facilitate learning, relates closely to varying practice. Constraints-based coaching uses moderate to high levels of practice variability.
- Lower variability in practice will lead to better performance in practice. However, greater variability of practice will result in greater learning and better preparedness for the game environment (see figure 3.14).

FIGURE 3.14 Practising in isolation (blocked) may not adequately prepare the performer for the demands of competition.



- There are circumstances in which it is preferable to produce immediate success, albeit in a low-variability environment. For example, in a pre-game warm up, basketballers practise their lay-ups in uncontested line drills to develop confidence and feel before they are exposed to the highly variable demands of the game (see figure 3.15).

FIGURE 3.15 Warming up without the pressure of competition gives the players confidence.



TABLE 3.3 Summary table of the practice considerations applicable to the different stages of learning. Recommendations are general and don't account for the specific circumstances of different learning environments.

Type of learner	Novice	Intermediate	Elite
Practice distribution	Distributed	Distributed (task dependent)	Distributed/massed (task dependent)
Practice variability	Blocked	Blocked and random	Random
Type of practice	Part practice	Part and whole practice	Whole practice (task dependent)

on Resources

Interactivities Practice variability (int-6787)
Types of practice (int-6785)

doc-41945

PRACTICAL ACTIVITY Variability of practice

Goal

To investigate the effect of variability of practice on performance.

Equipment

- Tennis balls
- Targets

Instructions

Use your non-preferred hand to bounce the ball on the floor before hitting a target on the wall. Score one point for each target hit.

Test conditions

Test 1: For half the class (group 1), run 15 practice trials standing three metres from the target.

Test 2: For the other half (group 2), run 5 practice trials standing three metres from the target, 5 trials standing four metres from the target and 5 trials standing five metres from the target.

Test 3: Both groups run 10 trials standing six metres from the target.

Record and analyse the results from each of the trials.

Primary data/Reflection

TABLE 1 Results for Test 1 – 3 metres from target

Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

TABLE 2 Results for Test 2 – 3, 4 and 5 metres from target

	3 metres from target					4 metres from target					5 metres from target				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

TABLE 3 Results for Test 3 – 6 metres from target

Trial	6 metres from target									
	1	2	3	4	5	6	7	8	9	10

- Group 1: What were the challenges and advantages of practicing at a constant distance from the target?
- Group 2: How did changing the distance from the target impact your accuracy and performance?

Questions

1. Which group (1 or 2) did you expect to score more points in tests 1 and 2? Why?
2. Which group scored the most points in test 3?
3. How did the results compare between the two groups in test 3, where both groups faced the same increased distance challenge?
4. Based on your personal experience and the class averages, what conclusions can you draw about the effectiveness of varying practice distances?
5. How can the findings from this activity be applied to other sports or skills that require precision and coordination?

3.4 Activity

3.4 Quick quiz on | **3.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	4, 5	2, 6

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TEST your understanding

1. **Define** *practice variability*.
2. **Explain** the difference between blocked and random practice.
3. **Outline** three ways in which highly variable practice can benefit the learner.

APPLY your understanding

4. **Discuss** when it's best to use blocked practice and when it's best to use random practice.
5. Think of the sport/s you play and a typical training session. **Discuss** ways in which you could increase the practice variability in your typical training session.
6. a. Make a copy of the table below. For each scenario, choose the most appropriate type of practice distribution and amount of practice variability for the stage of learning and the particular movement skill involved.
   b. In each case, **explain** your choice in relation to practice distribution and practice variability.

Skill learning	Practice distribution		Practice variability	
The learner and the movement skill	Massed	Distributed	Blocked	Random
An elite tennis player practising their groundstrokes, volleys and overheads				
A novice soccer player practising passing				
An intermediate golfer practising various iron shots				
A novice swimmer practising butterfly				
A highly motivated elite netballer practising game play				

3.4 Exam questions

Question 1 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.9;* © VCAA

Four different practice strategies were used to improve a movement skill. The table below gives a description of each of the four practice strategies used.

Practice strategy	Description
1	same skill repeated over and over in one practice session
2	variations of the same skill repeated in one practice session
3	multiple skills practised in any order in one practice session
4	multiple skills practised in a set order in one practice session

The graph below shows the improvement achieved by using each practice strategy.



What is the name of the practice strategy that led to the greatest improvement in performance?

A. massed practice
B. blocked practice
C. random practice
D. distributed practice

Question 2 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.2;* © VCAA

Which one of the following activities is likely to represent the highest level of practice variability for a passing skill in lacrosse?

A. modified games
B. closed drills
C. isolated drills
D. practising passing to a target on a wall

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.2.b;* © VCAA

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.

During batting practice, batters may use ball projection machines. Using these machines allows batters to hit many balls in a short period of time and to practise consistently and repetitively while focusing on one specific movement.

For each skill acquisition principle in the table below, circle the option that would best suit practising batting with a ball projection machine.

Skill acquisition principle	Option 1	Option 2
coaching approach	direct	constraints-based
stage of learning	associative	cognitive
practice variation	random	blocked

Question 4 (5 marks)

A tennis coach trains three different players. Player A is an experienced player who competes at an elite level, Player B is an intermediate performer who is just starting to participate in competitive tournaments and Player C is a complete novice. Complete the following table.

Player	Relevant stage of learning	Type of practice variability	Benefit of practice variability to relevant stage of learning
A			
B			
C			

Question 5 (5 marks)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.1;* © ACHPER

The diagram below illustrates a basketball player practicing set shots over a 30-minute period.



a. **Identify** the type of practice most likely being used in this picture. **(1 mark)**
b. **Outline two** disadvantages of this type of practice. **(2 marks)**
c. **Name** and **describe** a different method of practice which would reduce the disadvantages given in your answer to **part b**. **(2 marks)**

Question 6 (4 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.6.b;* © VCAA

Evaluate the type of practice variability (blocked or random) recommended for beginner swimmers, taking into consideration the skill classification of swimming in a pool (open or closed).

More exam questions are available in your learnON title.

3.5 Types of feedback

Key knowledge	Key skills
• considerations when coaching to enhance participation and performance: – frequency and type of feedback including intrinsic and augmented (knowledge of results and knowledge of performance)	• 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 • analyse primary data

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Feedback is any form of information a learner receives about their skill performance. Feedback can come from a variety of sources and provides information about skill errors or information that reinforces successful movement patterns. Coaches must think carefully about the types of feedback they provide and how to best tailor feedback to the specific needs of the learner (see figure 3.16).

FIGURE 3.16 Retired Olympic aerial skier Lydia Lassila undertaking water jumps as part of her training. Lydia relied on feedback to improve her skill performance.



Whatever the coach decides, it's important to recognise that feedback is a critical and indispensable part of skill acquisition.

Feedback works on a number of different levels:

- Feedback motivates the learner by providing information on the progress of skill learning.
- Feedback highlights skill errors and enables the learner to make appropriate corrections.
- Feedback also provides positive reinforcement, confirming when the learner is performing correctly.

3.5.1 Intrinsic feedback

Intrinsic feedback is the information the performer receives directly from their sensory systems. Intrinsic information is provided by the learner's visual and proprioception systems as well as their cutaneous system (the skin, which conveys information about pain, temperature and pressure). For example, a basketballer shooting at the free-throw line is aware of the coordination of their body parts to execute the shot (proprioception), feels the spin they impart on the ball at the point of release (cutaneous) and sees the flight path of the ball relative to the ring (visual). Auditory feedback can also be used to assess the relative success of movement skills. Examples include the swish sound the net makes when a basketball 'hits a clean shot', or the sound of a ball hitting a cricket or baseball bat's 'sweet spot'. Intrinsic feedback often allows the athlete to correct or improve their skill execution during the performance.

feedback information concerning the performance and/or outcome of a movement skill, including information about errors and how to correct them

intrinsic feedback sensory information the learner receives directly from skill execution

Coaches may use questioning as a strategy to enhance the performer's use of intrinsic feedback. For example, a cricket coach might ask: 'do you feel balanced or unbalanced when you successfully hit an off-drive in cricket?'

CONCEPT CONNECTOR

- Stand on one foot for 10 seconds and maintain balance. Discuss the intrinsic feedback that is important for you to remain balanced.
- Stand on one foot and close your eyes to remove visual information. Take notice of the changing angle at your joints and changing tension in the muscles and tendons crossing the ankle joint (proprioception). Take notice of the changing pressure at different positions under your foot (touch, cutaneous).

3.5.2 Augmented feedback

Augmented feedback refers to information that comes from sources external to the performer (see figure 3.17). Traditionally, augmented feedback comes from an instructor or a coach. For example, a basketball coach might tell a player that their free-throw shots are falling short because of a lack of knee bend. This can be reinforced by another form of augmented feedback, such as video analysis. The player and coach can review game video, recognise faults in the shooting technique and subsequently make the appropriate corrections.

FIGURE 3.17 Augmented feedback from a coach



In endurance sports involving continuous skills, such as cycling and running, augmented performance feedback can come in the form of monitors that record heart rate, cadence, speed and wattage. While this feedback does not relate directly to skill execution, it does provide information on the relative success or failure of the skill performance. Hence feedback can be divided into two broad categories: knowledge of performance (e.g. the basketballer's shooting technique) and knowledge of results (e.g. did the basketball go in the hoop?; did the cyclist reach their target speed?).

augmented feedback information about a skill performance that comes from an external source

knowledge of performance feedback regarding how a skill is performed; assessing performance on the basis of process and skill technique

3.5.3 Knowledge of performance

Knowledge of performance refers to feedback that provides information about the process of performing the skill. For example, a golfer might recognise they have a problem with their weight transferral after watching a video of their swing (see figure 3.18). This kind of feedback provides information on how the skill is performed, rather than the outcome or result of the skill performance. Knowledge of performance feedback can be augmented (e.g. video analysis or, more commonly, verbal feedback from a coach) or intrinsic (e.g. the golfer can feel when their weight is too far back in their stance, or if the club face is not square through the ball strike).

FIGURE 3.18 Knowledge of performance: feedback regarding skill execution



Coaches, for the most part, should concentrate on providing knowledge of performance feedback as this is the most effective means of correcting faults and facilitating learning.

3.5.4 Knowledge of results

Knowledge of results is information about the outcome of your skill performance. Using the previous example, the golfer receives knowledge of results regarding a golf shot by observing the ball flight and where the ball lands.

FIGURE 3.19 Seeing the basketball successfully go through the hoop is an example of knowledge of results.



Generally speaking, knowledge of results is clearly evident. The learner can see when the basketball goes into the hoop or when the softball is struck into the foul zone (see figure 3.19). However, a coach can draw attention to less obvious examples of knowledge of results, such as how much topspin a tennis player's forehand imparts on the ball. In this example, the coach can then connect the amount of spin successfully imparted on the tennis ball to the player's technique. This establishes a clear link between knowledge of results and knowledge of performance and helps the player to know where to focus their attention. Furthermore understanding knowledge of results can help the learner to use intrinsic feedback more effectively. The learner develops an understanding of what success feels like and looks like, and this in turn accelerates their ability to self-correct and to improve their performance.

3.5.5 Precision of feedback: qualitative versus quantitative

Qualitative feedback provides general, less technical feedback about movement skill performance. For example, an athletics coach tells their athlete 'your hips are too high and your back leg is too straight in the set position during the sprint start and this results in a lack of push off the rear block'.

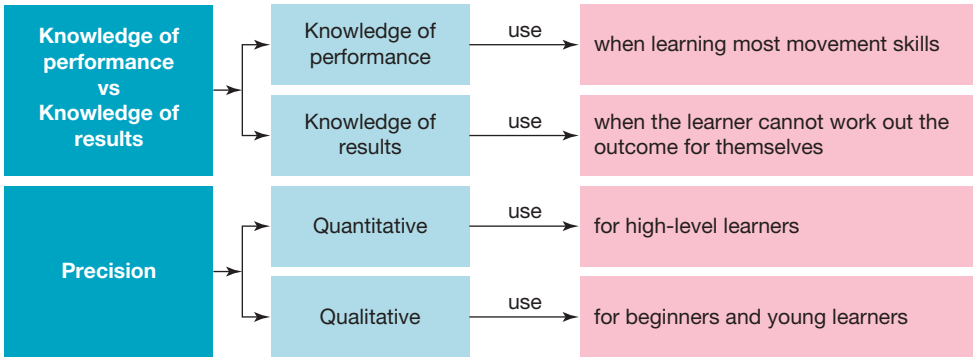
knowledge of results information about the outcome of skill performance; information regarding the relative success or failure in regard to the intended goal of the movement skill

Quantitative feedback is a precise form of feedback that often refers to specific numeric values (see figure 3.20). For example, a sprint coach might inform an athlete that the angle at the knee in their rear leg is 140 degrees. An experienced athlete can interpret and use this precise form of feedback, while a novice athlete will prefer more general qualitative feedback.

FIGURE 3.20 Quantitative feedback is precise and uses numerical values.



FIGURE 3.21 A summary of the different forms of feedback and their appropriate application



doc-41946

PRACTICAL ACTIVITY Feedback

Goal

To investigate the effect that the amount and type of feedback has on skill performance.

Equipment

- Volleyball
- Hoop

Instructions

Working in pairs, stand three metres from your partner, holding the ball and keeping your back to them. Try to throw the ball over your head (without looking) and through a hoop held by your partner. You have 10 chances.

Write down the number of successful scores for each of the following scenarios (use the point system to work out the total scores):

- Ball goes through hoop (3 points)
- Ball makes contact with the hoop (2 points)
- Complete miss (1 point).

Test conditions

Test 1: Receive no feedback.

Test 2: Receive limited feedback: 'yes the ball went through the hoop' or 'no, you missed'.

Test 3: Receive as much feedback as possible about the ball flight in relation to the hoop and about the relative success of the performance. Your partner can also make suggestions about how to improve your performance.

Record and analyse the results for each of the trials for your entire class; that is, what were the average results for tests 1, 2 and 3?

Primary data/Reflection

TABLE 1 Results of tests 1–3

	Trial									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Test 1										
Test 2										
Test 3										

TABLE 2 Results for the class

	Class average
Test 1	
Test 2	
Test 3	

- Reflecting on test 1, how did not receiving any feedback impact your ability to adjust and improve your throws?
- Considering test 2, did the limited feedback help you to make the necessary adjustments during subsequent attempts? How?
- How did the detailed feedback in test 3 contribute to your understanding of the task and your performance improvement?

Questions

1. Define the types of feedback received in tests 2 and 3.
2. What do the results of test 1 tell us about the importance of feedback in regard to skill learning?
3. Which test accrued the highest average score? Explain why.
4. Did you find it easier to stay motivated and focused with more feedback? Why or why not?
5. How might the findings from this activity be applied to other sports or activities where feedback plays a crucial role in skill development?

3.5 Activity

3.5 Quick quiz on | **3.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
5	3	1, 2, 4

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TEST your understanding

1. a. **Explain** what is meant by *augmented feedback*.
   b. **Outline** four examples of augmented feedback in relation to sports coaching.
2. a. **Explain** what is meant by *intrinsic feedback*.
   b. **Outline** four examples of intrinsic feedback in sports performance.
3. Research the following sensory systems:
   a. proprioception
   b. cutaneous.
   Using a sporting example, **discuss** the type of feedback each of these systems provide and the significance of this feedback in terms of successful skill performance.
4. **Explain** why knowledge of performance feedback is generally more effective than knowledge of results with respect to facilitating skill learning.

APPLY your understanding

5. A swim coach explains to a junior swimmer that their body position in freestyle is not streamline. Their legs are sinking too low beneath the surface of the water.
   The same swim coach provides an advanced level swimmer with their recorded time for a maximal effort 100-metre freestyle swim.
   a. **Identify** the type of feedback given to the junior swimmer, and **discuss** the potential benefit of this feedback for the learner.
   b. **Identify** the type of feedback given to the advanced swimmer, and **discuss** the potential benefits of this feedback for the athlete.

3.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.7;* © VCAA

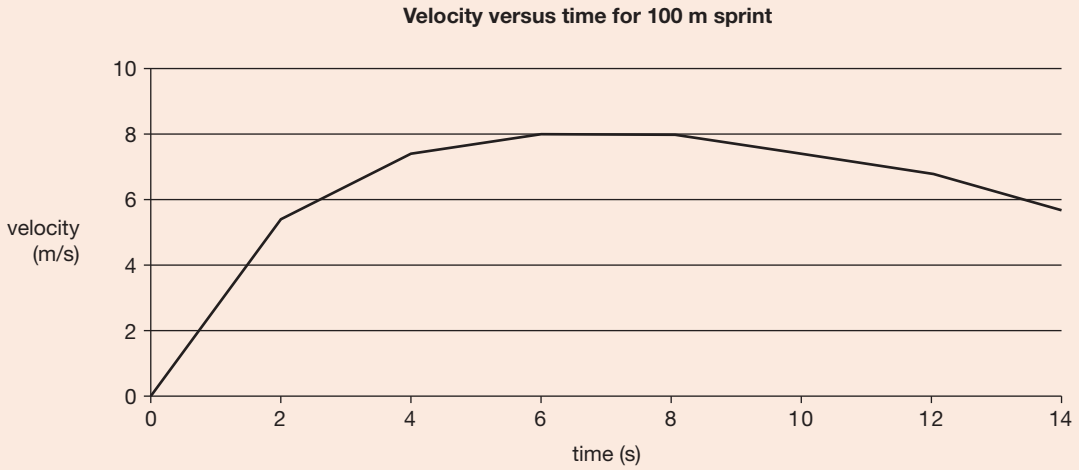
Which one of the following is an example of augmented feedback?

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

Question 2 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.14;* © VCAA

The following questions relate to a student's performance in a 100 m sprint conducted during their Physical Education class. The data for the student's sprint is shown in the graph below.



The teacher provided the following feedback to the student: 'Your time for the 100 m sprint was 14 seconds.' Which type of feedback was provided to the student?

A. knowledge of performance
B. knowledge of results
C. proprioceptive
D. intrinsic

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.1.b;* © VCAA

During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200 m and 400 m 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.

Question 4 (6 marks)

Source: Adapted from *ACHPER 2016, Trial Exam Units 3 & 4, Section B, Q.8;* © ACHPER

The table below has the results of a Year 11 Physical Education class who were investigating the effect of feedback on performance. The results were achieved by performing the same skill, with each group practising using different styles of feedback. Students were given 20 shots at throwing a basketball over their head into a net. They received two points for a basket, one point if they hit the edge and no points if they missed. The average score for each group is listed below.

Feedback	Condition 1	Condition 2	Condition 3
Average score	8 pts	12 pts	16 pts

a. Consider the average scores in the table for conditions 1, 2 and 3. Match each of these conditions to the correct description below.
   i. Extensive feedback on their performance and detailed feedback on results
   ii. No feedback at all
   iii. Feedback on results only (e.g. 'in basket' or 'missed basket') **(3 marks)**

b. Explain your choices in **part a** (i.e. why did you associate a particular point score with a particular type of feedback?). **(3 marks)**

Question 5 (1 mark)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section A, Q.2;* © ACHPER

It is the 5-minute halftime break of a basketball game.

Which type of feedback would the coach most likely utilise in this situation?

A. intrinsic
B. knowledge of results
C. knowledge of performance
D. video analysis

More exam questions are available in your learnON title.

3.6 Feedback frequency

Key knowledge	Key skills
• considerations when coaching to enhance participation and performance: – frequency and type of feedback including intrinsic and augmented (knowledge of results and knowledge of performance)	• 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 • analyse primary data

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

3.6.1 Frequency of feedback

feedback frequency how often an external source (e.g. coach) provides feedback to the skill learner

Frequency refers to how often a coach provides augmented feedback. Frequency can be measured as an absolute value (the total number of times feedback is provided) or a relative value (the percentage of the learner's practice efforts for which feedback is provided). It's difficult to say with certainty what the ideal **feedback frequency** is to maximise movement skill learning; however, the following principles should be considered:

- Feedback should be provided regularly to facilitate skill acquisition.
- More feedback should be provided in the early stages of learning and less in the later stages of learning. A beginner needs assistance understanding when they have made skill errors as well as advice on strategies to correct skill errors.
- Too much feedback can lead to information overload, particularly in the early stages of learning. Performers in the cognitive stage of learning need to dedicate a substantial amount of attention to understanding the basic mechanics of the new skill, as well as engage in a trial-and-error learning style. If the coach provides feedback too frequently, they risk compromising the learner's attention and disrupting learning.
- Too much feedback in the later stages of learning can lead to the learner becoming overly dependent on the coach's guidance to achieve success (see figure 3.22). As the learner becomes more competent in skill performance, it's important they learn to use their own intrinsic feedback to detect skill errors and correct mistakes. A low level of feedback frequency can reduce the standard of performance in training; however, it supports the transfer of learning to the game environment.

FIGURE 3.22 It is important that athletes don't become overly dependent on the coach's feedback.



3.6.2 Summary feedback

An effective strategy regarding feedback frequency is for the coach to only provide feedback after they watch a series of skill attempts (see figure 3.23). This is referred to as summary feedback. The advantage of summary feedback is that it allows the coach to address and prioritise the most significant and underlying causes of skill error. The coach draws attention to general performance trends rather than distracting the learner by commenting on every minor skill error. This will increase the chances of improving skill performance and reduce the risk of information overload. Summary feedback also allows the learner sufficient time to attempt the coach's corrective strategies, as well as cross-reference these changes with their own intrinsic feedback.

FIGURE 3.23 Feedback should be given after a series of skill attempts.



3.6.3 Performer-regulated feedback versus coach-regulated feedback

Performer-regulated feedback is feedback provided at the athlete's request. This kind of self-regulated feedback is more suited to experienced performers. Often an elite performer 'knows best' when it comes to the cause of their skill errors and, as such, can request the most relevant information to facilitate skill correction. Otherwise, for less experienced or novice performers, it is best that an experienced coach regulates the type and frequency of feedback given to facilitate effective skill learning.

TABLE 3.4 Summary table of feedback use in relation to the type of learner

Type of learner	Novice	Intermediate	Elite
Type of feedback	Knowledge of results and knowledge of performance	Knowledge of performance	Knowledge of performance
	Qualitative	Qualitative	Quantitative and qualitative
Frequency of feedback	Higher frequency	Moderate feedback	Lower frequency
	Summary feedback	Summary feedback	Summary feedback
	Coach-regulated	Coach-regulated	Performer-regulated

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PRACTICAL ACTIVITY Juggling

Goal

To investigate the effect of feedback timing on skill learning.

Instructions

Your teacher will give you some basic instruction, and/or play a short video demonstration, on how to three-ball juggle.

Students work in pairs. One student tries to juggle while the other plays the role of coach.

Pre-test the juggler: how long can they juggle continuously before they drop the balls?

Post-test the juggler: at the end of a double period or after several lessons of practice, test the juggler again.

Trial conditions

Divide the jugglers into two groups. One group completes trial 1 conditions and the other group trial 2.

Trial 1: Coaches constant feedback to their partner.

Trial 2: Coaches less frequent feedback concentrating on performance trends rather every single skill error.

Record and analyse the results for each trial for your entire class.

Primary data/Reflection

TABLE 1 Juggling data

	Pre-test time (s)	Post-test time (s)
Trial 1 or Trial 2		

TABLE 2 Class data

	Pre-test time average (s)	Post-test time average (s)
Trial 1		
Trial 2		

- How did the type of feedback provided impact your performance and learning experience?
- How did the feedback from your partner impact your motivation and confidence throughout the practice sessions?

Questions

1. Classify the type of feedback received in trial 1 and the type of feedback received in trial 2.
2. What type of feedback had more influence on skill learning? Explain why you think this is the case.
3. In which trial did you think the feedback was more frequent? Do you think this helped or hindered skill learning? Explain.
4. As the juggler, did video analysis help you learn the skill? What other types of feedback would be effective in this learning scenario?
5. Based on your personal experience and the class averages, do you think one method of feedback delivery is more effective for skill improvement than the other? Why or why not?

3.6 Activity

3.6 Quick quiz on

3.6 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	2	3

These questions are even better in jacPLUS!



- Receive immediate feedback
- Access sample responses
- Track results and progress

Find all this and MORE in jacPLUS

TEST your understanding

1. **Compare** and **contrast** the ideal feedback frequency for a novice performer with that for an expert performer.
2. **Discuss** why is it important that an athlete does not become overly reliant on their coach's feedback to facilitate a successful performance.

APPLY your understanding

3. A cricket coach thinks strategically about the type and frequency of feedback they will provide to improve the performance of an under-15-year-old fast bowler.
   The coach decides to provide summary advice; that is, only provide advice after watching multiple bowling deliveries. The coach also decides to focus on knowledge of performance feedback.
   Evaluate the effectiveness of the coach's feedback strategies.

3.6 Exam questions

Question 1 (1 mark)

Feedback frequency will be most effective when:

A. the coach provides very little feedback and allows the athlete to work it out for themselves.
B. the coach provides an ever-increasing level of detailed feedback.
C. the coach provides information about knowledge of performance only.
D. regular performance feedback is provided without the learner becoming overly dependent on the coaches' guidance.

Question 2 (1 mark)

As a general rule, feedback should be:

A. less frequent for beginners.
B. more frequent for advanced performers.
C. not given to advanced performers.
D. more frequent for beginners.

Question 3 (1 mark)

It is important for learners not to become over-reliant on their coaches' feedback because:

A. the learner must learn to use their intrinsic feedback to detect and correct mistakes.
B. the learner must learn to pay attention to knowledge of results feedback.
C. the learner must be intrinsically motivated to learn.
D. the learner must learn to use their augmented feedback to detect and correct mistakes.

More exam questions are available in your learnON title.

3.7 Psychological skills for enhanced performance

Key knowledge	Key skill
• considerations when coaching to enhance participation and performance: – psychological skills (confidence, motivation, optimal arousal and concentration) and accompanying strategies	• 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Sports psychology plays a key role in improving the performance of movement skills. In fact, most elite sporting teams make regular use of a qualified sports psychologist. Sports psychologists assist individuals to perform at their best by teaching a range of strategies that regulate thinking, emotions and attention.

With practice, athletes develop mental traits and characteristics that help to optimise performance. These characteristics include:

- confidence
- motivation
- optimal levels of arousal
- concentration.

FIGURE 3.24 Sports psychology can play a powerful role in improving performance.



3.7.1 Confidence

Confidence is the belief an athlete has in their ability to execute a specific task or goal successfully. The athlete will have **self-confidence** if they believe they can achieve their goal. When an athlete has self-confidence, they will:

- persevere, even when things are not going to plan
- show enthusiasm and motivation
- be positive in their approach and take their share of the responsibility in success and failure.

Self-confident athletes:

- believe in themselves and their skills
- exhibit positive emotions
- remain calm under pressure
- think more positively
- have a greater ability to follow, understand and execute game plans.

self-confidence what an individual has when they believe that they can successfully perform a task and achieve their goal

choking when an athlete fails to perform effectively under pressure conditions

An athlete's level of confidence is considered one of the key influencing factors that will differentiate between a successful and an unsuccessful performance (see figure 3.25).

> *I stopped listening to music pre-game because I felt it got me too wound up and I tried some different things . . . I don't think I have an ego, but I'm certainly confident in my ability and I feel like I can be a good player and I want to achieve what I feel like I am capable of achieving.*
>
> — Jack Viney

Confidence can be lost when athletes start focusing on things that are outside their control (e.g. other competitors' performances) or become overly critical of their own individual performance. In sporting terms, this is often referred to as **choking**. In addition to a loss of confidence or focus, choking can also produce physical changes, including increased heart rate, breathing rate and muscle tension. Even though an athlete may have performed the skill many times before, their anxiety about performing the skill correctly and under pressure can result in impaired performance.

Choking can appear as:

- an increase in negative self-talk
- poor judgement and decision making, leading to poor skill selection
- a decrease in selective attention and an inability to attend to relevant cues
- rushing and not taking the normal preparation time for skill execution
- a decrease in coordination and timing due to an increase in muscular tension.

Athletes are confident in an activity when they:

- know what to do
- know how to do it
- know when to do it
- have the resources and ability to do it
- want to do it.

FIGURE 3.25 Jack Viney (Melbourne Football Club) attributed some of the improvement in his performance to working with a sports psychologist.



Athletes can build confidence by:

- working hard at training
- practising good self-management
- rewarding themselves when successful
- recording/logging their successes.

Strategies to help athletes build confidence include:

- *working hard at practice, both physically and mentally.* In particular, athletes will gain confidence via developing skill mastery.
- *using positive self-talk and avoiding negative self-talk.* Athletes should avoid negative thoughts and instead maintain a positive internal dialogue. For example, they might try recalling previous occasions where they have successfully met new challenges.
- *using visualisation.* Athletes gain confidence through visualising a successful performance. An athlete must be able to imagine the performance in vivid detail for visualisation to be effective.
- *setting smaller, more achievable goals rather than outcome goals* (as discussed in the following section). Athletes should self-reflect on performance, both in practice and competition, and concentrate on what they did well as much as on their areas for potential growth.
- *gaining confidence from a supportive environment.* Athletes benefit from coaches and colleagues that recognise achievements and acknowledge the effort and application to practice.

FIGURE 3.26 Novak Djokovic is a supremely confident athlete. As of July 2024, he had won 98 single titles, including 24 Gland Slam titles, since turning professional in 2003.



3.7.2 Motivation

Successful sports performance depends on the athlete being fully committed and motivated towards achieving their goals (see figure 3.27). **Motivation** can be defined as 'the causes of the initiation, maintenance and intensity of behaviour'. In other words, motivation is the reason for participating in an activity, learning the skills involved, training and practising, and dedicating effort to improvement. It is also linked to the satisfaction gained from participation and from achieving ambitions. Motivation is the driving force behind an athlete's desire and determination to achieve their goals.

FIGURE 3.27 To be successful in ultra marathons and in his role as a motivational coach, ex-Navy SEAL David Goggins needs to be highly motivated to achieve his goals.



Athletes with high levels of motivation often exhibit the following characteristics:

- a desire for success
- a willingness to take risks
- an acknowledgment of their own ability as crucial to their success
- an ability to increase their effort and concentration as the task difficulty increases.

Athletes who do not have this level of motivation are less likely to perform successfully and less likely to achieve elite levels. Therefore, coaches have been greatly concerned with what optimally motivates athletes. One of the most widely used methods of achieving this is through the use of **goal setting**.

motivation a reason for participating in an activity; a reason for practising.

goal setting making plans to work towards achieving specific and beneficial objectives and results

3.7.3 Goal setting

Goal setting is an extremely effective motivational technique (see figure 3.28). However, to be a successful tool, goals must meet the following criteria, based on the acronym SMARTER:

FIGURE 3.28 Setting achievable yet challenging goals helps motivate an athlete to achieve their ultimate aim.



- *Specific*. Athletes and coaches should make their goals as specific and detailed as possible.
- *Measurable*. Goals should be measurable and assessed against a standard or previous performance, otherwise there is no way of determining whether they have been achieved.
- *Accepted*. All of the parties involved in the setting of the goals (e.g. the athlete, coach, manager, family members) should accept them.
- *Realistic*. Goals need to be challenging, but also achievable. Goals should be framed positively and focused primarily on improvement, rather than just on winning.
- *Timeframed*. Short-term and long-term goals should be set and there should be a specific date for when they will be achieved.
- *Exciting*. Tthe goals set should challenge, excite and inspire the athlete.
- *Recorded*. Tthe agreed goals should be recorded by the coach and the athlete to provide a constant reminder and to act as a source of motivation.

Goals can be categorised as:

- *Outcome goals*. Related to the overall results of a competition; for example, a golfer winning a tournament or elevating their ranking compared to other golfers.
- *Performance goals*. Related to the athlete's own personal level of performance, irrespective of others. For example, a golfer may analyse their game and aim to improve from hitting 50 per cent of the greens in regulation to hitting 60 per cent of the greens in regulation.
- *Process goals*. Related to performance goals, but the athlete focuses on the physical movement or game strategy aspects. For example, in addition to setting a performance goal of increasing the number of greens hit in regulation by 10 per cent, a golfer may develop a set routine to perform before every shot.

3.7.4 Intrinsic and extrinsic motivation

Motivation may be either *intrinsic* or *extrinsic*.

- Intrinsic motivation comes from within and involves factors such as enjoyment, satisfaction, improvement and enhanced feelings of self-worth as the primary motivators for performance.
- Extrinsic motivation comes from an external source and usually involves some form of material benefit, such as a financial reward (prize money), awards and trophies, or glory and recognition.

Most researchers agree that intrinsic motivation to perform is more desirable than extrinsic motivation, as it serves as a more powerful and sustainable source of motivation.

FIGURE 3.29 Gold medals in the Women's 4 x 100 Medley Relay Final at the Summer Olympics in Tokyo, Japan, 2021.



3.7.5 Arousal and performance

Arousal in sport can be defined as the degree of activation (both physiological and psychological) that an individual experiences when faced with a sporting situation or task. It can be viewed as a continuum ranging from drowsiness/sleep to a psyched-up, hyperactive state.

It is widely accepted that an athlete needs to be at an optimal level of arousal to perform at their best.

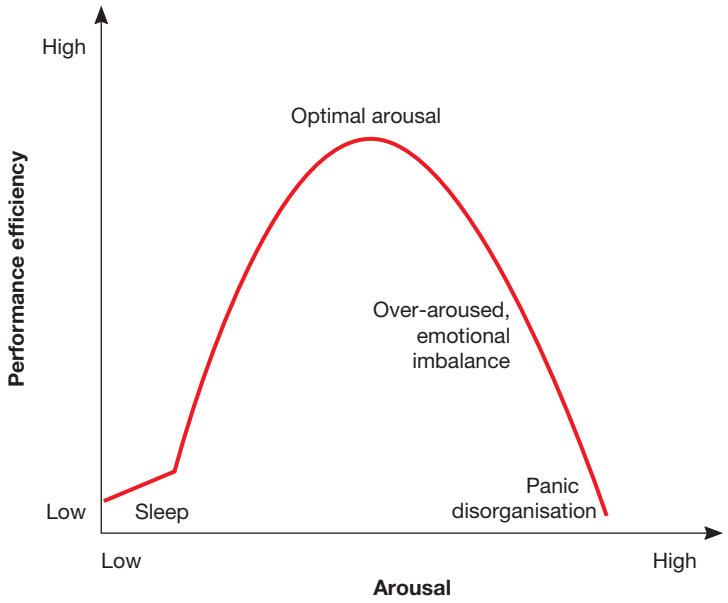
Two psychological models that help to explain the association between arousal and sports performance are the inverted-U hypothesis and the optimal arousal theory.

arousal the readiness an individual experiences when faced with a sporting situation or task

Inverted-U hypothesis

The inverted-U hypothesis predicts that the relationship between arousal and performance approximates an inverted-U shape (see figure 3.30). The theory is that as arousal increases, performance improves, but only up to a certain point (top of the inverted U). If the athlete's arousal increases beyond this point, then performance diminishes.

FIGURE 3.30 The inverted-U hypothesis proposes that increased arousal has a positive effect on performance only up to a certain point, after which continued increases in arousal detrimentally affect performance.



There are three broad categories of level of arousal:

1. Under-aroused (low arousal)
   - Athletes do not perform at their best (e.g. such as when competing against a less skilful opponent).
   - Levels of motivation and intensity are low.
2. Optimal arousal
   - Athletes perform at their best.
   - Level of preparedness and activation are optimal for the task at hand.
3. Over-arousal
   - Performance deteriorates.
   - Athletes are anxious and make poor decisions.

Optimum arousal theory

According to the optimum arousal theory, there is substantial individual variability in arousal–performance relationships. Each athlete will perform at their best if their level of arousal or competitive anxiety falls within their optimum functioning zone. Some athletes perform best under conditions of high arousal, some when arousal is moderate and some when it is low. To maximise performance, an athlete needs to find their optimal level of arousal.

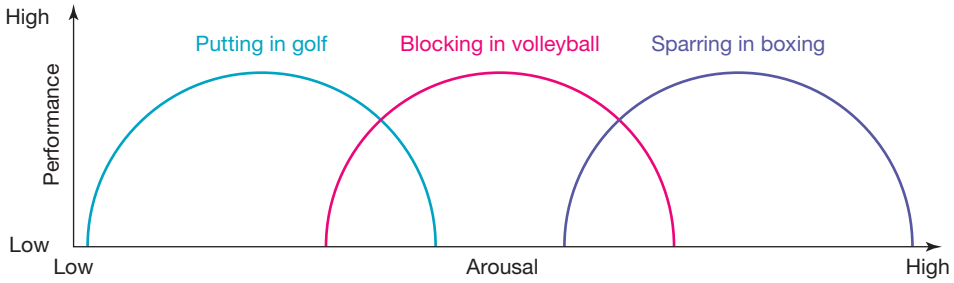
Think of the different personalities in high-profile sports; for example, the hyperactive, forever-fidgeting Australian cricketer, Steve Smith versus the more laid-back Australian cricketer, Mitch Marsh. Steve Smith performs best at a high level of arousal while Mitch Marsh performs best at a low to moderate level of arousal (see figure 3.31).

FIGURE 3.31 Steve Smith and Mitch Marsh have different optimal levels of arousal.



It should also be noted that the optimal level of arousal will change with different tasks. For example, a simple, gross-motor task such as sprinting (running) is best performed with a high level of arousal, while a more complex, fine-motor task, such as an intricate dance routine, is best performed with a lower level of arousal. Even within the same sport, different skills are suited to different levels of arousal; for example, in AFL, players benefit from a high level of arousal when tackling an opponent, but players will make a conscious effort to reduce their level of arousal to kick an accurate 'set shot' at goal.

FIGURE 3.32 Different sports and activities have different optimal levels of arousal.



An optimal level of arousal is essential for individuals to perform at their best. Therefore, it is important for individual players to learn psychological techniques and strategies that help to control arousal. These techniques and strategies either increase or decrease arousal levels as required and can be employed during competition and/or practiced outside of competition.

3.7.6 Techniques to decrease arousal levels

Progressive muscle relaxation

Athletes undergo a series of exercises that lead to progressive muscle relaxation (PMR) and eventually to total body relaxation. This technique is based on the simple premise of tensing (tightening) one muscle group at a time, followed by a release of the tension. Through repetitive practice, athletes quickly learn to recognise and distinguish between the associated feelings of a tensed muscle and a completely relaxed muscle. With this simple knowledge, they can then induce physical muscular relaxation at the first signs of the tension that

accompanies over-arousal and associated anxiety. This physical relaxation can then help to induce a state of mental relaxation and calmness in many situations. Regular use of progressive muscle relaxation has also been linked to improved sleep quality.

on Resources

Weblink Progressive muscle relaxation

Controlled breathing

The technique of controlling and slowing down breathing to release tension and anxiety can be used before or during performance. This technique helps the athlete to focus while they are preparing for the next action.

When an athlete experiences over-arousal, one of the first things that is disrupted is their breathing.

It becomes rapid and shallow, and oxygen supply to the working muscles may be compromised. Rapid and shallow breathing activates our sympathetic nervous system, which is associated with the 'fight or flight' response, heightening alertness and increasing arousal levels.

On the other hand, slow, controlled breathing activates the parasympathetic nervous system, which promotes a state of relaxation and lowers arousal levels. It also gives the athlete a greater level of confidence and enables them to more easily combat negative thoughts.

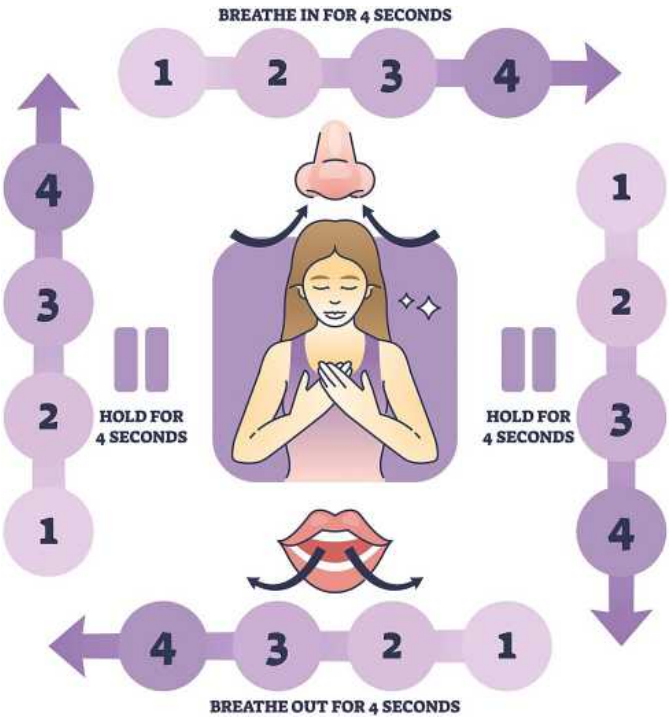
Controlled breathing involves taking smooth, slow and regular breaths. Sitting upright or standing allows the athlete to increase the capacity of their lungs.

A simple example of controlled breathing is 'boxed breathing' (see figure 3.33).

1. **Find a comfortable position**:
   - Sit with your back supported in a comfortable chair and place your feet flat on the floor.
   - Close your eyes if you would like.
2. **Breathe in**:
   - Inhale slowly through your nose for a duration of 4 seconds.
   - Feel the air enter your lungs.
3. **Hold your breath**:
   - Hold your breath for a duration of 4 seconds.
4. **Exhale slowly**:
   - Exhale through your mouth for a duration of 4 seconds.
5. **Wait and repeat**:
   - Wait for 4 seconds before starting the next cycle.
   - Repeat steps 2—4 at least 3 times.

Continue practicing this technique for 4 minutes or until you feel calm and centred.

FIGURE 3.33 Box breathing can lower arousal levels.



Meditation

Meditation is a mindfulness practice in which individuals attain a state of relaxation and calm by focusing the mind on a particular object, thought or activity. Meditation is used to help reduce stress before an event.

The aim of this technique is to calm the mind and relax the body and consequently reduce the level of arousal. Players improve their performance by 'staying in the moment', attempting one challenge at time, and not allowing their mind to race ahead and fixate on future hypothetical problems.

FIGURE 3.34 Meditation helps to reduce arousal levels.



CASE STUDY

Four reasons why every athlete should meditate

By Dr. Kristin Keim (clinical sports/performance psychologist) for the Headspace app.

'Bike racing is always physically hard, but the mental part can be even harder.'

Just the other day an athlete posted this on social media, and they're right. A mind that is not under control is a mind that makes mistakes — mistakes that could prevent you from winning. High levels of stress decrease your ability to maintain focus and concentration. Of course, stress can be a helpful tool when used correctly; but when it's not, it can not only impact your performance, but your life. As a clinical sport psychologist I have worked with a vast array of elite, professional and amateur athletes. Despite their differences in level and/or sport, they all face similar challenges: anxiety, depression, stress, inability to maintain focus, sleep difficulties, life balance, confidence, the list goes on. But so does the game. So when my athletes need to step up but are having trouble finding the mental wherewithal, one of the key techniques I rely on to change their thoughts and behaviours is meditation.

Why should you consider practicing meditation for athletic performance?

1. Stress reduction

Stress reduction is vital for optimal performance. Racing and competing when under stress has been proven to negatively impact athletic performance. A study published in the *Journal of Health Psychology* showed that the results of meditation are associated with reduced stress levels in addition to decreased levels of the stress hormone cortisol. Being relaxed and centred increases the ability to remain calm under pressure and also improves focus and concentration. By consistently practising meditation, your body will learn how to relax in stressful situations, building self-confidence and ultimately achieving a more positive mindset.

2. Improved sleep patterns and speeding recovery time

Sleep is imperative to all human beings, especially athletes. A study published in the *Journal of Sleep* showed that athletes who are not able to get enough sleep will experience a number of negative effects including: weight gain, mood disturbance, increased anxiety/depression, inability to maintain focus/ concentration and decreased motor control. Athletes who consistently practise meditation can help their body to recover quicker from training, racing and even injury. While physical training is good, it also places high levels of stress on the body, including muscle fibre tears. Recovery time from many common sports injuries can actually be reduced. In addition, meditation boosts the immune system, preventing illness that can hinder your training and/or performance. Researchers from the University of Wisconsin School of Medicine and Health found that those who practise

meditation experience fewer acute respiratory infections, as well as a shortened duration and severity of symptoms from the common cold. Therefore, meditation aids in improving the quality/length of sleep and the immune system.

3. Enhanced endurance

This might be one of the most popular reasons to include meditation into your training routine. By practising meditation that utilises visualisations, athletic endurance can be enhanced. Athletes who visualise accomplishing specific objectives/goals, combined with the regular practice of breathing exercises, can train the body to work harder and for a longer period of time in training and competition.

4. Improved sense of identity, self and the body

Meditation in sport can help athletes conquer those common 'blind spots' that tend to make performance challenges seem worse than they actually are. These blind spots negatively impact performance, and meditation helps you recognise your blind spots. By recognising these blind spots, you can work on improving your physical/mental training, skills and coping mechanisms. This serves to build your athletic identity and self-confidence, and improve performance. Furthermore, the meditator learns to enhance awareness of each muscle, which can help pinpoint an injury and prevent further damage. Finally, meditation in sport can greatly improve the mind-body connection, allowing you to discover your optimal zone of performance.

Meditation in sport is not only helpful for performance, but can also aid athletes who experience anxiety, depression and other mental health illnesses. The practice can help athletes through injury, as well as to overcome challenges such as the transition back into sport or out of sport (e.g. retirement).

The practice of meditation is a journey similar to that of any athletic pursuit, and it could offer that small percentage needed to make you a better athlete and a happier human being.

Source: www.headspace.com/

Biofeedback

Athletes can learn to recognise cues that inform them of their readiness for competition. These may be physical indicators such as heart rate and breathing rate, or mental cues such as attention and concentration levels.

FIGURE 3.35 Australian long jumper Brooke Stratton may use biofeedback to enhance her psychological readiness for performance.



Biofeedback is a process for monitoring information about physiological functions (heart rate, heart rate variability, muscle tension, body temperature, blood pressure and respiratory rate) which are controlled by the autonomic nervous system. By monitoring biofeedback, particularly under the stress of competition, athletes and coaches can develop strategies to alter future physiological responses to support optimal performance.

For example, for a long jumper who repeatedly commits a foot fault, the coach will use biofeedback such as heart rate responses to identify the precise moment of heightened anxiety and tension that the athlete feels during the jump sequence (see figure 3.35). The coach will then use this information to help the athlete develop an appropriate psychological strategy to maintain a consistent level of arousal throughout the jump.

Stress inoculation training

Stress inoculation training (SIT) involves an athlete being exposed to increasing levels of stress, building up to levels similar to those experienced during competition or games. This process allows the athlete to gradually develop their ability to cope with the heightened pressure of competition and enhance their overall performance.

This technique helps the athlete to learn to prepare for any stressors, control their responses to the stressors and maintain their focus. It is a way of developing an athlete's immunity to stress.

There are three stages of SIT:

1. the conceptualisation stage: becoming aware of positive and negative thoughts
2. the rehearsal stage: learning to use coping strategies such as positive self-talk and imagery
3. the application stage: practising the coping strategies, initially in low-stress conditions before gradually progressing to high-stress situations.

3.7.7 Techniques to increase arousal levels

Elevated breathing rate

By taking short sharp breaths, an athlete can trigger the central nervous system into an increased state of awareness.

Act energetic

Athletes can increase their physical intensity and 'pump themselves up' to increase their arousal levels. Former Australian tennis great Lleyton Hewitt's famous 'C'mon!' is an example of this (see figure 3.36).

FIGURE 3.36 Leyton Hewitt was known to act energetically to increase his arousal levels.



Positive self-talk

Athletes can increase their arousal levels by repeating positive self-statements/affirmations (e.g. 'I am feeling fit and strong', 'I am ready to go', 'I can do this'). They can also stay focused by using cue words to remind themselves of what they need to concentrate on.

Energising imagery

Athletes may visualise something that is uplifting to help them increase their arousal levels; for example, crossing the finish line in a 100 m sprint or kicking the ball through the goal posts in Australian Rules football.

Use of music

Music is a common tool used by athletes in many sports to control their arousal levels (see figure 3.37). Music has a profound physical and emotional impact; it can make an athlete feel inspired and motivated.

FIGURE 3.37 Lewis Hamilton listens to music before a Formula 1 race to help him channel his concentration.



Pre-competition workout

Athletes raise their arousal levels to desired performance levels before competition through the use of warm-up exercises such as shadow boxing, motivational addresses, music and video footage.

TABLE 3.5 Summary of the techniques to influence arousal levels

Technique	Increase arousal	Decrease arousal	Suitable for in competition	Suitable out of competition
PMR	X	√	X	√
Controlled breathing	X	√	√	√
Meditation	X	√	X	√
Biofeedback	X	√	X	√
Stress inoculation training	X	√	X	√
Elevated breathing rate	√	X	√	X
Act energetic	√	X	√	X
Positive self-talk	√	√	√	√
Energising imagery	√	X	√	√
Music	√	√	√	√
Pre-competition workout	√	√	√	X

Some arousal control techniques can be used during competition while other techniques are better used in training. For example, it would be impractical for an athlete to meditate while competing in a 4 × 100-metre track and field relay. However, the athlete could use, and benefit from, a simple box breathing exercise while waiting for the relay baton.

3.7.8 Concentration

Concentration (or attention) is the mental ability to focus on the task at hand while ignoring distractions. The capacity to 'concentrate' is widely regarded by athletes, coaches and sports psychologists as one of the keys to successful performance in sport. Coaches have long been concerned with how concentration or attention levels among athletes can be improved and maintained, and how distractions can be avoided. Common distractions include anxiety, skill errors and mistakes, fatigue, weather, public announcements, opposition players, 'sledging' and negative thoughts.

concentration (or attention) the ability to focus on the task at hand and ignore distractions

Research on concentration and attention suggests that coaches can assist athletes to improve their level of attention by:

- assessing the attentional strengths and weaknesses of their athletes. Coaches should encourage athletes to think about when and where they displayed good concentration and under what conditions or situations their concentration tends to wander.
- assessing the attentional demands of a given sport. Each sport is different in terms of its attentional needs. The demand for attention varies from sport to sport and even from skill to skill. For example, sustained attention is required for distance running and tennis, short bursts of attention are required for cricket and athletic field events, and intense attention is required for sprinting events and skiing.

FIGURE 3.38 The capacity to concentrate is key to successful performance.



3.7.9 Techniques to improve concentration and attention

A variety of techniques have been formulated to help improve concentration and attention. These techniques should be implemented after considering the athlete's attentional strengths and weaknesses, in addition to the sport-specific attentional demands.

FIGURE 3.39 Former AFL player Matthew Lloyd was a highly successful full-forward. He was famous for a pre-shot routine in which he would throw a tuft of grass in the air to assess the breeze. He did this even when playing indoors.



Centred or controlled breathing

Relating closely to optimal arousal levels, centred breathing allows the athlete to calm their mind, minimise distraction and concentrate on relevant cues and information.

Mental imagery and rehearsal (visualisation)

Imagining the competitive environment and visualising skill execution helps an athlete to maintain focus and attend to 'what matters', ultimately leading to enhanced performance.

Positive self-talk and cue words

Positive self-talk and cue words help the athlete to keep a positive frame of mind and enhance their concentration by keeping the focus simple. Examples include using the cue words 'relaxed hands' before making a golf swing, or 'kick through the ball' when taking a set shot for goal in AFL. Using cue words helps to prevent information overload, reduces the psychological pressure on the athlete and directs their focus to an important aspect of skill execution.

FIGURE 3.40 Min Woo Lee visualising his putt as part of his pre-shot routine.



Using a clear pre-performance routine

A consistent pre-performance routine cues the athlete into a heightened state of concentration and helps them to focus on the most important aspects of skill performance. Examples of pre-performance or pre-shot routines include tennis champion, Rafael Nadal bouncing the ball and adjusting his shorts before he serves; NBA basketballer, A'ja Wilson bouncing the ball three times before taking her free throw; or pro-golfer Min Woo Lee standing behind his putt and visualising the ball roll.

TABLE 3.6 Strategies that can be used to improve psychological characteristics.

Psychological characteristics	Definition	Concepts	Strategies
Confidence	To believe in one's ability to execute a task/goal successfully	• Resilience • Enthusiasm/motivation • Optimism • Positivity • Self-belief	• Application to practice • Positive self-talk • Visualisation • Goal setting • Establishing a supportive environment

Motivation	The causes of the initiation, maintenance and intensity of behaviour	• A desire for success • Intrinsic motivation • Extrinsic motivation	• Goal setting • SMARTER Goals • Outcome goals • Process goals • Performance goals
Arousal	The readiness an individual experiences when faced with a sporting situation or task	• Inverted-U hypothesis • Optimal arousal theory	To reduce arousal: • Progressive muscle relaxation • Controlled breathing • Meditation • Biofeedback • Stress inoculation training To increase arousal: • Elevates breathing • Act energetic • Positive self-talk • Energising imagery • Pump Up music • Pre-competition workout
Concentration	The ability to focus on the task at hand and ignore distractions	• Attention • Distractions	• Controlled breathing • Mental imagery • Visualisation • Cue words • Positive self-talk • Pre-performance routines

on Resources

Digital document Sport Competition Anxiety Test (SCAT) (doc-2913)

doc-41948

PRACTICAL ACTIVITY Arousal levels

Goal

To determine the effect of increasing or decreasing arousal levels.

Instructions

Participate in a team sport such as basketball or netball. Prior to the beginning of the game, use one of the following techniques to increase or decrease your arousal levels:

- progressive muscle relaxation
- meditation
- warm-up exercises
- pre-competition 'psyche up'.

At halftime, try a different technique before resuming the game.

Primary data/Reflection

- Did you notice any differences in your focus, concentration or overall performance during the second half of the game after using a different technique during halftime?
- Considering the outcome of the game, do you think the change in arousal techniques at halftime contributed to the team's success? Why or why not?
- Reflecting on your personal performance statistics, do you believe your performance was positively influenced by the arousal techniques used before the game and at halftime? How?

Questions

1. What techniques did you practise?
2. What effect did each of the techniques have on your performance?
3. Were these techniques appropriate for the sport you participated in? Explain.
4. Suggest a technique that you might implement to change your arousal levels. It should not be one of the techniques used in this practical. Explain the circumstances in which your chosen technique might improve your performance, and how.

3.7 Activity

3.7 Quick quiz on | **3.7 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3, 4, 7, 9	5, 6	1, 2, 8, 10, 11

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TEST your understanding

1. **Explain** what the acronym SMARTER stands for and how this supports the learner's skill performance.
2. a. **Explain** the inverted-U hypothesis. Include a diagram.
   b. **List** three strategies that an athlete could use to increase their arousal level.
   c. **List** three strategies that an athlete could use to reduce their arousal level.
3. **Outline** the process of mental imagery/visualisation.
4. **List** common distractions that can affect an athlete's ability to concentrate.
5. **Suggest** ways that coaches can assist athletes to improve their level of concentration.

APPLY your understanding

6. **Discuss**, in detail, two of the techniques that can be used to control performance anxiety and arousal.
7. **Identify** the techniques that involve the use of mental imagery and provide detailed examples of each technique.
8. Pre-performance routines have been identified as a strategy to assist an athlete's concentration. Choose three sports and **propose** a pre-performance routine that might be used in each of those sports.
9. Access **Sport Competition Anxiety Test (SCAT)** in the digital documents section of the Resources panel and complete the test. Then, answer the following.
   a. What was your level of anxiety?
   b. **Suggest** reasons for your score.
10. A basketball coach is worried that one her players lacks confidence when shooting from the free-throw line. **Explain** one strategy that may enhance the players confidence at the free-throw line and improve their shooting accuracy.
11. An AFL coach motivates his team by telling them to have fun and to 'play for one another'. **Explain** the type of motivation the coach is trying to instil in his players and discuss the potential benefit of this motivation.

3.7 Exam questions

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.1;* © VCAA

In preparation for the 2020 Tokyo Olympic Games, BMX freestyle cyclist Logan Martin recreated the course that he would compete on in his backyard.

Which one of the following psychological strategies was Martin using by practising on this recreated course?

A. simulation
B. mental imagery
C. biofeedback
D. goal setting

Question 2 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.15;* © VCAA

In aerial skiing, the athlete skis down a relatively short hill and off a jump, and then they perform a variety of twists and flips in the air before landing.



Which one of the following psychological strategies could an aerial skier use seconds before their jump in order to regulate feelings of stress and anxiety?

A. biofeedback
B. pump-up music
C. mental imagery
D. jumping around

Question 3 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.10;* © VCAA

In a women's gymnastics floor event, the gymnasts take part in movements that are performed on a square floor space.

Throughout the 90-second routine, the gymnasts are expected to make fast tumbling passes across the floor, often up to five in a routine, combined with several combinations of skills in succession, such as a sprint, leap, twist, somersault, flip and handstand, that require explosive energy. The gymnasts then rest for no more than a few seconds before repeating another high-intensity combination of moves lasting from three seconds to 20 seconds. This continues for the entire 90 seconds of the routine.

Inca is a gymnast waiting to compete in the floor routine. A strategy Inca uses while waiting is controlled breathing.

Describe how this strategy could help enhance Inca's performance.

Question 4 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.4;* © VCAA

At the start of a 100 m sprint race, an athlete starts to have feelings of anxiety, including sweaty palms and butterflies in their stomach.

Select the most appropriate psychological strategy that this athlete can use to enhance their performance in this race.

A. meditation
B. controlled breathing
C. stress inoculation training
D. listening to calming music

Question 5 (2 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.5;* © VCAA

At the start of their run-up, a long jumper performs mental imagery.

Describe how to complete mental imagery and how it could improve the long jumper's performance.

More exam questions are available in your learnON title.

3.8 Key skills

Key skill

- 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: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

3.8.1 Tell me

To address this key skill, it is important to remember:

- practice can be designed and organised in many different ways: massed, distributed, blocked or random
- different types of practice suit different types of skills; for example, complex or highly fatiguing skills are best suited to distributed practice
- a coach/teacher should decide on the type and frequency of feedback to provide based on the movement skill's classification and the participant's stage of learning
- appropriate practice and feedback facilitate effective movement skill learning
- to optimise performance, a coach should look to develop the athletes' psychological skills, such as concentration, motivation, arousal level control and confidence
- just as important as time spent on physical skills, time spent (in practice and in competition) on psychological techniques that develop key psychological skills can significantly enhance movement skill performance.

3.8.2 Show me

Practice question (8 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Andrei plays a high standard of club tennis. Andrei is a gifted tennis player, but he is having a poor season; he is struggling to live up to the promise he displays in practice.



a. **Outline** whether tennis should be classified as a *closed sport* or an *open sport*. (2 marks)

b. In the interests of improving the applicable skills in the sport of tennis, and in the interests of improving Andrei's match-day performance, **explain** the ideal level of practice variability. (4 marks)

c. Andrei often suffers from match-day nerves and his heightened anxiety disrupts his 'natural game'. **Outline** an in-competition psychological strategy that would help to reduce Andrei's level of arousal. (2 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Outline — general description but not in detail
  Explain — make the relationship between things evident
- **Key terminology** — *closed sport*, *open sport*
- **Key concepts** — practice variability, psychological strategy, level of arousal
- **Marking scheme** — 8 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question

Sample response and marking scheme

a. Tennis is a predominantly *open sport*. Skills are externally paced, that is, the type of skills performed by a tennis player and the condition in which the skills are performed, are influenced by their opponent.
Award 1 mark for identifying tennis is an open sport.
Award 1 mark for explaining the externally paced and unpredictable environment.

b. Andrei would benefit from a high level of practice variability. Practice variability should accurately reflect the constantly changing environment of an *open sport* such as tennis. In a tennis match for example, many different types of skills are performed in varying conditions and in random order. As such, random practice, a type of practice with a high level of practice variability, would help Andrei to improve his gameday performance.
Award 1 mark for identifying high practice variability.
Award 1 mark for explaining that practice variability should accurately reflect the degree to which the sport is unpredictable.

Award 1 mark for identifying random practice is most appropriate because of its high practice variability.
Award 1 mark for identifying the practice environment should accurately reflects the demands of a tennis match to help improve his match-day performance through concentrating on relevant performance cues and by reducing muscle tension which in turn improves coordination.

c. Andrei could employ controlled breathing. By consciously slowing down his breathing, Andrei releases tension, lowers his *arousal* to an *optimal level* and, as a consequence, improves his gameday performance.
Other strategies include positive self-talk and visualisation.
Award 1 mark for identifying a psychological strategy, such as controlled breathing.
Award 1 mark for explaining how the psychological strategy lowers arousal to an optimal level.

3.8.3 Let me do it

Question 1 (6 marks)

Anastasia is a 12-year-old, aspiring national gymnast who specialises in the uneven bars. To master the uneven bars, Anastasia needs to learn a series of highly complex and physically demanding skills.



a. **Outline** whether an uneven bar routine is an example of a discrete, serial or continuous skill. **(1 mark)**

b. Considering the classification of movement skills performed on the uneven bars as well as the individual constraints of Anastasia, **explain** the most effective practice distribution. **(3 marks)**

c. Anastasia is a talented gymnast; however, she often lacks confidence when attempting new skills.
Outline a psychological strategy that can improve Anastasia's confidence and help facilitate movement skill learning. **(2 marks)**

3.9 Review

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3.9.1 Summary

Types of practice

- The most suitable practice depends on the movement skill and on the learners stage of learning.
- Part practice is breaking a skill into smaller skill components. The smaller skill components are practiced in isolation before attempting the skill as a whole.
- Part practice is applicable when the skill is complex and/or the learner is novice.
- Whole practice is practicing the whole skill.
- Whole practice is suitable when the learner is proficient, more accurately reflects task representation and helps to develop specific timing and coordination.

Practice distribution

- Massed practice schedules involve fewer practice sessions of longer duration.
- A massed practice schedule is often more practical for the time-poor amateur sportsperson or sports club.
- Massed practice sessions involved more time spent actively practicing and less time spent resting.
- Massed practice sessions can be mentally and physically challenging and, as such, are well suited for elite-level athletes.
- Distributed practice schedules involve more frequent sessions of shorter duration.
- In distributed practice sessions, there is either more rest time than work time or at least equal parts work and rest.
- Distributed practice suits beginners who tire quickly and struggle to maintain concentration.
- Distributed practice is very effective for learning new movement skills, especially complex and physically demanding movement skills.

Practice variability

- Practice variability refers to the extent to which a variety of skills are practiced, and the degree to which the same skill is practiced in different ways and under different conditions.
- Practice variability develops versatile, game-applicable movement skills and improves decision-making.
- Random practice involves a high degree of practice variability. Random practice is well suited to the experienced performer and is particularly applicable to open sports.
- Blocked practice has very low levels of practice variability. Blocked practice involves working on the same skill, in the same practice conditions, in a stable and predictable environment for an extended period of time. The novice learner benefits from blocked practice.
- Low practice variability is generally the most efficient way for a novice performer to learn a new skill; that is, the performer can learn the basic mechanics of the skill with very few distractions.
- As a general rule, when organising training sessions, there should be low levels of practice variability for participants in the early stages of learning, and high levels of practice variability for participants in the later stages of learning.
- Practice variability should reflect the physical and cognitive demands of competition.

Types of feedback

- The role of feedback is to motivate the learner, correct skill errors and reinforce successful performance.
- Different types of feedback suit different types of tasks and different stages of learning.

- Intrinsic feedback is information the performer receives from their sensory systems; for example, how it feels to the batsman when the cricket ball strikes the middle (sweet spot) of the bat.
- Augmented feedback is feedback received from an external source; for example, a coach yelling instructions from the sideline.
- Knowledge of results is feedback relating to the outcome of a skill performance; for example, in AFL, whether the football went through for the goal posts.
- Knowledge of performance is feedback relating to how a skill is performed; for example, a gymnastics coach providing feedback to the gymnast about the parts of their technique they are doing well and what parts that can be improved.
- Qualitative feedback is a general form of feedback regarding skill performance and/or a form of encouragement; for example, a tennis coach compliments a player for 'reaching high' during the service action.
- Quantitative feedback is a precise form of performance feedback involving numerical values; for example, a tennis coach informs their player 'your arm was 10 degrees off vertical at the top of the service arc'.
- Qualitative feedback suits the novice, whereas quantitative feedback suits the experienced athlete.

Feedback frequency

- Frequency of feedback refers to how often a coach gives feedback.
- As a general rule, a novice performer will require more frequent feedback than an experienced performer.
- An elite performer requires less frequent, but more precise, feedback.
- A coach must be careful not to overload the novice performer with information.
- If feedback is consistently too frequent, there is a risk the athlete will become overly dependent on the coach to facilitate successful performance.
- The goal of the coach should be to develop autonomy in their learners, including their ability to use their own intrinsic feedback to enhance their performance, particularly during competition.
- Summary feedback enables the coach to address the underlying causes of skill error and allows the learner to rehearse a number of skill attempts before having to process further performance feedback.

Psychological skills for enhanced performance

- Sports psychologists focus on techniques and strategies that athletes can use in competitive and training situations to optimise their performance.
- An athlete needs to be at an optimal level of arousal to perform at their best.
- The inverted-U hypothesis describes three broad states:
  - under-arousal — where performance is lackluster
  - over-arousal — where performance is hindered by anxiety
  - optimal arousal — where the athlete performs at their best
- The optimal arousal theory explains that the optimal arousal level for a performance depends on the type of skill and the personality of the performer.
- Techniques to decrease arousal levels include PMR, controlled breathing, meditation, biofeedback and stress inoculation training.
- Techniques to increase arousal levels include rapid breathing, acting energetically, positive self-talk, energising imagery, listening to music and pre-competition workouts.
- Concentration involves focusing on the task at hand and can be improved via techniques such as mental imagery and rehearsal, positive self-talk, cue words and using pre-performance routines.
- Confidence is an essential ingredient in movement skill performance. An athlete can develop confidence by practicing hard, using positive self-talk, visualising successful performance, setting smaller achievable goals and being in a supportive environment.
- Motivation drives an athlete to achieve their performance goals. SMARTER goals help to motivate athletes.
- The most sustainable and effective form of motivation is intrinsic motivation. This comes from within, and is fuelled by improvement, enjoyment, sense of self-worth and 'a love of the game'.

3.9.2 Key terms

arousal the readiness an individual experiences when faced with a sporting situation or task
augmented feedback information about a skill performance that comes from an external source
blocked practice a type of practice in which each skill component is practised repetitively as an independent block
choking when an athlete fails to perform effectively under pressure conditions
concentration (or attention) the ability to focus on the task at hand and ignore distractions
distributed practice a form of practice in which smaller practice time intervals are interspersed with rest periods. This applies equally to both the practice schedule and the individual practice session.
feedback information concerning the performance and/or outcome of a movement skill, including information about errors and how to correct them
feedback frequency how often an external source (e.g. coach) provides feedback to the skill learner
goal setting making plans to work towards achieving specific and beneficial objectives and results
intrinsic feedback sensory information the learner receives directly from skill execution
knowledge of performance feedback regarding how a skill is performed; assessing performance on the basis of process and skill technique
knowledge of results information about the outcome of skill performance; information regarding the relative success or failure in regard to the intended goal of the movement skill
massed practice a form of practice in which there is little or no rest between repeat performances of a skill
motivation a reason for participating in an activity; a reason for practising.
part practice learning smaller parts of a skill in isolation
practice distribution the ratio between time spent actively practising and time spent resting
random practice a form of practice that involves rehearsing a number of different skills in an unpredictable sequence
self-confidence what an individual has when they believe that they can successfully perform a task and achieve their goal
variability the amount of change and uncertainty in an environment or in the performance of a skill
whole practice learning all of the skill

3.9 Exam questions

3.9 Section A — Multiple choice questions

Question 1 (1 mark)

When Ekon gets to soccer training, he feels unmotivated, drowsy and apathetic. Which of the following psychological techniques would assist Ekon to increase his level of arousal and improve his performance at training?

A. Meditation
B. Elevated breathing rate
C. Progressive muscle relaxation
D. Centred breathing

Question 2 (1 mark)

Random practice is best described as:

A. predictable and repetitive.
B. highly varied practice involving numerous skills.
C. working on one skill in several different ways.
D. practice that suits less-fatiguing skills.

Question 3 (1 mark)

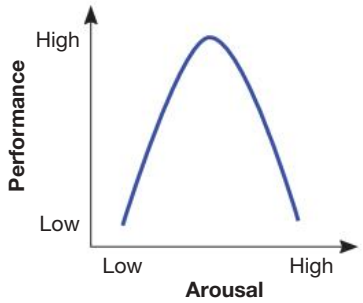
A soccer player watches his penalty kick sail past the keeper and into the back of the goal net. This is an example of which type of feedback?

A. Intrinsic feedback, knowledge of results
B. Augmented feedback, knowledge of results
C. Intrinsic feedback, knowledge of performance
D. Concurrent feedback

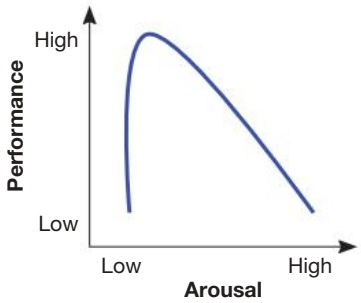
Question 4 (1 mark)

An archer competing at the Olympics in the gold-medal round would require which of the following arousal levels for the best chance of success?

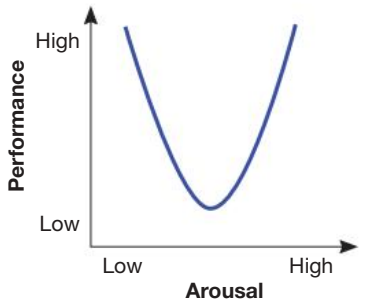
A.



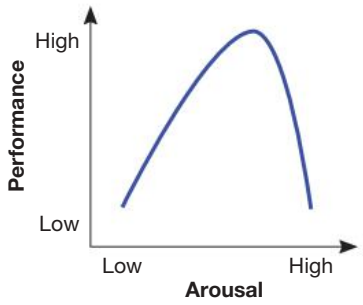
B.



C.



D.



Question 5 (1 mark)

Blocked practice can assist:

A. in the development of game sense.
B. a novice performer to become familiar with the basic mechanics of a new skill.
C. in adding a high degree of practice variability.
D. in the simultaneous development of many skills.

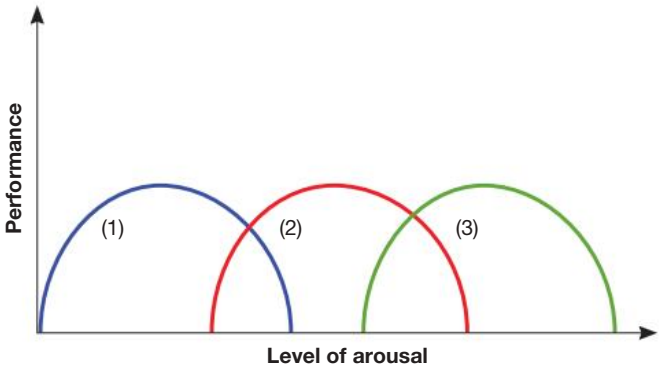
Question 6 (1 mark)

Chloe, an AFLW coach, decided she needs to introduce more practice variability into her team's training sessions. She does this by introducing more short-sided, modified games and by reducing the number of line drills.

As a consequence of the changes in training, Chloe's players are likely to:

A. perform worse in training but transfer what they have learned to matchday more effectively.
B. perform worse in training and lose motivation to practice.
C. perform better in training but struggle to transfer what they have learned to matchday.
D. perform better in training and better on matchday.

Question 7 (1 mark)



The above graph represents the performance arousal curve for three different sports.

Arousal curves 1, 2 and 3 are best represented by:

A. (1) Boxing, (2) Basketball, (3) Archery
B. (1) Basketball, (2) Archery, (3) Boxing
C. (1) Archery, (2) Basketball, (3) Boxing
D. (1) Netball, (2) Basketball, (3) Soccer

Question 8 (1 mark)

When coaching hockey players to improve their penalty strokes, the coach should:

A. vary the practice conditions.
B. organise blocked practice to replicate effective technique.
C. ensure the physical and cognitive demands of practice are similar to those in a match.
D. make the players practice without a goalie.

Question 9 (1 mark)

Agnese is a 12-year-old Little Athletics participant learning to high jump. Agnese is learning the Fosbury Flop technique, which involves a run up, leaping off one foot, twisting her body to travel over the bar shoulders first, and landing safely on her back on the crash mat. Successfully performing the Fosbury Flop technique requires a large amount of muscular power.

What is the most appropriate practice distribution?

A. Distributed
B. Blocked
C. Massed
D. Random

Question 10 (1 mark)

Given Agnese is in the early stages of learning and given the demands of high jump, what is the most suitable type of practice?

A. Coach-centred practice
B. Part practice
C. Whole practice
D. Blocked practice

3.9 Section B — Short answer questions

Question 1 (5 marks)

Source: Adapted from *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.1;* © ACHPER

The image below illustrates a basketball player practicing set shots over a 30-minute period.



a. **Identify** the type of practice most likely being used in this picture. **(1 mark)**

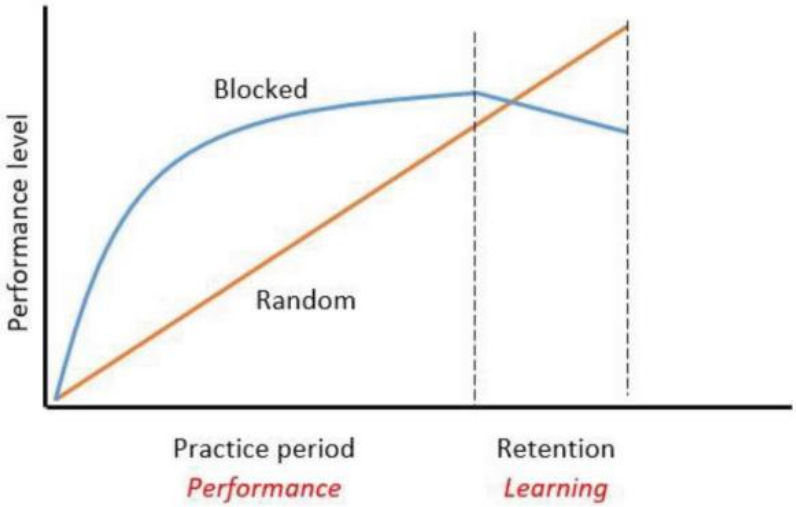
b. **Outline** two disadvantages of this practice. **(2 marks)**

c. **Name** and **describe** a different method of practice that would reduce the disadvantages that you identified in your answer to **part b**. **(2 marks)**

Question 2 (7 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.3.a,b,c;* © ACHPER

Comparison of blocked and random practice modalities



Source: Adapted from D Farrow & W Maschette, 'The effects of contextual interference on children learning forehand tennis groundstrokes', *Journal of Human Movement Studies*, vol. 33, pp. 47–67, 1997

The above diagram compares the results of two different practice modalities: blocked practice and random practice.

a. **Explain** blocked practice using a sporting example. **(2 marks)**

b. **Explain** random practice using a sporting example. **(2 marks)**

c. Using the above graph, **evaluate** the longer-term effectiveness of random practice. **(3 marks)**

Question 3 (4 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.4.c;* © ACHPER

At the Commonwealth Games on the Gold Coast in 2018, long jump competitors and their coaches used tablet computers during the competition to record and view their jumps following each attempt.

i. **Name** the type of feedback being provided to the athlete. **(1 mark)**

ii. With reference to the stages of learning, **evaluate** the relative effectiveness of this type of feedback for athletes in the Commonwealth Games compared to a 10-year-old girl at her school athletics carnival. **(3 marks)**

Question 4 (5 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.8*; © VCAA

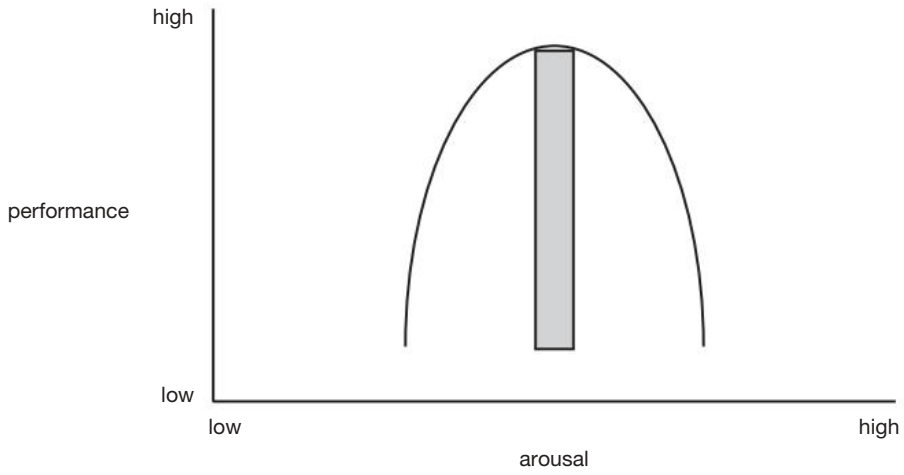
Alex is a 20-year-old athlete at state level who has been playing tennis for 10 years. Prior to the start of the new tennis season, his coach has presented him with data that was collected from Alex's last match of the previous season.

Data from Alex's last match

Measurements	Total
total number of forehands	85
total number of backhands	56
first serves in	40%
first serves won	60%
second serves in	50%
second serves won	42%
average speed of first serve	130 km/h
total metres covered in a match	1200 m
total time of match	125 minutes
total time spent above 70% HR max.	60 minutes
time spent above 85% HR max.	20 minutes
time spent above 95% HR max.	5 minutes

The diagram below, known as the inverted-U model, shows the relationship between arousal and performance with the zone of optimal performance shown by the shaded rectangle.

Relationship between arousal and performance



a. As tennis players walk onto the court, they regularly listen to pump-up music in their earphones in order to regulate their arousal levels. On some days, Alex listens to pump-up music before a match, but on other days he prefers not to because it may have a negative effect on his performance.
On the diagram above:
- label with an 'X' when Alex may feel that he needs to use pump-up music
- label with a 'Y' when Alex may feel that he does not need to use pump-up music. **(2 marks)**

b. During matches, Alex has to return tennis serves that are as fast as 200 km/h, and he must therefore be able to concentrate effectively on the ball as it leaves the opponent's racquet.
Identify one psychological strategy that Alex may use to improve concentration and **describe** how this strategy could improve Alex's ability to concentrate and return serves successfully. **(3 marks)**

Question 5 (6 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.1;* © VCAA

During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200 m and 400 m freestyle swimming events.

a. i. **Identify** the stage of learning Titmus was in at the 2020 Tokyo Olympic Games. **(1 mark)**

ii. **List** two characteristics of the stage of learning identified in **part a.i.** **(2 marks)**

b. **Explain** why the frequency and use of intrinsic and augmented feedback should have changed as Titmus progressed through the stages of learning. **(3 marks)**

Continue to build your exam skills

Access the Unit 3 Area Study 1 Review at the end of Topic 4. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

4 Biomechanical principles

4.1 Overview

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LEARNING SEQUENCE

4.1 Overview
4.2 Linear and angular concepts of human movement
4.3 Newton's laws of motion
4.4 Levers
4.5 Projectile motion
4.6 Equilibrium and stability
4.7 Qualitative analysis of movement skills
4.8 Key skills
4.9 Review

4.1.1 Introduction

Biomechanics is the science that studies the movement of living things. In the field of sports science, biomechanics applies the laws of mechanics to analyse human performance. The goal is to gain a greater understanding of why the human body moves the way it does, how we can optimise human movement to produce optimal sporting performance and what differentiates elite performers from the rest. Biomechanics can also be used to produce hi-tech sports equipment, such as aerodynamic swimsuits and bike helmets, and it informs injury rehabilitation techniques.

In this topic, the main focus is on how biomechanics has informed sports techniques and movement skills, leading to improved peak performance. A prime example lies within the sport of high jump, where athletes employ various techniques, such as the Fosbury Flop and the Straddle method, to achieve optimal height clearance. Through biomechanical analysis, the intricacies of these techniques can be unravelled, exploring how factors like force application and body positioning influence athletic prowess in high jump and beyond.

FIGURE 4.1 Understanding the principles of human motion has allowed new sporting techniques to be developed. Before the Fosbury flop, the straddle technique was used to clear the bar in high jump.



4.1.2 Key knowledge and Key skills

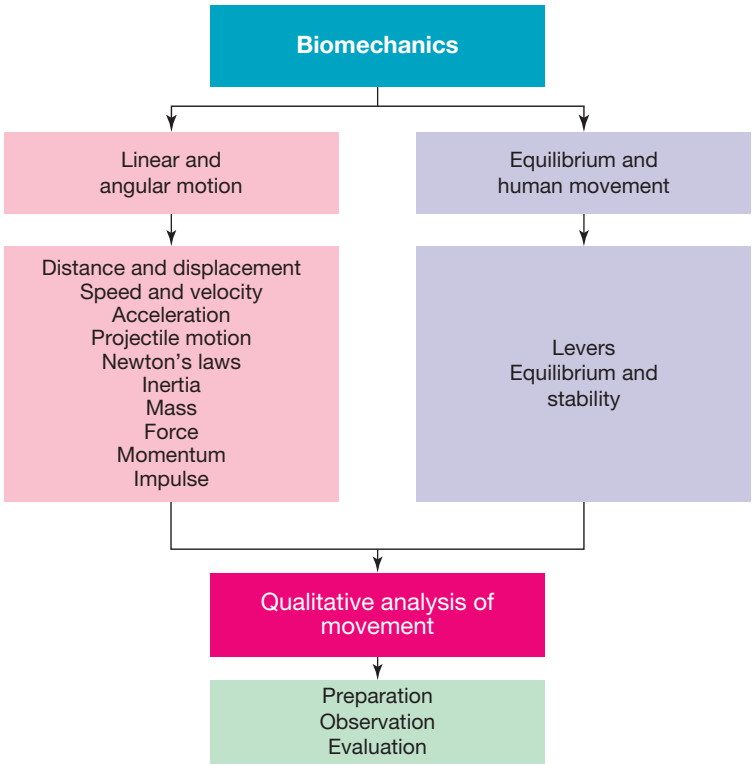
Key knowledge	Key skills	Subtopic
• biomechanical principles for analysis of human movement: – linear and angular concepts of human movement including torque/ force, momentum, impulse, speed/velocity	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills	**4.2**
– Newton's three laws of linear motion: inertia, acceleration and action-reaction		**4.3**
– projectile motion (height, angle and speed of release)		**4.5**
– 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)		**4.4** **4.6**
• qualitative movement analysis stages (preparation, observation, evaluation and error correction)	• perform a qualitative movement analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills	**4.7**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

on Resources

Weblink An athlete uses physics to shatter world records — Asaf Bar-Yosef

4.1.3 Topic preview



4.2 Linear and angular concepts of human movement

Key knowledge	Key skill
• biomechanical principles for analysis of human movement: – linear and angular concepts of human movement including torque/ force, momentum, impulse, speed/velocity	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

4.2.1 Types of motion

motion the change in position of a body in relation to time
linear motion occurs either in a straight line or curved path
angular motion takes place when a body moves along a circular path
general motion the combination of linear and angular motion

The term **motion** refers to a body's change in position in relation to time. Motion can be linear or angular (or a combination of these in the case of general motion), and relates to both living (animate) and non-living (inanimate) bodies. Humans and animals are examples of animate bodies, while a baseball is an example of an inanimate body.

Linear motion, also commonly referred to as translation, takes place either in a straight line or curved path. Movement in a straight line is referred to as rectilinear motion, where all parts of a body travel the same distance, in the same direction, at the same time (e.g. a young child sledding down a mountain on a toboggan). Movement over a curved path is referred to as curvilinear motion (e.g. the path of a ball thrown through the air until gravity forces it to the ground).

Angular motion, also commonly referred to as rotation, occurs when a body moves along a circular path at the same angle, in the same direction, at the same time. Angular motion occurs around some type of axis, which can be either external or internal. An example of an external axis in sport is a gymnast rotating around a high bar, while an internal axis would be a joint in the body around which a body part rotates (see figure 4.2).

In sport, true linear motion is rarer than angular motion, as movement is typically generated by the angular motion of body parts or equipment. Far more common is the combination of the two types of motion, referred to as general motion. An example of **general motion** is the running in a straight line seen in a 100-metre sprint caused by the angular rotation of the arms and legs (see figure 4.3)

FIGURE 4.2 The bowler is rotating their arm around an internal axis (shoulder).



FIGURE 4.3 The angular motion of a runner's arms and legs promotes general motion.



4.2.2 Understanding angular and linear concepts of human movement

There are a range of angular and linear concepts of human movement. In this topic, we begin with linear motion and then consider angular motion. The key concepts to be covered include:

- mass
- inertia and moment of inertia
- force and torque
- speed, velocity, acceleration and angular speed, velocity and acceleration
- momentum and angular momentum
- impulse.

4.2.3 Mass

The term **mass** is used to describe the quantity of matter found within a particular body. Mass is typically measured in kilograms. A person with a large mass is composed of large quantities of matter, while a person with a small mass is composed of a small quantity of matter. There is a direct relationship between the amount of mass an object has and its weight. While the terms 'weight' and 'mass' are commonly used interchangeably, they are in fact two different quantities. Weight refers to the force that a body exerts on the ground and is found by multiplying mass and the acceleration of gravity.

mass the quantity of matter found within a particular body

inertia the resistance of a body to a change in its state of motion

force the product of mass and acceleration

4.2.4 Inertia

Inertia describes the reluctance of a body to change its state of motion; it is closely linked to an object's mass. A body at rest may be reluctant to move, and a body that is moving may be reluctant to stop. An object with a small mass is able to change its state of motion more easily than an object with a large mass can (see figure 4.4).

A ball with a small mass has less inertia and is easier to throw than a ball with a large mass and large inertia. Similarly, once moving, the ball with large mass and inertia will be much more difficult to catch or stop than the ball with small mass and small inertia. Think of the challenges if you were asked to both throw and catch a medicine ball instead of a tennis ball.

FIGURE 4.4 Sumo wrestlers aim to overcome the inertia of their opponent's large mass.



CONCEPT CONNECTOR

Bring in a variety of objects of different sizes and masses. Line them up in a row and have students provide a gentle push to get them moving. Compare how far they move. Next, set up an inclined plane and let the objects roll down the incline. Observe how their mass influences their speed and motion. You can also place an object at the base of the incline to observe what happens to the rolling object. Think of sports in which inertia is important.

4.2.5 Force

Force is defined as a push or a pull. Its formula is:

$$F = ma \text{ (Force = mass} \times \text{acceleration)}$$

The unit of force is called the Newton (N), after Sir Isaac Newton. One Newton (1 N) is the amount of force required to cause a 1 kilogram mass to accelerate at 1 metre per second squared (1 m/s^2). To change the state

of a body (move it), a force must be applied to it that causes it to accelerate (speed up), decelerate (slow down) and/or change direction. For example, in rowing, the rower will apply a force to the oar that causes the boat to accelerate (speed up). There is an advantage in rowing if the boat has a small mass (weighs less), as a lighter boat will accelerate faster when the rower applies the same force. We will discuss this further when we explore Newton's Laws in section 4.3.

Although forces have the capacity to alter motion, they need to be sufficient to overcome the inertia of a body. For example, a heavy barbell on the floor in a weightlifting competition will only be lifted if sufficient force is created to overcome its inertia (see figure 4.5).

Forces can be defined in relation to the body, as internal (interactions inside) or external (interactions outside). There are different types of internal and external forces that act on bodies. In sport, the force generated by the contraction of the skeletal muscles is generally classified as an internal force. External forces include gravity, air resistance and friction (see figure 4.6).

FIGURE 4.5 Force is used to overcome the inertia of the heavy barbell, so that it can be lifted from the ground to overhead.

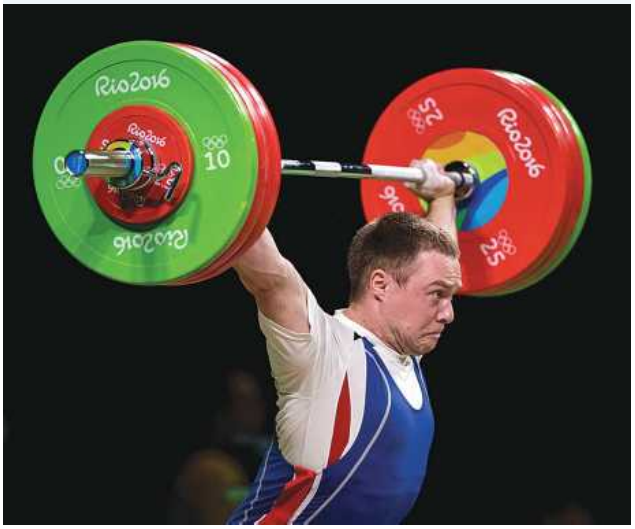
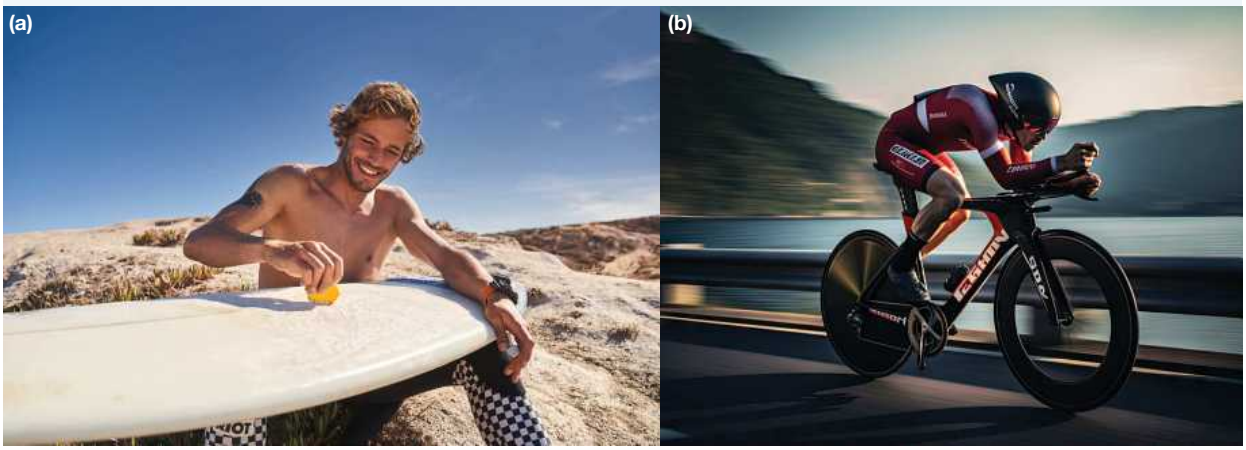


FIGURE 4.6 (a) The surfer tries to increase friction by using wax on their surfboard to avoid falling off. **(b)** The cyclist wears an aerodynamic suit and helmet to reduce the dragging effect of air resistance.



4.2.6 Velocity and acceleration

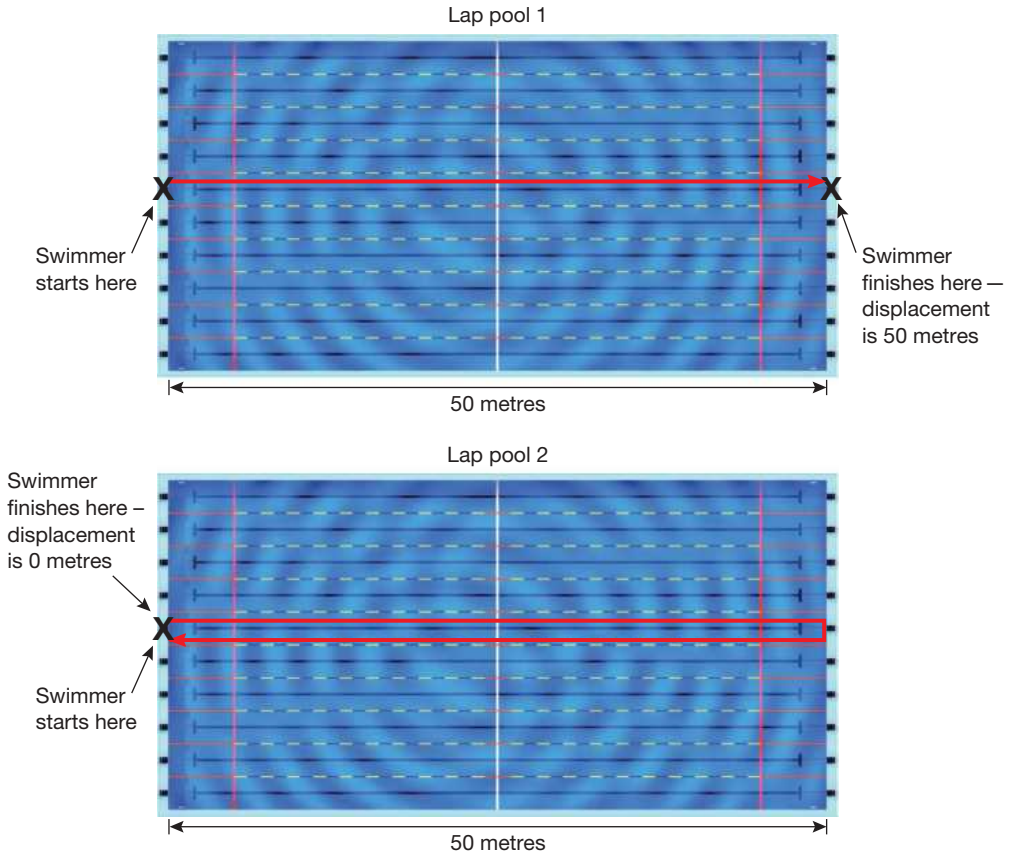
Speed, velocity and acceleration are common terms used to describe motion. In order to understand these differences, we must understand the difference between **distance** and **displacement**.

distance the length of space between two points

displacement the difference between the initial position and final position of an object

Distance refers to how much ground an object covers throughout its motion, while displacement refers to an object's overall change of position from one point in time to another. To understand the difference between distance and displacement, consider the following swimming events: a 50-metre swim, where a swimmer starts at one end of the pool and finishes at the other end, and a 100-metre swim, where a swimmer starts at one end of the pool, swims to the other end, turns around and swims back to the starting position (see figure 4.7).

FIGURE 4.7 In this example, the displacement of the swimmer in lap pool 1 is 50 metres (distance between starting and finishing points), while the displacement of the swimmer in lap pool 2 is 0 metres (distance between starting and finishing points).



In the first example, the swimmer has swum a distance of 50 meters, and their displacement is also 50 metres because they have finished the race 50 metres from the starting line (see table 4.1).

TABLE 4.1 The difference between total distance and total displacement

Event	Description	Total distance travelled	Total displacement
50-metre swim	Swim from one end of a 50-metre pool to the other	50 metres	50 metres
100-metre swim	Swim from one end of a 50-metre pool to the other, turn around and swim 50 metres back to starting position	100 metres	0 metres

In the second example, the swimmer has covered a distance of 100 meters, but their displacement is 0 meters because they have finished in the exact same place that they started. There has been no change in position from one point in time (start) to another (finish).

Another example of this is seen in a marathon. In the case of the Melbourne Marathon, the start of the race is outside the Melbourne Cricket Ground (MCG) and the finish line is inside the stadium on the hallowed turf in front of the members' stand. The distance from the start and finish line may be no more than 400 metres, but to get to that finish line the runners are sent on a 42.195-kilometre course through Melbourne. The marathoners run a total distance of 42.195 kilometres, but their displacement is just 400 metres.

Would distance or displacement be more valuable to sports scientists, coaches and players?

on Resources

Weblink Melbourne Marathon course map

4.2.7 Linear speed and velocity

Similar to distance and displacement, **speed** and **velocity** are common terms used interchangeably to describe the rate with which an object moves from one location to another, but they are in fact not the same.

speed the rate of motion (distance/time)
velocity the rate of the speed at which an object moves its position

The average speed of a body refers to the distance covered divided by the time taken. The formula for this is represented by:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$s = \frac{l}{t}$$

s = speed (metres/second)

l = length of path (distance) (metres)

t = time (seconds)

Velocity measures the displacement an object experiences over time and should always include a direction (e.g. positive, negative, south, north). The formula for this is represented by:

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

$$v = \frac{d}{t}$$

v = velocity (metres/second)

d = displacement

t = time (seconds)

An example of the difference between velocity and speed can be seen in table 4.2 where a swimmer completes two laps of a 50-metre pool. The swimmer travels at a speed of 2 m/s during the first lap, then turns and continues to swim at a speed of 2 m/s for the return lap. Their average speed has not changed, but their average velocity will be 0 m/s because the swimmer's displacement is 0.

TABLE 4.2 The difference between speed and velocity

Swim event metres (m)	Description	Total distance travelled (l)	Total displacement (d)	Time of swim (t)	Average speed $S = l/t$	Average velocity $V = d/t$
50	Swim from one end of a 50-metre pool to the other	50 metres	50 metres	25.00 seconds	2 m/s	2 m/s right
100	Swim from one end of a 50-metre pool to the other, turn around and swim 50 metres back to the starting position	100	0 metres	50.00 seconds	2 m/s	0 m/s

Velocity and speed are important concepts in sports such as athletics, cycling and swimming, where success is measured by how fast an athlete completes the event. The analysis of times such as splits can be used to inform coaches of where an athlete can make improvements and gain advantage over their competitors.

4.2.8 Linear acceleration

Acceleration refers to the rate of velocity change experienced by an object over time. This is represented by the following formula:

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

$$a = \frac{v_f - v_i}{t}$$

a = acceleration (m/s^2)

v_f = final velocity (m/s)

v_i = initial velocity (m/s)

t = time (s)

- If the velocity increases over the period of time measured, then the object will experience positive acceleration; that is, it speeds up.
- If the velocity doesn't change over time, then the body will be travelling at the same velocity (zero or no change in velocity); therefore, zero acceleration occurs.
- If the final velocity is slower than the initial velocity, the object is said to have negative acceleration. It is normal for the term 'deceleration' to be used to describe this.

An example of an athlete experiencing positive, zero and negative acceleration during an event is a 100-metre runner (see figure 4.8). When watching a 100-metre sprint, the observer sees the athletes explode from the blocks and accelerate to maximum velocity to compete for the win. The reality, however, is that the athlete does indeed accelerate but typically reaches maximum velocity at approximately the 40- to 50-metre point in the race. They then try to hold their maximum velocity for as long as possible (zero acceleration), but will decrease their velocity (due to fatigue) to varying degrees over the last half of the race, experiencing negative acceleration (deceleration) during this time.

FIGURE 4.8 The Paralympic 100-metre sprinters will experience positive, zero and negative acceleration during the race.



4.2.9 Momentum

The term **momentum** describes the quantity of motion a particular body of mass has. It is a combination of mass and velocity: mass (measured in kilograms) multiplied by velocity (measured in metres travelled per second).

momentum the product of mass and velocity; for example, a body with greater mass moving faster will have greater momentum than a lighter object moving slower

This is written as:

$$\text{momentum (p)} = \text{mass (m)} \times \text{velocity (v)}$$

If an object has zero velocity (not moving), then it has zero momentum. The higher the mass and the higher the velocity, the greater the momentum will be. An example can be seen by comparing athletes running in a 100-metre sprint, as shown in table 4.3.

An object can also have no momentum. This can be seen when a teeball is sitting on a tee. The teeball has mass but because it is stationary, it has zero velocity. The batter in teeball, who is trying to hit a home run, will strike the ball with as much force as possible. This force will increase the velocity of the ball, giving it momentum (mass × velocity). The objective is to maximise momentum so that the ball travels as far as possible.

TABLE 4.3 Comparison of athletes running in a 100-metre sprint

Lane	Athlete's mass (m)	Athlete's peak velocity (v)	Athlete's peak momentum (p)
1	80 kg	10 m/s	800
2	80 kg	9 m/s	720
3	90 kg	10 m/s	900
4	90 kg	8 m/s	720

Another example is seen in figure 4.9. The freight train is massive and can weigh thousands of kilograms, so it doesn't need to move at a very fast velocity to have an enormous amount of momentum. In comparison, a gridiron player would need to be travelling very fast indeed to produce the same momentum given their much smaller mass. In collision sports like gridiron, there is an advantage to having a large mass as long as it doesn't compromise velocity, so players spend long hours in the gym increasing their muscle mass. But think about how hard it would be to tackle the freight train.

FIGURE 4.9 (a) The momentum of a freight train is much larger than **(b)** the momentum of gridiron players.



4.2.10 Conservation of momentum

Whenever two bodies collide, their combined momentum is conserved (i.e. it stays the same). This is referred to as the principle of conservation of momentum. An example of this is in tenpin bowling (see figure 4.10). The momentum of the bowling ball and pin when combined are the same pre- and post-collision. The bowling ball when thrown has significant momentum due to its combined mass and velocity. The pin, however, has zero momentum due to its zero velocity. Once the bowling ball hits the pin, a significant quantity of momentum is transferred from the bowling ball to the pin, causing the pin to increase in velocity and the bowling ball to reduce its velocity. The combined momentum, however, will be the same. All hitting sports use this concept.

FIGURE 4.10 Tenpin bowling illustrates the principle of conservation of momentum.



Think about a cricket bat colliding with a cricket ball. The bat always has a larger mass than the ball and often higher velocity. During the collision, momentum is passed from the bat to the ball; due to the ball's smaller mass, this causes it to fly from the bat with high velocity, allowing the batsman to score runs. Imagine if the ball had more momentum than the bat, like if you tried hitting a medicine ball with a plastic bat. It doesn't work.

4.2.11 Force summation (summation of momentum)

Force summation (or summation of momentum) refers to the correct timing and sequencing of body parts to produce maximal force. It is particularly important in sports where the objective is to throw, hit or kick an object or ball as far as possible, such as in javelin, discus, soccer or baseball.

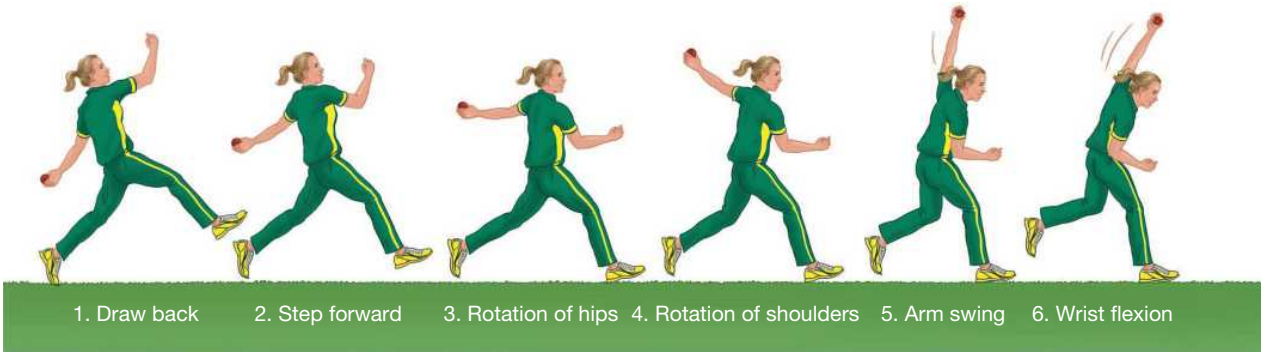
force summation the correct timing and sequencing of body parts to produce maximal force

A shot-putter, for example, doesn't just use their arms to put the shot; they practice and refine a rotational technique that involves many parts of the body, including the legs, moving in sequence and in perfect timing. The shot-putter will use the principle of conservation of momentum to transfer momentum from one body part to the next, culminating in a put that must leave the hand at maximal velocity to travel maximal distance.

For maximum force, it is important to consider the following:

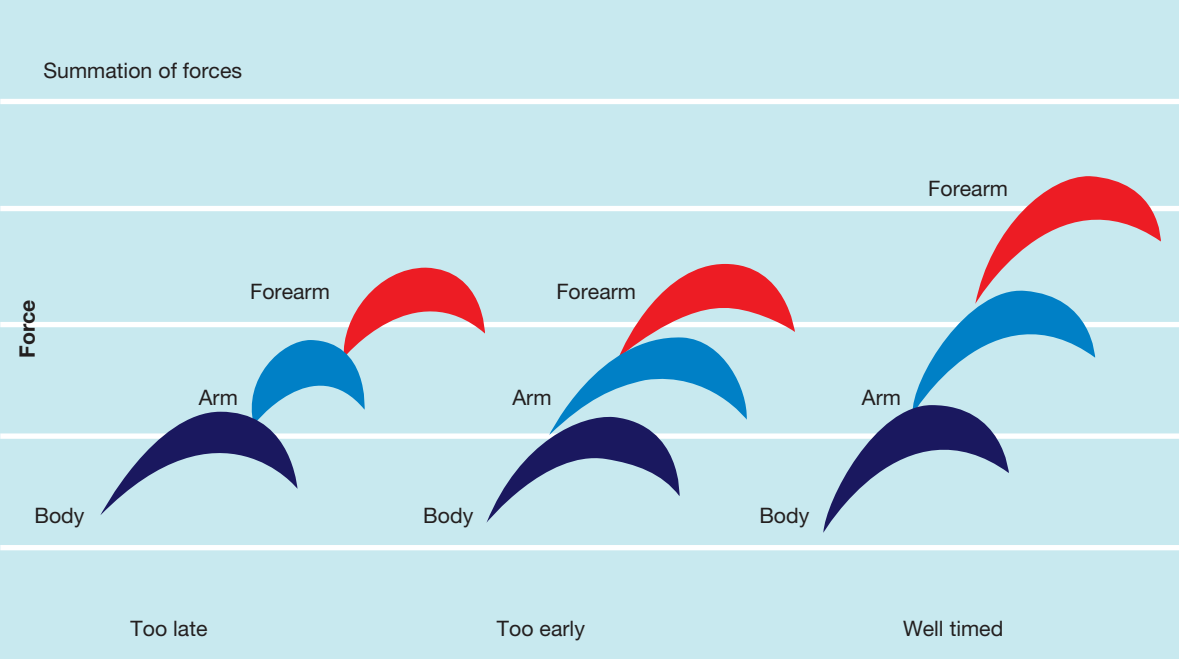
1. Use as many body parts as possible. Greater momentum can be produced by applying force over a longer period of time. By recruiting more body parts in sequence, the total time over which momentum can be generated is increased. This momentum can then be transferred to the desired action (see figure 4.11).

FIGURE 4.11 In this cricket bowl, there is a sequential transfer of momentum between different body parts, starting with the large muscles of the lower body, which transfer force to the torso, then the smaller muscles in the arms, before the momentum is transferred to the ball on release.



1. Use the correct sequencing of those body parts, such that we use the heaviest but slowest body parts (e.g. the legs) first (MASS × velocity), followed by the lighter but faster body parts (e.g. wrist and fingers) (mass × VELOCITY). In shot-put, the heaviest body parts are the legs and hips, while the lightest and fastest body parts are the fingers, which are in contact with the shot and transfer momentum to it.
2. Stabilise each body part once it passes momentum to the next body part. Momentum can be lost if this does not occur. Athletes often work on their core stabilising muscles (e.g. by doing pilates and yoga exercises) to ensure they are more stable and more powerful.
3. Use the correct timing to pass momentum. When the previous body part reaches maximal velocity, the next part must begin moving (see figure 4.12).
4. Use a follow-through to ensure that the final body part in contact with the object or ball is at maximal velocity and not slowing down too early.

FIGURE 4.12 The best-timed actions will ensure that momentum is transferred from one part of the body to the next when the force is maximal.



EXAM TIP

BEST is a good mnemonic to remember force summation.

Body parts

s**E**quence

Stabilisation

Timing

4.2.12 Impulse

Impulse is a change in momentum. The formula for impulse is:

$$\text{impulse} = \text{force} \times \text{time}$$

impulse the product of force and time

We need to understand impulse, or changes in momentum, in two different ways.

1. Momentum breakers decrease momentum (e.g. when a cricketer catches a ball or a gymnast lands on the mat after jumping off the beam).
2. Momentum makers increase momentum (such as when a golfer drives a golf ball or a footballer kicks a football).

Momentum breaker (force reception) — impulse remains the same

When reducing momentum, such as when a cricketer catches a ball, the aim is to stop the momentum. The change in momentum will be whatever the ball's momentum was (determined by its mass and velocity) to zero. So, when we are momentum breakers, impulse remains the same.

However, since impulse is calculated by multiplying force and time, any increase in time will *reduce the force* and so the catcher will try to *increase the time* over which they catch the ball by moving their hands back with the flight of the ball. By increasing the time, they reduce the force required to catch the ball and the force that the ball exerts on the hands. This means that their hands won't hurt or get injured. This also applies when you jump in the air or over obstacles (see figure 4.13).

FIGURE 4.13 When jumping over objects, it is important to land with bent knees. This increases the time it takes to land and reduces the force on your joints, bones and muscles.

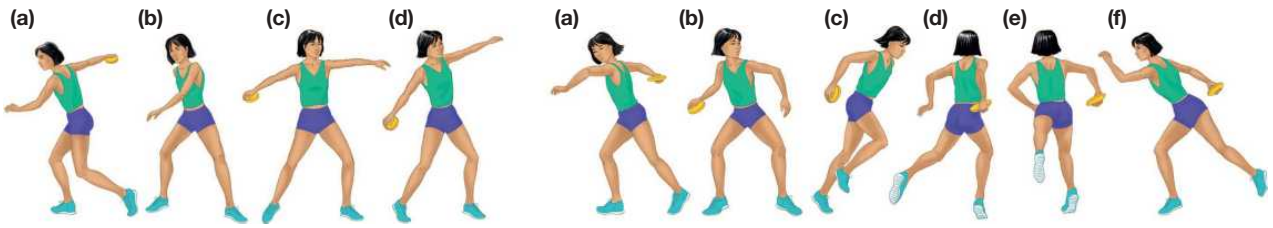


Momentum maker — impulse can be increased

When batting in teeball, the batter's aim is to increase the change in momentum of the ball to maximum. While the ball is on the tee, it has no momentum because its velocity is zero. But by swinging at maximal force using force summation principles and applying the force for as long as possible by following through, the batter can increase the impulse, increase the change in momentum and increase the chance of scoring a home run.

Sports such as discuss and hockey have developed techniques that allow athletes to apply force for longer periods so that they can increase impulse and achieve better results (see figures 4.14 and 4.15).

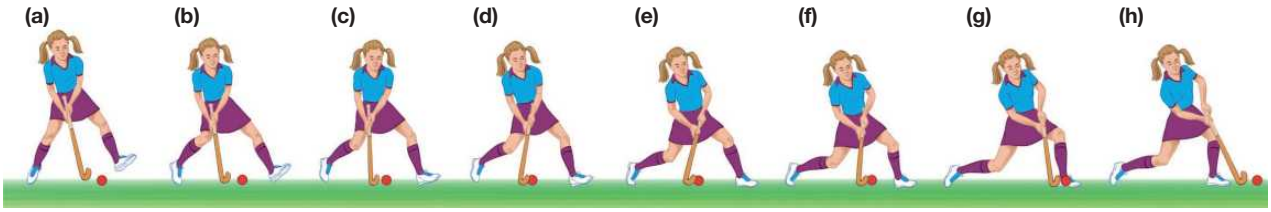
FIGURE 4.14 This diagram depicts the same discus thrower with two different techniques prior to releasing the discus. When using the standing throw, the athlete uses a quick half-spin prior to releasing the discus, meaning that force is applied over a short period of time, resulting in a small impulse. When applying force over a longer period during the one-and-a-half turn throw, greater impulse and subsequent momentum is generated.



The standing throw

The one-and-a-half turn throw

FIGURE 4.15 The hockey player applies greater momentum when making contact with the ball over a longer time frame (c to h).



4.2.13 Understanding angular concepts of human movement

As discussed earlier in the topic, angular motion is rotation that occurs around an axis (either internal or external). Whereas linear motion is caused by a force (a push or pull). All angular motion is caused by an **eccentric force**, which is simply a force that is off-centre or not directly through an object's **centre of mass**.

eccentric force a force that is off-centre or not directly through an object's centre of mass

centre of mass the position where the weight of the object is evenly distributed

torque a force that is applied at a distance away from the centre of mass, that causes the object to rotate

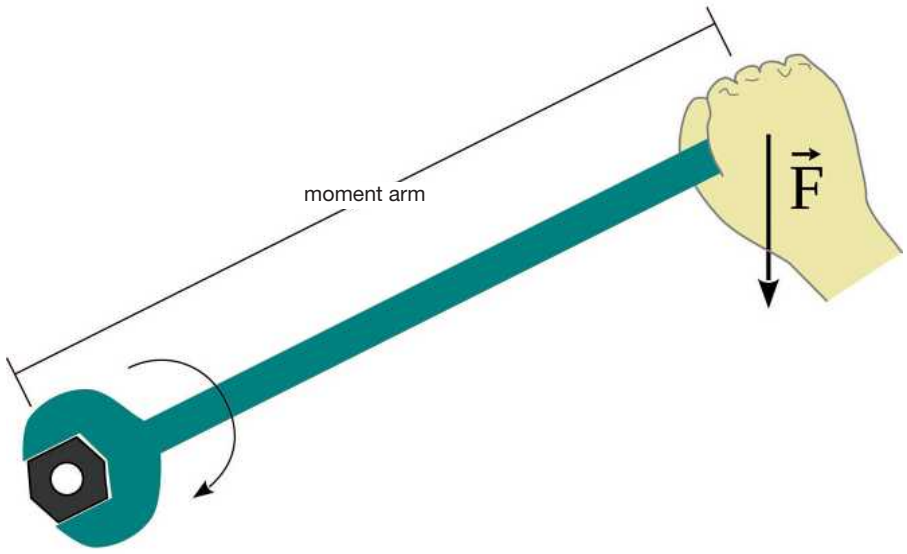
4.2.14 Torque

Another name for an eccentric force that causes an object to rotate is **torque** (see figure 4.16). The amount of rotation an object has is determined by the amount of torque applied to it. It can be calculated using the following rule:

$$\text{Torque} = \text{force} \times \text{moment arm}$$

(where the moment arm is measured from where the force is applied to the axis of rotation)

FIGURE 4.16 A force is applied to the end of the moment arm in order to create rotation.

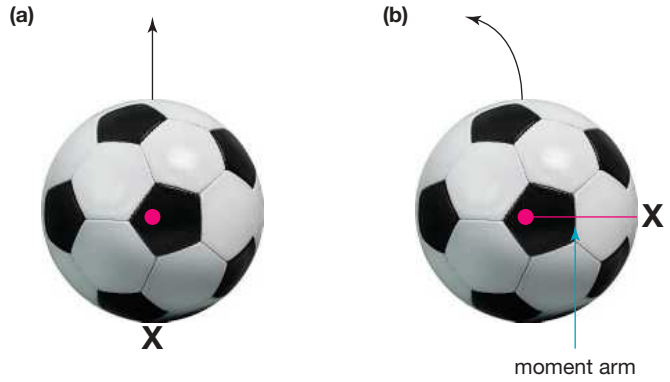


The amount of rotation an object has is not only determined by how much force is applied onto it but also by where that force is applied in relation to the object's axis of rotation or centre of mass.

A sporting example of applying torque is when David Beckham kicks a soccer ball and can 'bend' the ball through the air.

To kick the ball straight (linear motion), Beckham would kick the soccer ball (apply a force) through its centre of mass, but to get the ball to spin, he must kick it away from the centre of mass (apply torque). The further away from its centre of mass that he kicks it (e.g. on the outside of the ball), the longer the moment arm will be, the faster the ball will rotate and the more the ball will bend.

FIGURE 4.17 (a) If the player's foot makes contact at the X, then the ball will go straight. **(b)** If the player's foot makes contact to the side of ball, then the ball will rotate and will have a curved trajectory.



CONCEPT CONNECTOR

Using a door, open and close the door by applying force at different points along the width of the door. (This creates a longer moment arm.) Note down observations about the amount of force needed to open or close the door depending on the length of the moment arm. This activity can also be done with a textbook on a table.

4.2.15 Angular distance and displacement

The concepts covered with regard to linear distance and displacement can also be transferred to angular motion. When a body rotates from one position to another, it experiences angular motion. The **angular distance** is the total of all of the object or body part's angular changes between the starting and finishing position. Consider the example of a tenpin bowler swinging their arm during the bowling action (see figure 4.18). If the bowler moves their arm two-thirds of a full rotation (a full rotation is 360 degrees), the angular distance covered would measure 240 degrees.

angular distance the angle between the initial and final position

angular displacement the change of angle between the initial and final position

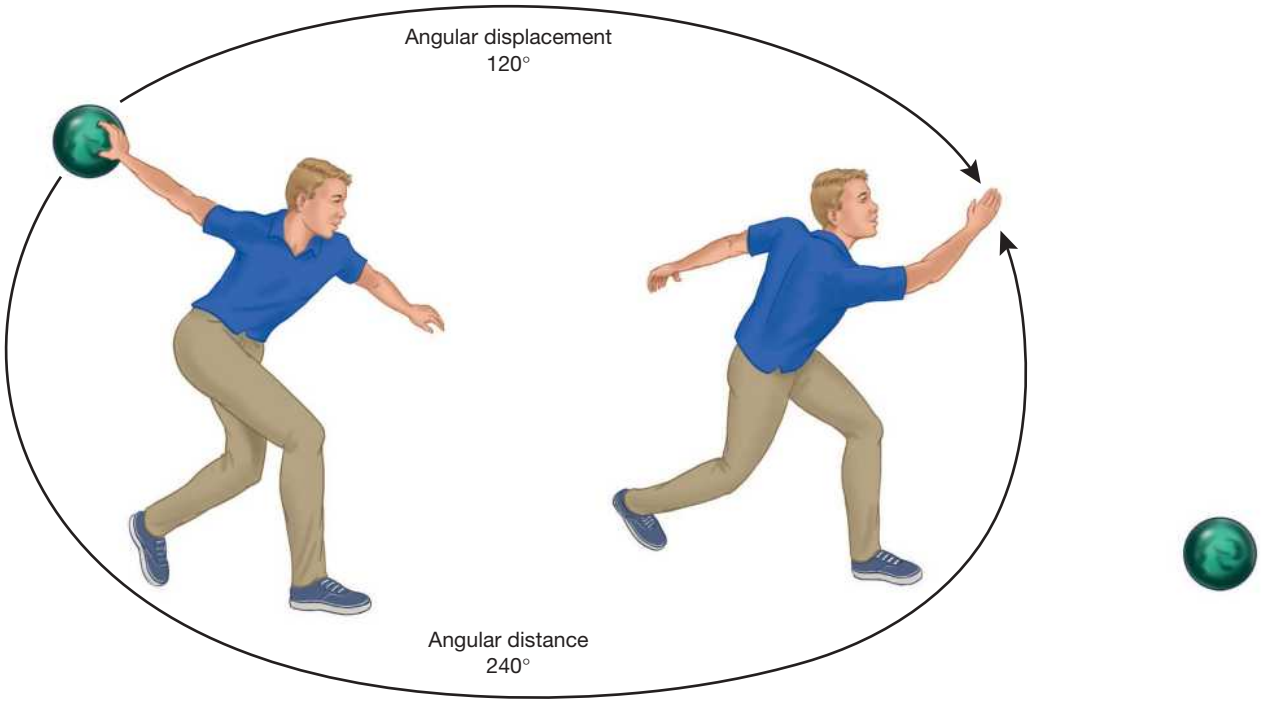
angular speed the change in angular distance over time

The **angular displacement** is the difference in degrees between the object or body part's initial and final positions. It is measured by the smaller of the two angles. In this particular example, the angular displacement would be 120 degrees. Angular displacement has both size (magnitude) and direction. Typically, clockwise movements are referred to as positive and anticlockwise movements are negative.

4.2.16 Angular speed and velocity

The term **angular speed** refers to the angular distance covered divided by the time taken. For example, a rotating object that completes two full revolutions (full circles) per second would have an angular speed of 720 degrees per second (360 degrees × 2).

FIGURE 4.18 In this example, the angular displacement of the tenpin bowler's arm between these two positions (start of forward swing of the ball and end position of arm after release) is 120 degrees, while the total angular distance the arm travels is 240 degrees.



The **angular velocity** is measured by dividing the angular displacement by the time taken.

angular velocity the change in angular displacement over time, which indicates how quickly an object rotates

This can be written as:

$$\text{angular velocity} = \frac{\text{initial angle} - \text{final angle}}{\text{time}} \text{ (including direction)}$$

$$\omega = \frac{\theta}{t}$$

ω = angular velocity (°/s)

θ = angular displacement (°)

t = time (s)

The linear speed can also be calculated if the angular velocity and radius of rotation are known, using the formula:

$$\text{Linear speed} = \text{angular velocity} \times \text{radius of rotation}$$

$$s = \omega \times \text{r}$$

s = linear speed (m/s)

ω = angular velocity (°/s)

r = radius of rotation (m/°)

This will be useful to know when we discuss levers and we begin to understand why a longer lever can magnify speed greater than a shorter one.

Think about the length of a golf driver in golf compared to a shorter putter. It is easy to see that the head of the driver travels faster because the golfer applies more force to the club for greater angular velocity and the radius of rotation is longer (longer club). The linear speed of the club head is faster!

CONCEPT CONNECTOR

Have five students link arms to form a chain and then move around in a circle, 'pivoting' around one student. After a few full turns, stop moving and add a few more students onto the chain. Start moving again, pivoting around one student like before. Continue this process of stopping and adding more students until all of the students are part of the chain. Throughout this activity, observe the speeds of different students within the chain. Use angular velocity and linear speed to explain the difference in the speeds of the students at different points in the chain.

4.2.17 Angular acceleration

The angular acceleration is the rate of change of angular velocity (final velocity – initial velocity) over time.

$$\text{angular acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

$$\alpha = \frac{(\omega_f - \omega_i)}{t}$$

α = angular acceleration (degrees/s^2)

ω_f = final velocity (degrees/s)

ω_i = initial velocity (degrees/s)

t = time (s)

FIGURE 4.19 The angular acceleration of a gymnast can be calculated by using their angular velocity and time.



Example

A gymnast rotating around a high bar who speeds up from 100 degrees per second to 300 degrees per second in 0.5 seconds has an angular acceleration of 400 degrees per second. This is written as:

$$\alpha = \frac{300\text{ degrees/s} - 100\text{ degrees/s}}{0.5}$$
$$= \frac{200\text{ degrees/s}}{0.5\text{ s}}$$
$$= 400\text{ degrees/s}^2$$

4.2.18 Angular momentum

Angular momentum is a measure of how much rotation a body has around an axis. It is the product of **moment of inertia** (MOI) and angular velocity (AV). This can be expressed as:

$$\text{angular momentum} = \text{moment of inertia} \times \text{angular velocity}$$

Moment of inertia

Moment of inertia is a measure of an object's resistance to change in its rate of rotation (i.e. to start or stop rotating). The moment of inertia is dependent on both:

- the mass of the rotating object or body
- the distance the weight is distributed from the axis of rotation, or its radius.

moment of inertia a measure of an object's resistance to change in its rate of rotation

The formula for moment of inertia is:

$$\text{moment of inertia} = \text{mass} \times \text{radius}^2$$

$$\text{MOI} = \text{m} \times \text{r}^2$$

m = mass (kg)

r = radius (m)

A baseball bat that is heavy (large mass) and long (long radius) has a higher moment of inertia than one that is lighter and shorter. Since the long, heavy bat is more reluctant to rotate, it requires a larger force to swing it. This is optimal for a professional athlete who can generate enough force to swing the bat with great angular velocity. However, for children being introduced to the sport, modified equipment is necessary.

In baseball, a young child may be given a lighter (smaller mass), shorter bat (smaller radius), which has a smaller moment of inertia and is less reluctant to rotate. A bat with a lower moment of inertia requires less force to swing it. This is optimal for children, who often cannot generate large forces due to their smaller muscles (see figure 4.20).

Angular momentum can be maximised when moment of inertia and angular velocity are optimal. For example, a professional baseballer might want to use a heavy and long bat to achieve greater angular momentum. However, they need to make sure they can swing it with high angular velocity. There is a sweet spot when selecting a bat because if it is too heavy and long, its moment of inertia will be too high, reducing how fast the batter can swing the bat (decreased angular velocity) and decreasing the overall angular momentum (see figure 4.21).

FIGURE 4.20 This young child may have trouble swinging a bat of this size due to its large moment of inertia. Fortunately, modified equipment can make it easier for children to learn sports.



FIGURE 4.21 The mass and length of a baseball bat will affect the overall angular momentum of the swing.



It is advantageous to maximise angular momentum in hitting, kicking and throwing sports because this momentum is transferred to the object or ball. In the case of baseball, this might mean the batter hits a home run!

There is clearly a relationship between moment of inertia and angular velocity. A common example can be found in running. During the recovery stride, when the leg is off the ground, the knee is bent (see figure 4.22). This reduces the moment of inertia of the leg due to the reduced radius (the centre of mass of the leg from the axis of rotation at the hip). This allows the leg to move faster through the air at a higher angular velocity. Then, for the same force applied, the leg returns to the ground faster. Ultimately, this means we can run faster.

FIGURE 4.22 When running, the angular momentum in each leg is conserved throughout the action. When the leg is bent, the moment of inertia drops but the angular velocity in that leg increases to conserve momentum, speeding up forward movement for the next running stride.



on Resources

Digital document Moment of inertia (doc-3562)

4.2.19 Conservation of angular momentum

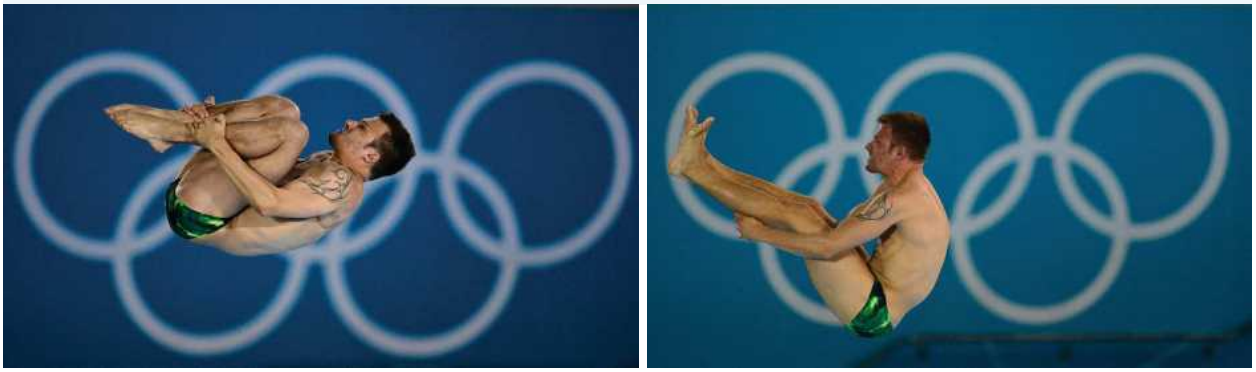
When an object is airborne, no external force acts on it that will change its angular momentum. Gravity will bring the object down but will not alter its angular momentum until the object hits the ground.

The principle of conservation of momentum says that while airborne there will be **NO change of angular momentum**.

However, in sports such as diving and gymnastics, the athletes will change their angular velocity by altering their moment of inertia in midair. Think of a diver who tucks to somersault and then lays out to stick the landing (see figure 4.23).

- The diver will decrease their moment of inertia by tucking their body (mass remains the same, but radius is reduced) and this will be met with a corresponding increase in angular velocity (faster spin). There has been no change in angular momentum.
- Just before landing, the diver will layout. This will increase the moment of inertia (radius increases) and cause a corresponding decrease in angular velocity. If the diver times it perfectly, the decreased angular velocity will allow a vertical entry into the water and a perfect bubble entry culminating in a high-scoring dive.
- In both instances, there is no change in angular momentum (angular momentum = moment of inertia × angular velocity); however, both angular velocity and moment of inertia have changed.

FIGURE 4.23 Once the diver leaves the diving board, angular momentum will be conserved. However, the diver can alter the moment of inertia and angular velocity by moving body parts into different positions. During the tuck, the moment of inertia is reduced significantly, which, in turn, increases angular velocity (degree of rotation) and conserves the momentum. The opposite occurs coming out of a tuck, where velocity decreases due to an increase in the moment of inertia.



EXAM TIP

When answering biomechanics questions, go DEEP.

Define — define the concept.

Equation — include the equation, if there is one.

Explanation — explain the concept using the scenario in the question and the terms in the equation.

Performance link — identify how the concept has affected the performance.

doc-41949

PRACTICAL ACTIVITY Linear acceleration

Goal

To compare a runner's split times with Usain Bolt's and determine average velocity, acceleration and maximal velocity for each runner.

Instructions

Set up a 100-metre course and mark every 10 metres with a cone. One person will stand next to each cone with a timing device.

On a given signal, one person will sprint the 100 metres. Each person standing at a cone must start their stopwatch on the signal, at the same time, then stop their timer as the runner passes their cone.

Collate the results, then mathematically determine the split times for each segment of the race, as well as the average velocity and acceleration.

Primary data/Reflection

TABLE 1 Data comparison against Usain Bolt

Name: Usain Bolt					Name:			
Segment	Time (sec)	Split (sec)	Velocity (m/s)	Acceleration (m/s^2)	Time (sec)	Split (sec)	Velocity (m/s)	Acceleration (m/s^2)
0-10 m	1.85	1.82						
10-20 m	2.87	1.02						

Name: Usain Bolt					Name:			
Segment	Time (sec)	Split (sec)	Velocity (m/s)	Acceleration (m/s^2)	Time (sec)	Split (sec)	Velocity (m/s)	Acceleration (m/s^2)
20-30 m	3.78	.91						
30-40 m	4.65	.87						
40-50 m	5.5	.85						
50-60 m	6.32	.82						
60-70 m	7.14	.82						
70-80 m	7.96	.82						
80-90 m	8.79	.83						
90-100 m	9.69	.90						
Total	9.69	9.69						

Questions

1. Which segment was the slowest for both runners?
2. Which segment was the fastest for both runners?
3. Using data, justify who had the fastest maximal velocity: Usain Bolt or the student.
4. Graph the velocity of both runners and identify periods of positive acceleration, negative acceleration and any periods of zero acceleration.

doc-41950

PRACTICAL ACTIVITY Tennis ball throw

Goal

To investigate the principles of force summation when throwing tennis balls.

Instructions

Place a cone on the ground and have each person throw a tennis ball four times for each of the following scenarios:

Throw 1 — Lie on the ground. Keeping all body parts flat on the ground except the throwing arm, throw the ball as far forward as possible. Measure the distance the ball travelled.

Throw 2 — In a sitting position with your feet and bottom flat on the ground, throw the ball as far forward as possible. Measure the distance the ball travelled.

Throw 3 — With feet firmly planted on the ground (both facing forward), throw the ball as far as possible. Measure the distance the ball travelled.

Throw 4 — With a five-metre run up, throw the ball as far forward as possible. Measure the distance the ball travelled.

Collate the results of the throws for the class to obtain an average for each throw.

Primary data/Reflection

What did you learn about the importance of body position and momentum in maximising the throwing distance for each scenario?

TABLE 1 Class data for each throw

Name	Throw 1 distance (m)	Throw 2 distance (m)	Throw 3 distance (m)	Throw 4 distance (m)
AVERAGE				

To calculate the average distance for each throw, add up all the values, then divide by the number of values.

Questions

1. Why did the ball travel different distances for each throw? Use the principles of force summation in your response.
2. Were there any outliers or unexpected results in the data? How might factors such as technique or individual differences have influenced the outcomes?
3. Consider the biomechanical principles of force summation. How did the sequential activation of body segments contribute to the effectiveness of each throw?
4. Discuss the practical implications of these findings in sports performance contexts. How can athletes optimise their throwing technique based on these results?

doc-41951

PRACTICAL ACTIVITY Egg throw

Goal

To explore how 'giving with the ball' when catching can increase the time taken to catch the ball, thus reducing the force on the hand.

Instructions

With a partner standing 1 metre away, underarm throw an egg or water balloon to each other, making sure to 'give' with the egg by moving your hands back with the egg as you catch it.

After a few throws (or as you become more confident), one partner moves another metre away (total of 2 metres). Continue throwing the egg. Repeat this process, increasing the throwing distance by 1 metre at a time. See how far apart you can get before the egg breaks.

Primary data/Reflection

- How did the force experienced by the egg or water balloon change as the distance between partners increased? Discuss the relationship between force, distance and time of contact during the catch.
- What did you observe about the relationship between force, time of contact and distance during the catching activity?
- What would happen if we didn't give with the egg while trying to catch it?

Questions

1. How many meters could you throw without breaking the egg?
2. What happens to impulse when we are momentum breakers?
3. Using the impulse formula, explain how giving with the egg reduces the chances of breaking it.
4. Using your understanding of impulse, describe how gymnasts use this same concept when sticking a landing from the balance beam.

doc-41952

PRACTICAL ACTIVITY Straight knees vs bent knees

Goal

To explore the relationship between angular velocity and moment of inertia while running.

Instructions

Have a short 50-metre race with a partner. One person should run the race with bent legs in the normal running style. The other person should run using straight legs only.

Time each runner and record the results, then swap running styles.

Primary data/Reflection

- Reflect on any variations in acceleration and deceleration patterns observed during the race. How did these variations impact the final race times?
- Reflect on your personal experience of running with bent legs and straight legs only. How did each running style feel in terms of comfort, stability and efficiency?

Questions

1. What is the formula for moment of inertia?
2. Explain how bending the knees alters the moment of inertia of the leg.
3. What effect does bending the knees have on the angular velocity of the leg?
4. Using your understanding of angular momentum and using the data, justify and explain why a runner with bent legs runs faster than a runner with straight legs.

4.2 Activity

4.2 Quick quiz on

4.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 6, 7, 8, 11	2, 9, 10, 11, 12	3, 4, 5, 13, 14

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- Track results and progress

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TEST your understanding

1. **Describe** what a force is and give an example of an internal force and an external force that acts on a body.
2. **Compare** the differences between speed, velocity and acceleration using the terms *distance* and *displacement*.
3. **Explain** when a runner is most likely to experience positive, zero and negative acceleration during a 100-metre sprint race.
4. **Provide** the formula for momentum and **explain** why a teeball bat has more momentum than the ball.
5. Using your understanding of impulse, **explain** two ways that a teeball batter could increase the change in momentum when they hit the ball to score a home run.
6. **List** four of the force summation principles that should be followed for maximum force production.
7. **Identify** the difference between *force* and *torque*. Give the formula for torque in your response.
8. There are three units used to measure angular motion. **List** the three different units and highlight the one commonly used in sports coaching and biomechanics.

APPLY your understanding

9. You are a coach of two junior athletes. One of your athletes, Fiona, is positioned 1 kilometre away in a straight line from where you are, while another, Nouf, is next to you. Fiona runs to you, taking five minutes to get there. You instruct Nouf to run two full laps of an oval with a distance of 500 metres per lap, finishing where she started.

Using the information above, **calculate** the average speed and average velocity of Fiona and Nouf, assuming they both run at the same speed. **Compare** the results.

10. The table below shows the velocity experienced by a 100-metre sprinter at different stages, including at the starting line before the race starts and at each 20-metre interval of the race thereafter.

Sprinter's position	Velocity
Starting line	0
20-metre point	7
40-metre point	11
60-metre point	10
80-metre point	8
100-metre point	7

   a. **Identify** the point in the race where the sprinter experienced the greatest velocity.
   b. **Identify** the unit that velocity is measured in.
   c. The sprinter finished the race in 11 seconds. Using the correct formula, **calculate** their iraverage velocity from start to finish.

11. An athlete who has a mass of 75 kg reaches a peak velocity of 4 m/s during a 400-metre run. **Calculate** their peak momentum.
12. The table below shows some data relating to the mass and velocity of two athletes in a sprint.

Lane	Athlete's mass (m)	Athlete's peak velocity (v)
1	50 kg	8 m/s
2	60 kg	7 m/s

    Calculate each athlete's peak momentum during the sprint, highlighting whether the athlete in lane 1 or lane 2 generates the most momentum.

13. A rugby player receives a pass from a teammate while stationary. Immediately after receiving the ball, he is tackled by an opposition player. **Explain**, using the principle of transfer of momentum, what would happen next.
14. With reference to angular momentum, **explain** why using a heavier bat in cricket can increase the distance a batsman can hit the ball.

4.2 Exam questions

Question 1 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.10;* © VCAA

If a gymnast goes from a full layout position to a tuck position, what will happen to their angular momentum?

A. It will stop.
B. It will increase.
C. It will decrease.
D. It will remain the same.

Question 2 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.14;* © VCAA

In aerial skiing, the athlete skis down a relatively short hill and off a jump, and then they perform a variety of twists and flips in the air before landing.



Which biomechanical principle is the athlete applying to their performance by spreading their arms away from the torso during aerial skiing?

A. acceleration
B. displacement
C. Newton's first law of motion
D. conservation of angular momentum

Question 3 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.2.c;* © VCAA

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.

Discuss how a pitcher could successfully use the principle of summation of momentum to produce maximal force while pitching.

Question 4 (3 marks)

Janet, an Australian Olympic diver, over-rotates and has a poor landing after completing three somersaults on her first attempt. Using the equation for angular momentum, **provide** some feedback to Janet so she can improve her next attempt.

Question 5 (3 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.2.c;* © VCAA

An under-14 secondary school volleyball team completed a day of fitness testing and training at the Australian Institute of Sport with the national women's volleyball team.

Throughout the day, the students completed fitness testing specific to volleyball. One of the tests was the vertical jump.

Individuals undergoing the vertical jump test are briefed on the correct jumping and landing techniques.

Use your understanding of impulse to **explain** why it is important for athletes to land correctly when performing the vertical jump test.

More exam questions are available in your learnON title.

4.3 Newton's laws of motion

Key knowledge	Key skill
• biomechanical principles for analysis of human movement: – Newton's three laws of linear motion: Inertia, acceleration and action-reaction	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Isaac Newton first compiled his three laws of motion in 1687. These laws describe the relationship between a body and the forces acting upon it. They also explain how these forces affect the motion of a body as a consequence.

4.3.1 Newton's First Law of Motion — inertia

Newton's First Law of Motion is the law of inertia. This law states that an object will remain at rest or in uniform motion unless acted on by an unbalanced force.

Newton's First Law of Motion states that an object will stay at rest or continue to travel in the same direction at a constant velocity unless acted on by an unbalanced force

In other words, objects that are at rest will not begin to move unless the forces acting on them become unbalanced. Likewise, if an object is moving in one direction at a constant speed (i.e. in a state of uniform motion), a force would need to be applied to disrupt that motion (e.g. to accelerate, change the direction of or stop the motion; see figure 4.24). The larger the mass of a body, the greater the inertia and the more force required to overcome this inertia. This is true both for objects that are static and those that are moving.

FIGURE 4.24 This bike rider is experiencing inertia as his body continues to travel in the same direction at a constant velocity after the bike hits the rails. The bike has been met by an external force that has slowed it down considerably but the rider's inertia has propelled him forward and will only be slowed by air resistance, gravity and whatever he actually lands on.



4.3.2 Newton's Second Law of Motion — acceleration

Newton's Second Law of Motion states that:

Newton's Second Law of Motion states that the rate of acceleration of a body is proportional to the force applied to it and in the direction in which the force is applied

A force applied to an object will produce acceleration in the direction of the force. The acceleration is directly proportional to the size of the force and inversely proportional to the object's mass. The formula is:

$$\text{force} = \text{mass} \times \text{acceleration}$$

$$F = ma$$

F = force (N)

m = mass (kg)

a = acceleration (m/s^2)

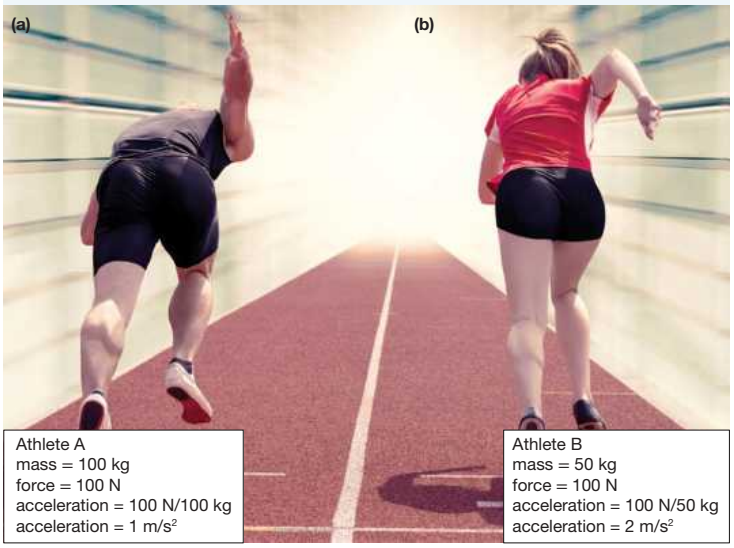
Since force is the product of mass and acceleration, to produce maximal force, mass and acceleration should be maximised. Think of a baseball bat. The higher the mass and the more it is accelerated, the higher the overall force that can be transferred to the baseball.

The greater the force applied to the baseball, the faster the ball will accelerate and the further it will travel. Conversely, a smaller force will produce slower acceleration, which may be the objective when a batter decides to bunt, for example. This is what is meant by saying that acceleration is directly proportional to the size of the force (the second part of Newton's Second Law of Motion). Therefore, as force increases, so too does acceleration, as long as the mass remains constant $\left(a = \frac{F}{m}\right)$.

The third part of this law states that there is an inverse relationship between the mass of an object and its acceleration, provided the same force is applied. 'Inversely proportional' means that as mass goes up, acceleration goes down as long as the force remains constant.

Figure 4.25 shows two sprinters of different mass applying the same force on the starting blocks. If $a = \frac{F}{m}$, then the person with the lower mass must accelerate faster if the same force is applied. This would be similar in the case of the baseballer who attempts to hit a 3 kilogram medicine ball instead of a baseball with their bat. If both were struck with maximal force, it is easy to imagine which ball would accelerate from the bat faster.

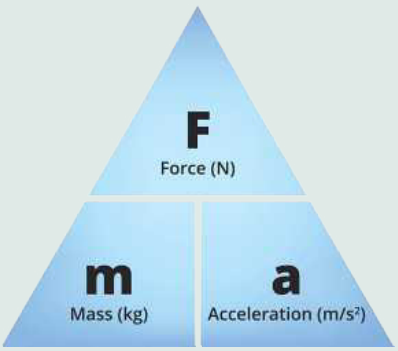
FIGURE 4.25 Compare the acceleration generated by the two athletes despite applying the same force to the starting blocks. Athlete B's faster start is due to her smaller mass.



EXAM TIP

To determine the formula needed, put your finger over the variable you are calculating. For example, if the question is asking you to find the acceleration of an object, place your finger over acceleration. The formula will be:

$$a = \frac{F}{m}$$



4.3.3 Newton's Third Law of Motion — action and reaction

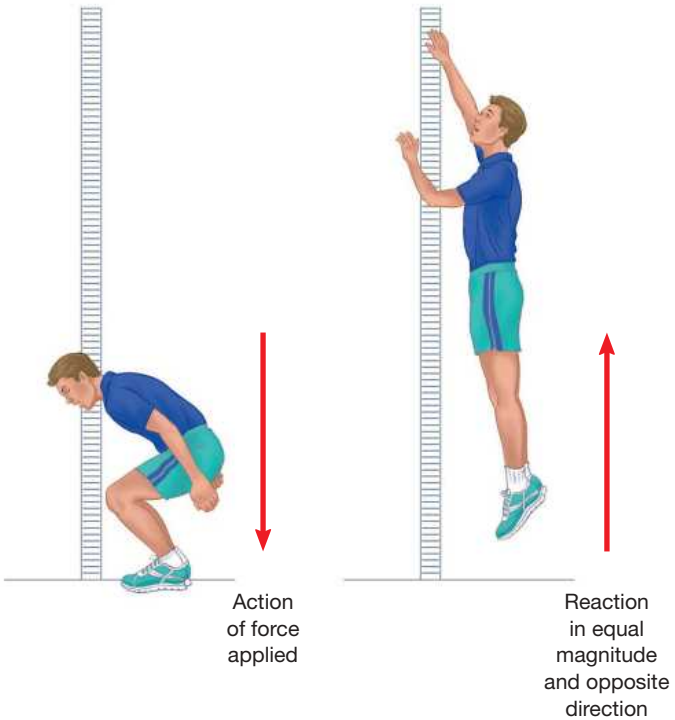
Newton's Third Law of Motion states that:

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction

'For every action, there is an equal and opposite reaction.'

This means that when one body applies a force against a second body, the second body applies an equal force in the opposite direction onto the first body. Consider the same individual jumping three different times. If the individual aims to jump directly in the air and land on the same spot, then in order to go directly up, the force must be applied directly down (see figure 4.26). In the second jump, the athlete aims to propel themselves up and forward. To do this, the force must be applied down and back. In the last jump, the person wants to jump up but backwards. The force to enable this jump to succeed is to push down and forward. In all three jumps, the magnitude (size) of the force dictates the force applied back to the person jumping. The greater the force, the greater the propulsion.

FIGURE 4.26 The direction and magnitude of the force applied will determine the direction and magnitude of the movement.

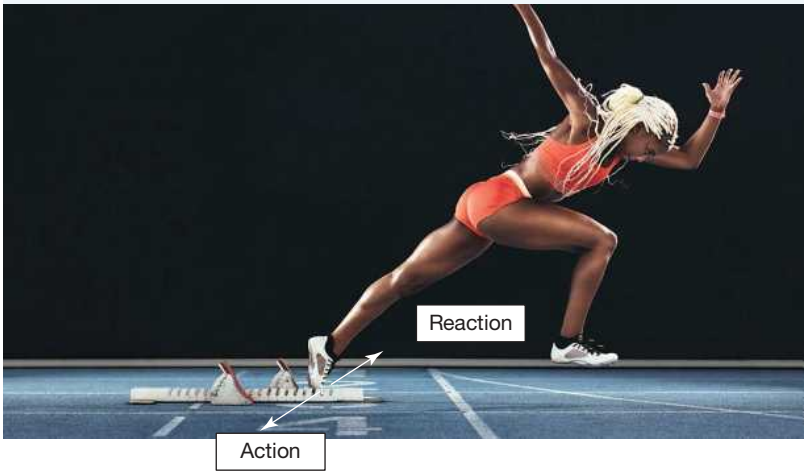


Consider other examples in sport. A basketball hitting the backboard at an angle bounces off on an angle with similar force to that with which it was thrown. A soccer player aiming to move sideways to their left to change direction must apply a sideways force to their right. Again, the greater the force applied to the ground (action), the greater the force that the ground applies back to the soccer player (reaction).

Looking at Newton's Third Law in isolation tends to be confusing. This is because the effects of these equal and opposite forces are visibly very different. The ground clearly doesn't move — the person jumping does. The basketball clearly rebounds off the backboard, but the backboard doesn't visibly shift. Newton's Second Law helps to explain this phenomenon. In the case of the individual jumping, the force applied (in accordance with Newton's Second Law) by the individual is their mass multiplied by their acceleration ($F = ma$). The earth responds with the same force. Considering the enormous mass of the earth, its acceleration is miniscule (so tiny it is not detected by the human eye).

In the other example, where the basketball hits the backboard and bounces off, the backboard can be shifted if the force of the ball is strong enough. In this case, you may see or hear the backboard move (accelerate from a stationary position). Due to its higher mass than the basketball, its acceleration will be much smaller than that observed in the basketball.

FIGURE 4.27 The runner who aims to move forward and up must apply a force back and down according to Newton's Third Law. This creates an equal and opposite reaction.



4.3 Activity

4.3 Quick quiz on | **4.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	6	3, 4, 5

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TEST your understanding

1. **Identify** which of Newton's laws is often referred to as the law of action and reaction.
2. According to Newton's Second Law of Motion, the force produced is a product of two variables. **Identify** what these two variables are.
3. A bike rider quickly puts on their front brake to avoid a collision but, as the bike slows down, the cyclist is thrown over the handlebars and becomes airborne. **Explain**, using Newton's First Law, why this occurs.

APPLY your understanding

4. There are two wrestlers, one with a larger mass than the other. **Explain**, using Newton's First Law of Motion, why the wrestler with the larger mass would be harder to move than the wrestler with the smaller mass, all other factors being equal.
5. Using your understanding of Newton's Second Law and referencing the formula, **explain** why a tennis ball would travel further than a cricket ball if both balls were hit with the same force.
6. As a class, play a game of indoor hockey with plastic sticks. Play with a light ball and then play with a shot or much heavier ball. **Discuss** which ball was harder to hit and stop using each of Newton's three laws.

4.3 Exam questions

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.15;* © VCAA

Which one of the following is an example of Newton's second law of motion?

A. when performing a somersault, rotating at the same angular velocity unless an external force acts to change the rotation
B. when performing a long jump, swinging the legs forward, which causes the upper body and arms to rotate forward
C. when performing bicep curls, putting more weight on the dumbbell, which requires more force to lift the dumbbell
D. when performing a throw in netball, the netball not travelling with the same acceleration as a tennis ball when thrown with the same force

Question 2 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.10;* © VCAA

In a women's gymnastics floor event, the gymnasts take part in movements that are performed on a square floor space.

Throughout the 90-second routine, the gymnasts are expected to make fast tumbling passes across the floor, often up to five in a routine, combined with several combinations of skills in succession, such as a sprint, leap, twist, somersault, flip and handstand, that require explosive energy. The gymnasts then rest for no more than a few seconds before repeating another high-intensity combination of moves lasting from three seconds to 20 seconds. This continues for the entire 90 seconds of the routine.

Explain how Newton's third law of motion relates to the take-off when performing a somersault as part of a floor routine in gymnastics.

Question 3 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.1;* © VCAA

Basketball players spend many hours practising free throws to improve their performance of this skill. Research comparing free throw performance during training sessions and games has indicated several differences. These differences have allowed researchers to determine how free throws may be better practised. One difference noted was that players performed more free throws in a row during training than they do in a game.

	Game	Training session
Volume (average number of free throws performed in a row)	1–2 shots	7.53 shots
Percentage of successful free throws	69.2%	74.5%

Data: B Kozar et al., 'Basketball free-throw performance: practice implications', *Journal of Sport Behavior*, vol. 18, no. 2, 1995

Explain how Newton's first law relates to the free throw in basketball.

Question 4 (3 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.4.b*; © ACHPER

The results and split times of two students who had their 100 m sprint times recorded during an intraschool athletics carnival are shown below.

Student	Height cm	Weight kg	20 m split seconds	40 m split seconds	60 m split seconds	80 m split seconds	100 m finish seconds
A	180	80	3.25	5.45	7.59	9.64	12.12
			3.25	2.20	2.14	2.05	2.48
B	175	75	3.08	5.42	7.72	10.14	13.22
			3.08	2.34	2.30	2.42	3.08

With reference to information provided and using Newton's first law, **explain** one likely reason for the differences in the split times from the start of the race to the 20 m mark.

More exam questions are available in your learnON title.

4.4 Levers

Key knowledge	Key skill
• biomechanical principles for analysis of human movement: – 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)	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

4.4.1 Levers

A lever is a rigid bar that allows the application of either increased force and/or speed (see figure 4.28).

All levers have common parts:

- an axis (point of rotation) **A**
- a resistance (load to be overcome) **R**
- a force (the point where the force is applied) **F**

Levers are classified depending on the location of the axis, force and resistance in relation to each other. They are categorised as either first-class, second-class or third-class levers.

FIGURE 4.28 The mechanic is using a first-class lever to magnify the force they can place on the car, to hopefully lift it.



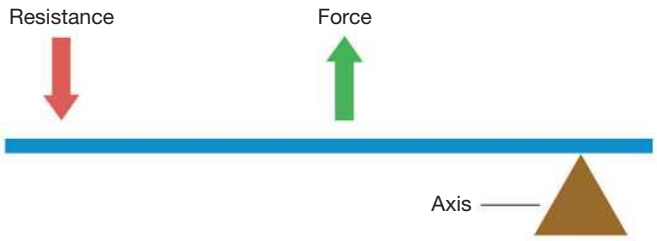
- A first-class lever always has the axis in the middle, between the force and the resistance.
- A second-class lever always has the resistance in the middle.
- A third-class lever will always have the force in the middle.

While the human body has examples of each lever, by far the most common lever found in the body is the third-class lever.

4.4.2 Third-class levers

Third-class levers are always built to amplify speed. They always have the force between the axis and the resistance, as shown in figure 4.29.

FIGURE 4.29 The force being applied is always between the axis and resistance in a third-class lever.



A good example of a third-class lever in the body is the upward phase of a bicep curl (see figure 4.30). The elbow joint is the axis (joints are always axes in the body), the force is where the biceps muscle attaches to the radius and ulna, and the resistance is the weight in the hand.

FIGURE 4.30 The upward phase of a bicep curl is a good example of a third-class lever in the body.

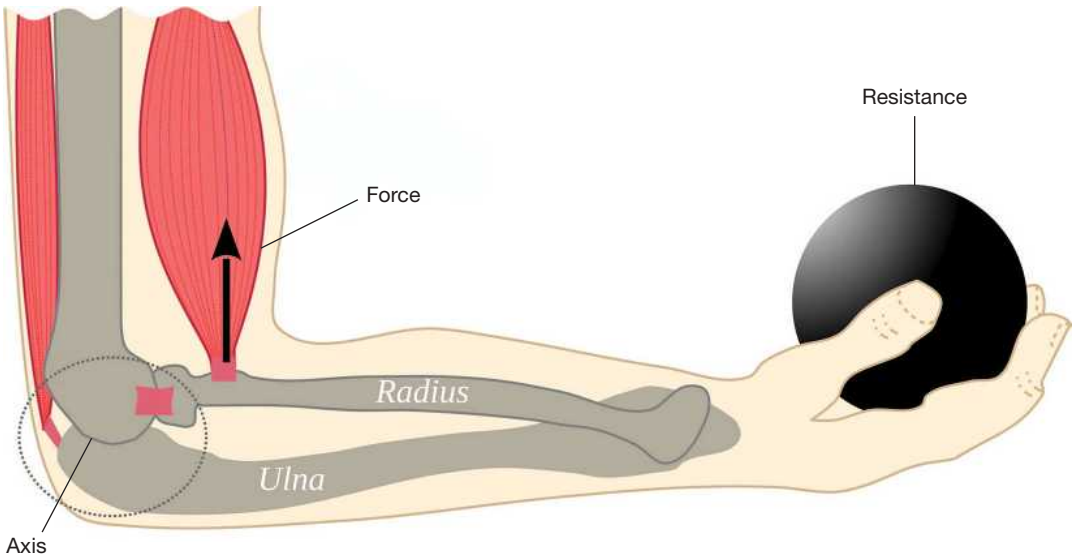


FIGURE 4.31 Another example in sport where a third-class lever can be used to magnify speed is in Australian Rules football. Note how straight the kicker's leg is when she strikes the ball. This decreases mechanical advantage and magnifies speed.



Resources

Digital document Levers in sport (doc-3559)

eLesson Leverage (eles-2753)

4.4.3 Mechanical advantage

Mechanical advantage is a measure of how much a lever amplifies force.

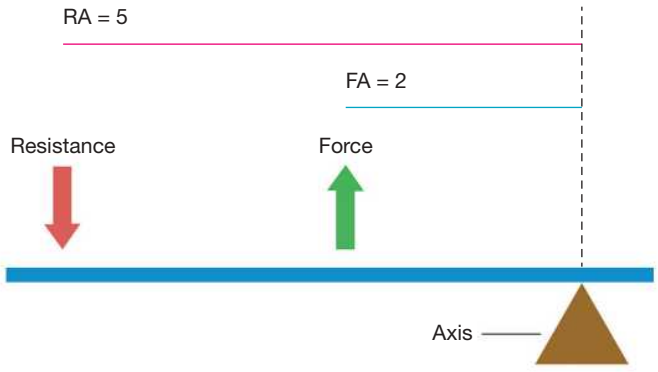
- A lever with a mechanical advantage greater than 1 (>1) will increase force (ARF).
- A lever with a mechanical advantage equal to 1 is balanced between speed and force.
- A lever with a mechanical advantage less than 1 (<1) will increase speed (AFR).

The formula is:

$$\text{mechanical advantage} = \frac{\text{force arm}}{\text{resistance arm}}$$

To calculate a lever's mechanical advantage, we must measure the force arm and the resistance arms from the axis. In figure 4.32, the force arm is 2 and the resistance arm is 5.

FIGURE 4.32 To calculate a lever's mechanical advantage, the value of the force arm and the resistance arm must be measured.



Using the information, we can calculate the mechanical advantage as:

$$\begin{aligned}\text{mechanical advantage} &= \frac{\text{force arm}}{\text{resistance arm}} \\ &= \frac{2}{5} \\ &= 0.4\end{aligned}$$

Since the mechanical advantage of this lever is less than 1, it is a speed magnifier. In fact, all third-class levers are speed magnifiers because they all have longer resistance arms than force arms. The longer the resistance arm and the further below 1 the mechanical advantage is, the greater the speed that can be produced by the lever due to the greater range of motion at the end of the longer lever compared to the shorter one.

Coaches will use this concept when they coach. Figure 4.33 shows a young child being instructed to grip the bat towards the end of the handle and straighten their elbows when they swing at the ball. This will increase the length of the resistance arm (measured from the axis — the shoulder joint — to the end of the bat), decreasing the mechanical advantage of the lever to further below 1 and increasing the speed at which the end of the bat is travelling. A faster bat speed will create greater transfer of momentum on impact with the ball. This can also apply to tennis (see figure 4.34)

FIGURE 4.33 Gripping the bat towards the end of the handle and straightening your elbows will decrease the mechanical advantage of the lever and increase the speed of the end of the bat.



FIGURE 4.34 Roger Federer extends his arm (third-class lever) on impact to maximise the length of his resistance arm and ensure maximal speed at the racket head. He could also use a longer racket as long as he can overcome the increased moment of inertia.



Angular velocity and linear speed

The linear speed at the end of a lever can be calculated using the formula:

linear speed = angular velocity × moment arm (distance from axis to the end of the lever)

A longer arm may in fact decrease angular velocity slightly due to the increased moment of inertia; however, the end of the lever may still be traveling faster due to the longer moment arm.

doc-41953

PRACTICAL ACTIVITY Levers and projectile motion

Goal

To measure the effect that a long lever such as a ball launcher (dog toy) can have on the length of a throw.

Instructions

You will require at least one ball launcher and a ball. Set up a long measuring tape and measure your longest throw with and without the ball launcher.

You may need multiple throws to get used to throwing with the ball launcher so that you acquire the skill.

Primary data/Reflection

Note the effect the launcher has on the speed of release.

	Distance (m)
Longest throw	
Longest throw with the ball launcher	

Questions

1. Identify the axis, force and resistance in this third-class lever.
2. How does the ball launcher manipulate the resistance arm of the lever compared to a normal throw?
3. With reference to mechanical advantage and using data, explain why people use ball launchers to throw balls.
4. A golf club is also a third-class lever. Using your understanding of levers and mechanical advantage, explain why there might be an advantage to having a longer club.

4.4 Activity

4.4 Quick quiz on

4.4 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	4, 5, 7	2, 6

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TEST your understanding

1. **Label** the diagram of a person doing a sit-up with the following:
   - axis (A)
   - resistance arm (R)
   - force arm (F).
2. There are three classes of lever. **Explain** the difference between them.
3. **Identify** which measurement you get when dividing the force arm by the resistance arm.
4. **Discuss** the advantage of having a longer resistance arm in terms of range of motion and mechanical advantage.



APPLY your understanding

5. A young tennis player is 'choking' the racket by holding it closer to the head and further away from the grip. **Discuss** how this alters the mechanical advantage of this lever.
6. Using your understanding of mechanical advantage, **discuss** why using a longer hammer might increase the distance of the throw.



7. **Compare** the mechanical advantage of a golf club swing versus a cricket bat swing. How does the length of the lever arm affect the distance of the shot?

4.4 Exam questions

Question 1 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.4; © VCAA* 68425

The advantage of a second-class lever is

A. an increase in the angular velocity of the lever.
B. an increase in the range of motion of the lever.
C. a decrease in the force required to move a mass.
D. a decrease in the mechanical advantage of the lever.

Question 2 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.9.a;* © VCAA

In golf, a driver (a long club with a large striking head) can hit a golf ball further than a 9-iron (a shorter club with a smaller striking head). They are approximately the same mass despite their difference in length.

Based on your understanding of biomechanical principles, give **two** reasons why the driver can hit the golf ball further. Your response should include reference to how the following will impact performance:

- lever length
- conservation of momentum

Question 3 (4 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.6.a;* © VCAA

A lacrosse stick is used to throw and catch. It is a type of lever with a net at one end.



a. The lacrosse stick shown in the image above is an example of which class of lever? **(1 mark)**
b. **Explain** the mechanical advantage of a lacrosse stick and the impact that this mechanical advantage has on velocity during a throw. **(3 marks)**

Question 4 (2 marks)

Identify and **justify** what class of lever kicking a ball is.



Question 5 (2 marks)

Describe what is meant by mechanical advantage and **outline** how this is calculated.

More exam questions are available in your learnON title.

4.5 Projectile motion

Key knowledge	Key skill
• biomechanical principles for analysis of human movement: – projectile motion (height, angle and speed of release)	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Kinematics is the study of movement with reference to time, distance, displacement and velocity. It studies things such as how fast or how far bodies move, without being interested in what causes these objects to move the way they do (which is covered by kinetics). By using kinematic concepts, coaches and athletes can better understand human movement and develop techniques to maximise performance.

4.5.1 Projectile motion

As soon as an object or body is released into the air, it becomes a projectile and is automatically under the influence of two external forces: gravity and air resistance.

A projectile is any airborne object and includes sporting equipment such as balls, shots, javelins and discuses as well as people (e.g. a long jumper, high jumper or diver).

Factors affecting the path of a projectile

Gravity affects a projectile vertically by forcing it to the ground. If there was no gravity on Earth, a javelin or shot-put might continue through the air forever, and a volleyballer who launches into the air to block a ball would continue upwards until they hit the roof!

Air resistance will affect a projectile horizontally by slowing it down, thereby reducing the horizontal distance travelled by the projectile. Some sports, such as golf and cycling, go to great lengths to reduce the effects of air resistance (see figure 4.35). For example, cyclists wear aerodynamic clothing and helmets, and golf balls have dimples on their surface to reduce air resistance, which enables the golfer to hit the ball further.

FIGURE 4.35 The surface of a golf ball has dimples that reduces air resistance, while cyclists wear aerodynamic clothing and helmets to cycle faster.



The main factors of projectile motion that athletes can control and manipulate are the:

- speed of release
- angle of release
- height of release.

Coaches and athletes will manipulate these three factors depending on the aim of the sport and what they are trying to achieve. For example, the objective of a discus thrower is to throw the discus a maximal distance horizontally. The high jumper, however, is aiming for maximal vertical distance. It is easy to see how these different objectives would affect the optimal angle of release for these athletes. For a basketballer shooting a basket, the aim is accuracy; they therefore need to calculate the optimal height, angle and speed of release depending on where they are on the court as well as whether a defender is trying to block them or not.

4.5.2 Speed of release

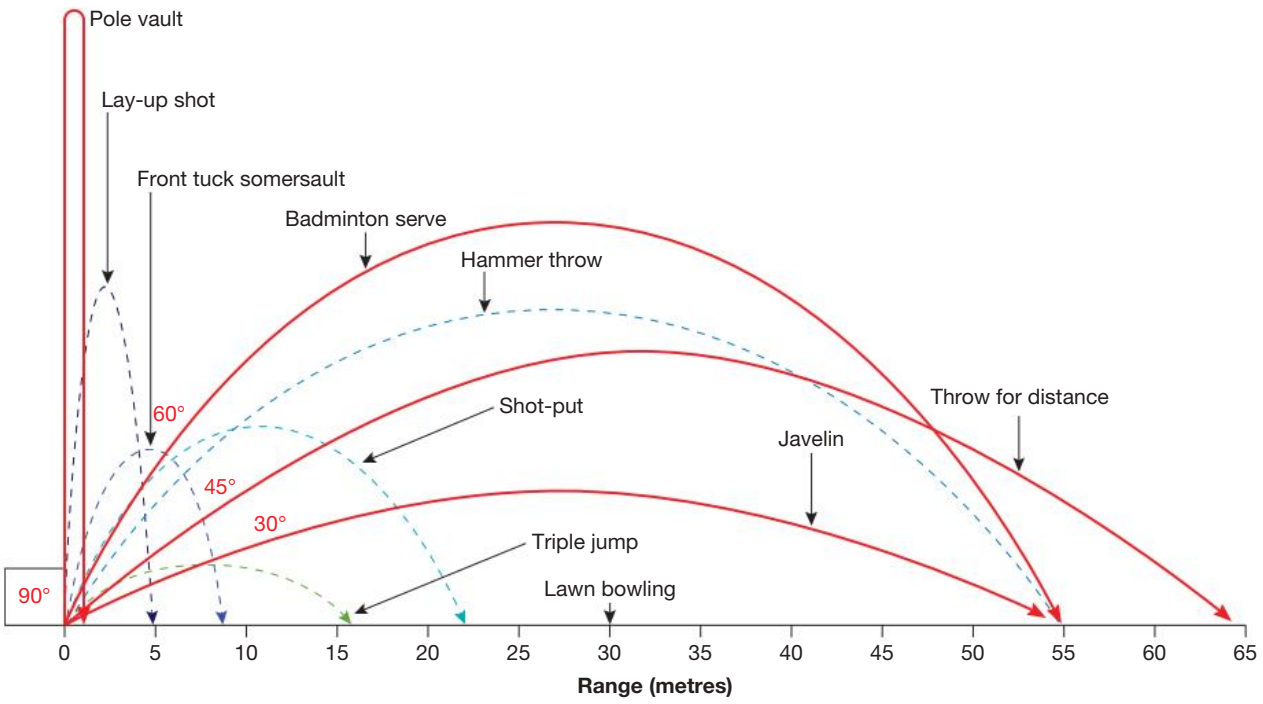
The force applied to the projectile will have a large impact on its motion. The force can vary in amount as well as in the direction of application. The greater the force applied to the projectile, the greater the speed and the further it will travel, all other factors being equal. A technique to increase force is to use as many body parts as possible (as discussed in the section on force summation).

4.5.3 Angle of release

In sporting situations where maximal horizontal distance of a projectile is desired, there is an optimal angle of release, to minimise the effects of both gravity and air resistance. In these instances, the desired angle of release should be referenced to 45 degrees. A shot-putter, for example, has an optimal angle of release of just below 45 degrees because they are releasing the shot from the shoulder, which is approximately 1.5 meters (depending on the height of the athlete) above the landing point of the ground.

Some sporting situations that require accuracy demand that the angle of release be higher or lower than 45 degrees (see figure 4.36). For instance, in events where the ideal trajectory (the flight path of the projectile) is low, then the angle of release will be well below 45 degrees. An example of this is a tennis forehand from the baseline, where the ball should be kept as low as possible when going over the net.

FIGURE 4.36 The optimal angle of release is determined by the needs at any given time. This graph shows some examples of typical angles of release that would be deemed ideal in a variety of contexts.



The opposite would occur in a volleyball set, where the aim is to achieve height so that the ball reaches a hitter with height. The angle of release, therefore, should be higher than 45 degrees. In fact, the angle should be high enough to achieve its aim; in these instances, it is not necessary to reference 45 degrees.

FIGURE 4.37 The angle of release from the setter should give the outside hitter enough time to complete their run up and spike the ball with speed and power.



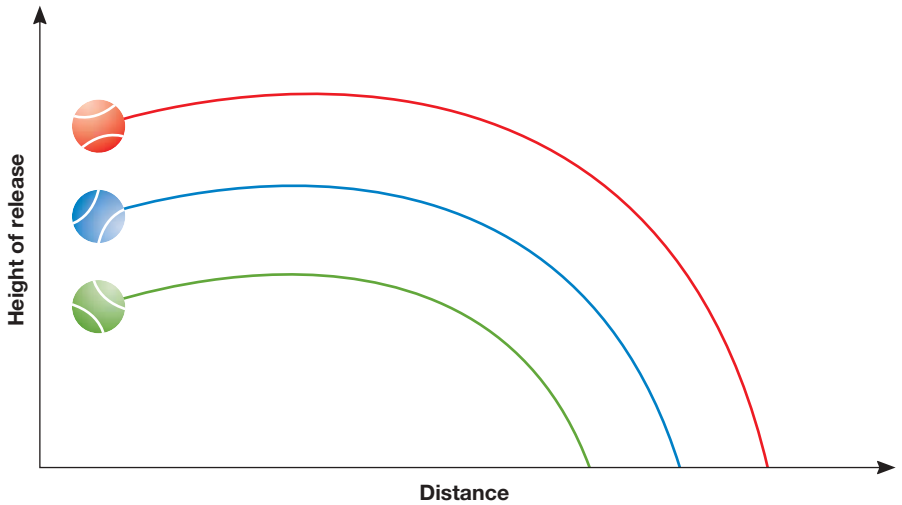
on Resources

Interactivity Throwing a cricket ball (int-1831)

4.5.4 Height of release

Another factor that may affect the distance a projectile will travel is the height of release. If the angle and speed of release are constant, an object released from a higher point will travel further than one released from a lower point (see figure 4.38). A taller athlete who naturally releases a ball when throwing would therefore have an advantage over a shorter athlete.

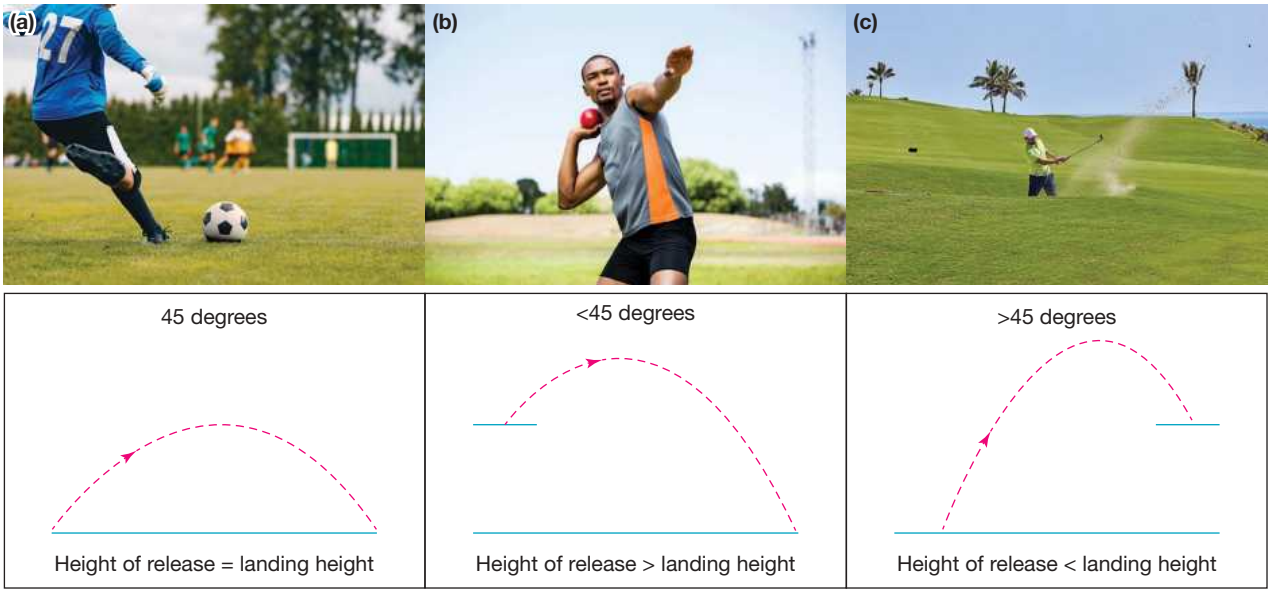
FIGURE 4.38 All other factors being equal, the higher the release, the further the projectile will travel due to having greater time in the air.



When maximal horizontal distance is the objective and the:

- height of release is the same as the landing height, the best angle of release is 45 degrees (see figure 4.39)
- height of release is higher than the landing point (i.e. shot-put), the optimal angle of release is less than 45 degrees
- height of release is lower than the landing point, the optimal angle of release is above 45 degrees.

FIGURE 4.39 (a) To achieve maximal horizontal distance in soccer, the best angle of release is 45 degrees. **(b)** An angle of release less than 45 degrees will help the shot-putter achieve maximal horizontal distance, as the release height is higher than the landing point. **(c)** In golf, when the landing point is higher than the release point, the optimal angle of release is above 45 degrees.



doc-41954

PRACTICAL ACTIVITY Projectile motion

Goal

To manipulate the height, angle and speed of release of a projectile while playing quoits.

Instructions

Play 4 rounds of quoits with a small group of students.

Round 1: set the spike up 3 meters from a throw line and play, with each player taking turns to throw 5 quoits.

Round 2: move the spike so that it is sitting 3 meters away but on a desk in a higher position from the ground. Players take turns to throw 5 quoits each.

Round 3: Move the spike back so that the distance is 10 metres. Players take turns to throw 5 quoits each.

Round 4: Move the spike so that it is 3 meters from the throw line, but this time have a stationary defender stand between the throw line and the spike. Players again take turns to throw 5 quoits each.



Primary data/Reflection

Reflect on how the thrower had to manipulate the height, angle or speed of release to be successful during each round. Also consider any environmental factors that may have influenced the flight of the quoit.

Questions

1. In which round did the speed of release need to be the fastest? Why?
2. Using your understanding of projectile motion, explain how the thrower would most likely manipulate the angle of release to ensure accuracy between round 1 and round 2. Why is this necessary?
3. How does putting a defender in between the thrower and the spike affect all three variables of projectile motion?
4. Compare the differences between the three variables of projectile motion (height, angle and speed of release) for a basketballer who is performing a free throw versus a slam dunk.

4.5 Activity

4.5 Quick quiz on

4.5 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4	3, 5	2, 6

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TEST your understanding

1. **Identify** what the term *projectile* means when discussing biomechanical principles.
2. When throwing a javelin, **explain** why the optimal angle of release is below 45 degrees.
3. A person standing on the mark while their opponent takes a shot at goal in AFL football should put their hands high in the air. **Predict** what this means for the trajectory of the kick.

APPLY your understanding

4. You kick a soccer ball from the ground into the air at an angle of 30 degrees. It lands 20 metres away.
   a. **Describe** how the ball is affected by external forces once in the air.
   b. For the next kick, your objective is to kick the soccer ball further. **Describe** three things that you could do to achieve this.
5. The optimal angles of release for three different sports are as follows: high jump — 60 degrees; a throw for distance — just below 45 degrees; a javelin throw — 30 degrees. **Draw** a graph to visually represent this information. You must label both axes and include all necessary information.
6. Using your understanding of the three variables in projectile motion, **explain** the advantage of being tall when serving in tennis.

4.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.8*; © VCAA

A beginner basketballer often misses shots for goal by throwing the ball directly at the ring.

To increase the chance of a successful shot, a coach may suggest

A. standing closer to the basket.
B. increasing the angle of release.
C. decreasing the angle of release.
D. increasing the speed of release.

Question 2 (1 mark)

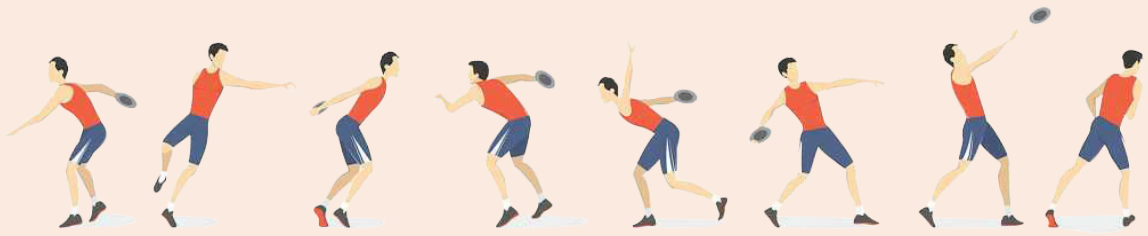
Which of the following best describes the relationship between the height of release and the distance travelled?

A. The higher the height of release, the less distance travelled.
B. The lower the height of release, the less distance travelled.
C. The higher the height of release, the greater the distance travelled.
D. The lower the height of release, the greater the distance travelled.

Question 3 (3 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.5.b*; © ACHPER

In a discus event, an athlete attempts to throw the discus a further distance than his or her competitors.



Elite male discus throwers are typically over 2.0 metres in height.

Referring to the factors impacting on projectile motion, **explain** why being tall can be an advantage when throwing a discus.

You may use a diagram to assist your explanation.

Question 4 (2 marks)

Consider these two different shots in basketball.

Three-point shot	Free throw
	

Suggest and **justify** which shot would require the lower angle of release.

Question 5 (3 marks)

Using your understanding of height, angle and speed of release, **describe** the optimal conditions for a record-breaking javelin throw.

More exam questions are available in your learnON title.

4.6 Equilibrium and stability

Key knowledge	Key skill
• biomechanical principles for analysis of human movement: – 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)	• analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

4.6.1 Equilibrium

Equilibrium is a term commonly used in sport. It refers to a state in which there is a balance of forces or influences in opposition to each other. Equilibrium is seen when all parts of a body are at rest, such as a ball stationary on the ground or a gymnast balanced on a beam (see figure 4.40). This is an example of a body experiencing **static equilibrium**. Equilibrium can also be seen when all parts of a body are moving with the same constant velocity created by balanced forces (see figure 4.41). This refers to **dynamic equilibrium**.

FIGURE 4.40 This gymnast is balanced as she is controlling her equilibrium, but she is unstable. It would be easy to push her over.



FIGURE 4.41 These Sumo wrestlers are both balanced and stable. It would be difficult to push a Sumo wrestler over!



4.6.2 Stability and balance

Stability and **balance** are important in many sports, particularly where force is required to move another human body, such as in a rugby scrum, or where force is required to resist movement, such as a rugby player not wanting to be shifted. The term 'stability' refers to the degree to which a body resists changing its equilibrium. Balance is the ability to control the state of equilibrium. This balance can refer to a person being in control of their body position while stationary (e.g. a gymnast holding a steady handstand; an example of static balance) or it can refer to a person in control of their body position while moving. An example of this would be a squash player or netballer moving with speed and control on the court (see figure 4.42).

static equilibrium the state in which a body has zero velocity and zero acceleration. A body is in equilibrium when the sum of all forces and the sum of all movements acting on the body are zero

dynamic equilibrium the state in which a body is in motion with a constant velocity

stability the degree to which a body resists changing its equilibrium

balance the ability to control the state of equilibrium

FIGURE 4.42 Netballers use both static and dynamic balance on the court. They need to be in control of their bodies while still and while moving.



4.6.3 Some important stability definitions

The centre of gravity (COG) is the central point of an object around which all of its weight is evenly distributed and balanced. This point shifts with every movement of the body (see figure 4.43).

FIGURE 4.43 A person's centre of gravity (red dot) moves when body parts are shifted from one position to another.



The line of gravity is an imaginary line that passes through the centre of gravity and continues down into the centre of an object's base of support (see figure 4.44).

The base of support refers to the area of an object that is in contact with the surface supporting it.

FIGURE 4.44 The further an object's line of gravity is from its base of support and its line of gravity, the greater the instability and rotation.

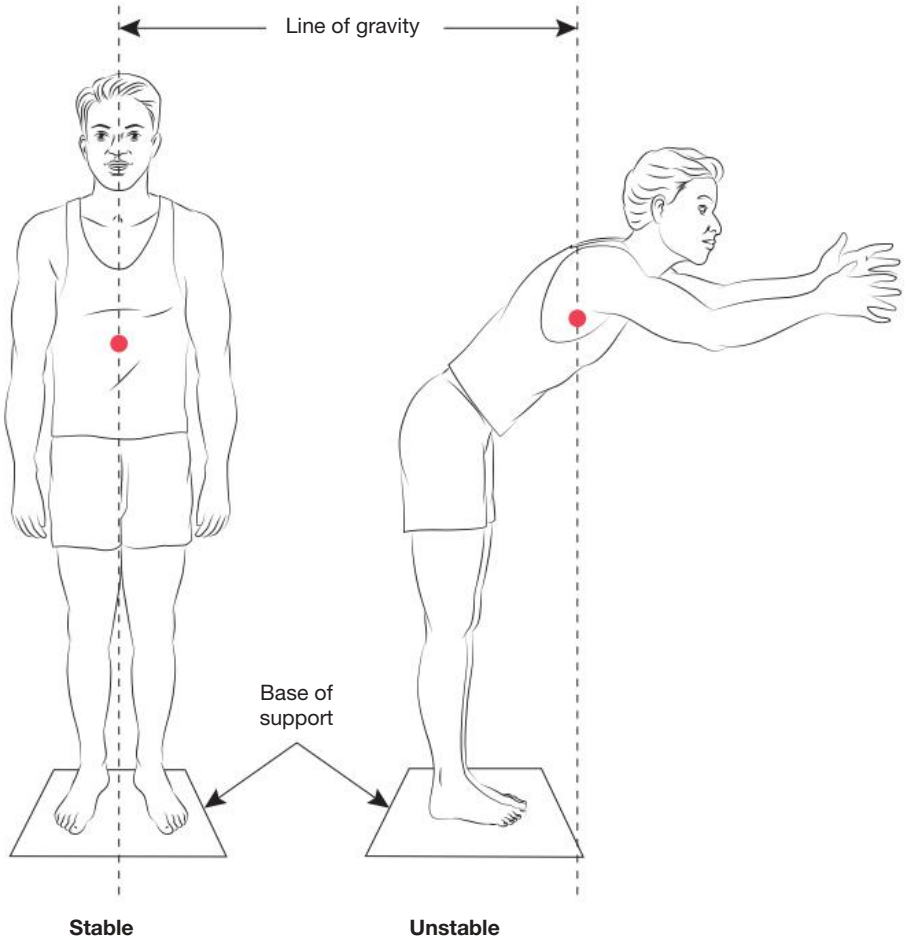


TABLE 4.4 Tips for increasing or reducing stability and balance

	Tips	Example
Increasing stability and balance	• Lower the centre of gravity. • Ensure the line of gravity is over the base of support. • Increase the size of the base of support. • Increase the friction between two or more bodies. • Increase the mass. • Extend the base of support in the direction from which a force is coming.	In order to increase stability and maintain balance, the surfer lowers their centre of gravity by bending their knees, widens their base of support by widening their stance on the board and ensures that their line of gravity remains within their base of support (see figure 4.45). Surfers will also use wax on their surfboards to increase friction.
Reducing stability and balance	• Raise the centre of gravity • Shift the line of gravity to the edge or outside the base of support. • Narrow the base of support. • Decrease the friction between two or more bodies. • Decrease mass.	The sprinter will reduce their stability by raising their centre of gravity and shifting their line of gravity to the very front edge of their base of support (see figure 4.46). This enables a fast start. If their body is in a stable position, it will be harder to disrupt their equilibrium and start the race.

FIGURE 4.45 A surfer needs to increase their stability and maintain their balance on the changing waves.



FIGURE 4.46 A sprinter needs to reduce their stability and maintain their balance to enable a fast start.



doc-41955

PRACTICAL ACTIVITY Crouch start with weight forward and back

Goal

To explore the effects of the line of gravity on stability during a crouch start.

Instructions

Choose a partner to race against in a 20-metre sprint race. Both partners must use a crouch start; however, one person should shift their line of gravity to the front edge of their base of support by leaning forward, and the other must shift their line of gravity to the back of their base of support by leaning back.

Have someone time the 20-metre sprint for both partners and then swap roles and collect times again. Have a 5-minute rest break between races.

Primary data/Reflection

- Record the times of the 20-metre sprint into a table.

	Line of gravity forward	Line of gravity backward
Partner 1		
Partner 2		

- Describe any differences you noticed in your body positioning and muscle engagement between the forward and backward line of gravity positions.

Questions

1. Using the data from race 1 and 2, identify which method of crouch start was the fastest.
2. In which starting position was the athlete the least stable? Why?
3. Using your understanding of stability, discuss how the racers manipulated their line of gravity within their base of support and explain the performance benefit by comparing both starting positions.

4.6 Activity

4.6 Quick quiz on

4.6 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	4	3, 5

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TEST your understanding

1. A surfer is told by a coach to bend their knees and crouch down. **Outline** the impact that this will have on the surfer's stability and why.
2. **State** what advice you would provide to a surfer to increase their stability.
3. **Explain** what is meant by the terms *static balance* and *dynamic balance*. Give an example of each in gymnastics.
4. A gymnast must be both stable and unstable throughout a floor routine. **Identify** an example of when they would want to be stable and an example of when they would want to be unstable. **Describe** how they manipulate their base of support, centre of gravity and/or line of gravity to become stable and unstable.

APPLY your understanding

5. You are a sumo wrestling coach. Your task is to **explain** to your sumo wrestlers how they can increase their stability and balance using the terms *centre of gravity*, *line of gravity* and *base of support*.

4.6 Exam questions

Question 1 (1 mark)

To avoid being tackled to the ground in rugby, players require great stability.

Which of the following increases stability?

A. Higher centre of gravity
B. Lower centre of gravity
C. Having your feet close together
D. Standing up as tall as possible

Question 2 (3 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.3;* © VCAA

A rugby player is about to tackle an opponent who is running directly towards them.

Describe how the rugby player can adjust their line of gravity in relation to their base of support in order to improve their stability prior to contact with their opponent.

Question 3 (5 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.9;* © VCAA

The sport of skateboarding will be featured for the first time at the Tokyo Olympic Games. One of the two disciplines on the skateboarding program at the Tokyo Olympic Games will be the street skateboarding competition.

This competition will be held on a street-like course featuring stairs, handrails, kerbs, benches, walls and slopes. A variety of tricks will be performed, such as sliding the skateboard along the kerbs or handrails. Competitors will complete two 45-second runs on the same course with approximately one hour between runs. Their five best tricks will be scored.

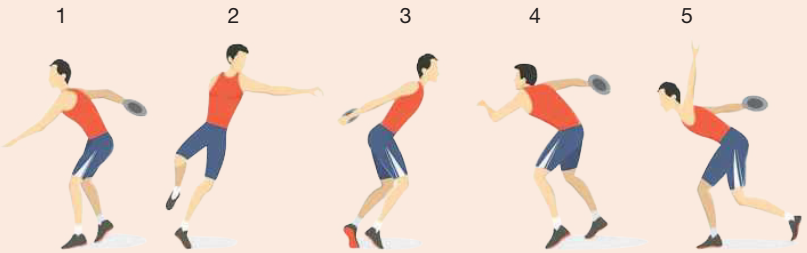
a. **Explain** the importance of balance for street skateboarding. **(2 marks)**
b. The image below shows a skateboarder performing a trick. **(3 marks)**



From a biomechanical perspective, **describe** how a skateboarder could manipulate their centre of gravity, base of support and line of gravity to improve stability when performing the trick shown above.

Question 4 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.5;* © ACHPER



Identify the most unstable throwing position in the image above, using the number assigned to it, and **outline three** reasons to support your choice, making specific reference to the image.

Question 5 (2 marks)

Identify a sporting event that requires dynamic balance, and **justify** your selection.

More exam questions are available in your learnON title.

4.7 Qualitative analysis of movement skills

Key knowledge	Key skill
• qualitative movement analysis stages (preparation, observation, evaluation and error correction)	• perform a qualitative movement analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

4.7.1 Qualitative movement analysis

Qualitative movement analysis involves using a systematic approach to analyse the performance of skills, and to then provide feedback to the performer about the quality of those skills.

When a spectator says ‘great catch’ at a cricket match, they are using a simple and incomplete form of qualitative analysis. A more thorough qualitative analysis uses a four-stage approach that involves preparation, observation, evaluation and finally an error-correction stage (see figure 4.47). This provides coaches with a framework to observe an athlete and provide relevant feedback to improve performance (see figure 4.48). You may like to remember the stages using the mnemonic **P**lanes **O**ver **E**astern **E**urope, where the P, O, E, E corresponds to preparation, observation, evaluation and error-correction, respectively.

FIGURE 4.47 The four stages of qualitative analysis.

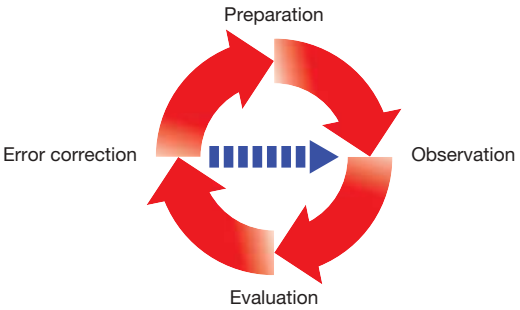


FIGURE 4.48 Qualitative analysis provides coaches with a framework to observe performance and provide feedback to an athlete.



4.7.2 Preparation

The first task in performing a qualitative analysis is to gather the relevant knowledge. During this phase, the coach conducting the analysis should gather information about:

1. the critical features of the skill (i.e. the parts of a movement that are important for success) — this can be gained through years of experience in the sport, as well as through research, including watching and analysing the techniques of the world’s best performers
2. the performer/s
3. the requirements of the observation stage — the coach may need to organise equipment, facilities, recording devices, etc.
4. what constitutes effective instruction — for example, the teaching and coaching strategies available to correct technique in the particular sport.

4.7.3 Observation

During this task, the skill is recorded/measured. This might involve watching the performer or digitally recording them performing the movement. The details of the observation will have been planned during the preparation. The purpose of this task is to gather and organise the information. The observation task involves the actual recording/measurement of the skill. It is important to note that there are advantages to digital recording in this stage. Performances can be replayed and slowed down, as well as shown to the performer themselves. Direct observation cannot do any of these things, but it remains a very practical and cost-free method.

4.7.4 Evaluation

In this stage, the coach will identify the errors in, and the positive aspects of, the performer's technique (i.e. their strengths and weaknesses). This is where a coach's experience in the sport is critical and the research that they performed in the preparation stage is used to identify the difference between the performer's technique and world's best practice.

4.7.5 Error correction

Once the strengths and weaknesses of the performer's technique have been established, the coach can use this information to improve the player's performance. They can provide verbal feedback, and they can also plan training sessions and drills to modify the techniques that were identified as requiring improvement.

- *Feedback.* Providing verbal feedback is a common method of error correction (see figure 4.49). It can be given as corrective instruction with the aim of providing the performer with knowledge about their performance and how to improve their technique.
- *Modify practice*. During practice, tasks can be broken into parts, made easier or there can be less focus on the outcome and more on the technique (see figure 4.50). Practice can also be undertaken in a closed environment to focus on skill development.

FIGURE 4.49 Verbal feedback is a common method of error correction to help the athlete improve their technique.



FIGURE 4.50 A basketball player can modify their practice by concentrating on a particular part of the shooting technique.



4.7.6 Qualitative analysis of movement skills in action — tennis serve

CASE STUDY

Biomechanical analysis of stroke production

Introduction

- How do I modify stroke production to improve performance? That is, how does the player:
  - **a.** hit the ball more powerfully with control;
  - **b.** manoeuvre the ball to different parts of the court in order to create a better tactical game situation.
- How do I reduce the potential for injury in the following situations?
  - **a.** During player development as the body matures
  - **b.** For the tournament player, who is required to repeatedly perform — how do I reduce the incidence and severity of overuse injuries?

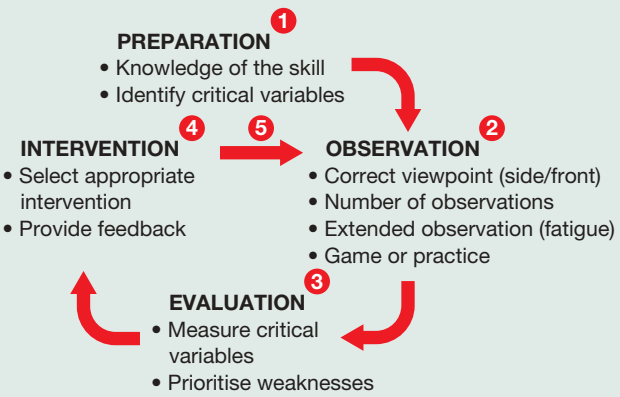
Achieving these results requires an effective analysis structure. A systematic approach to analysis generally requires five stages (see figure 4.51) to permit the coach to 'see and then evaluate' what is happening during stroke production. Such an approach enables the coach to confidently analyse movements at all levels of development.

The preparation phase of the analysis process involves identifying the critical mechanical variables that underpin stroke development. Armed with the knowledge of these critical variables or key ingredients, you can observe and evaluate the performance of any stroke. Some of these critical variables include:

- level of rotation of the hip and shoulder alignments in groundstrokes (separation angles)
- racket trajectory pre- and post-impact in creating 'heaviness' in stroke production
- level of knee flexion prior to the drive phase of the serve
- positioning of the 'line of drive' from the feet through the lower limbs to the trunk in the serve
- the alignment of the racket and hand in a volley.

All of these must be formatted in your mind prior to commencing the actual analysis and will likely change with player age (or even gender).

FIGURE 4.51 5-stage analysis process — a key to effective analysis (modified from Knudson & Morrison, 2002)



Remember:

- These critical features of stroke production will vary depending on the stage of player development. For example, in the serve, rhythm may be the most important aspect of early learning, whereas internal rotation at the shoulder may be an area needing development as players mature (i.e. for a 16-year-old).
- The need for variability in stroke production will dictate the mechanical factors that are emphasised at the various stages of development (Elliott, Reid & Crespo, 2009). For example, in 'building' a forehand, it is important to hit balls of various heights, spin types and court locations. In the world of biomechanics, a coach may approach the analysis of stroke production in a number of ways:
  - Qualitative analysis: use of the eyes attached to a thinking mind (here, video may be used in the observation phase to provide more detailed and repeated viewings of performance). This is the type of analysis used by coaches on an everyday basis.
  - Two-dimensional (2D) quantitative analysis: use of video with appropriate software (e.g. Dartfish or Siliconcoach) to measure features of performance that are clearly 2D — that is, the movement is in one plane (i.e. planar). Obviously, this kind of software can also be used to assist in qualitative analysis. For example, you might draw a line on a sequence of frames (the head in a forehand drive) to qualitatively appraise some aspect of balance. Make sure that you place your camera

perpendicular to the line of motion if you intend to measure any 2D angles or distances from the video.

- Three-dimensional (3D) quantitative analysis: this level of analysis would only be used with national level programs, where a player has problems with injury or power generation. Coaches can use data from 3D analyses of players to improve their ability to qualitatively analyse performance.

How then can a coach use biomechanics and the methods of analysis most readily available to them (e.g. qualitative and 2D quantitative) to shape their approach to technique development? Let me use a series of images from Andy Roddick's serve to explain. As a coach, you may do some or all of the following. The points listed are examples of what may be performed and a comprehensive list can be found in Elliott, Reid and Crespo (2003, 2009).

With a sound understanding of the biomechanics of stroke production (preparation), the coach can analyse movement effectively (observe and evaluate) and then start the very difficult task of modifying motion (intervention) — by far the hardest part of the analysis structure. Remember, the learning pathway requires you to look for different mechanical aspects of stroke production at the various stages of development.

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Bruce Elliott (Winthrop Professor of Biomechanics, The University of Western Australia)

ITF Coaching and Sport Science Review 2010; 50 (18): 5–6

Roddick sequence Mechanical feature of interest	Free throw	Qualitative analysis
	• Balance • Position of the racket and ball to body • Position of the feet relative to each other • Position of the hips and shoulders • Alignment of the trunk	• The distance between the feet • Alignment of the trunk (hips and shoulders)
	• Angle of the front arm (a characteristic of the Roddick serve, where he positions the ball closer to the body — permits good back-hip drive) • Knee flexion and position of both knees (drive-line to the ball) • Hip and shoulder alignment rotations (both horizontal and vertical) • Position of the back to the front foot	• The inclination angles of the shoulder and hip alignments • Rotation of hip and shoulder alignments • The height of the ball toss compared with player standing height • The level of knee flexion

	• Position of the racket relative to back (away from the back and with respect to the hips) • Level of external rotation at the shoulder • Leg and particularly back-hip drive • Position of the head and front arm	• The position of the racket to the back • The velocity of the back-hip during the upward drive • Alignment of the forearm to the court (indicator of maximal external rotation at the shoulder)
	• Position of the head • The rotation of the trunk from A to D (check movement of the trunk about the 3 axes of rotation, particularly shoulder-over-shoulder) • Presence of internal rotation	• Flexion angle of the trunk • Hip alignment • Position of the back compared with front hip joint
	• Body positions at impact (vertical, forward-back and laterally with respect to body) • Alignment of racket and forearm • Shoulder abduction angle • Trunk flexion • Position of head and non-racket arm	• Impact position (vertical, forward-back and laterally with respect to body) • Alignment of the racket and the forearm • Shoulder abduction angle
	• Follow through of racket (include forearm pronation and shoulder internal rotation) • Landing position and preparedness for next stroke • Arabesque of back leg (following landing — not in image shown here) • Balance	• Landing position in the court — both forward and lateral • Flexion angle of the trunk

4.7 Activity

4.7 Quick quiz on

4.7 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4	3, 5	2

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TEST your understanding

1. **Describe** the key features of the preparation stage of a qualitative analysis.
2. You will notice that figure 4.47 has a dotted line between 'error correction' and 'observation'. **Explain** why this dotted line may be included in the model.
3. **Construct** a training drill that a swimming coach could use during the error-correction phase to improve the freestyle kick of a 10-year-old swimmer.
4. **Name** the stage where the coach would identify critical features involved in a golf swing.

APPLY your understanding

5. Choose a closed skill to analyse. You will then film the skill and complete a qualitative analysis. You should **compile** this as a report that uses the following headings: preparation, observation, evaluation and error correction.
   - You should write a preparation document, conduct an observation and evaluation and then document some feedback for the performer in the evaluation section.
   - Please note: you may not have the specialised equipment necessary for an accurate analysis; however, follow the steps and do your best with the resources that you have available.
   - Use the content of subtopic 4.7 as a guide for what is required for each part of your analysis.
   - Once you have completed your report, it may be helpful to compare it to those of your classmates so that you can help each other correct errors in your knowledge and extend your understanding of the qualitative analysis of movement.

4.7 Exam questions

Question 1 (1 mark)

Qualitative analysis can be provided by a coach to an athlete. **Identify** which stage of qualitative analysis this image shows.



A. Preparation
B. Observation
C. Evaluation
D. Error correction

Question 2 (2 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.9.b*; © VCAA

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.

Question 3 (2 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.9.c*; © VCAA

Outline two limitations of using direct observation to analyse the golfer's swing technique.

Question 4 (2 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.9.d*; © VCAA

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.

Outline the two remaining steps in a qualitative analysis that the coach is undertaking in order to be able to give feedback to the golfer about their swing technique.

Question 5 (1 mark)

Describe qualitative analysis.

More exam questions are available in your learnON title.

4.8 Key skills

Key skills

- analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills
- perform a qualitative movement analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

4.8.1 Tell me

To address these key skills, it is important to remember:

- a qualitative movement analysis is a process that a coach can undertake to gain information on the quality of a performer's technique or skills
- the four stages of a qualitative movement analysis are
  - preparation
  - observation
  - evaluation
  - error correction
- the first three stages require an understanding of biomechanical concepts in order to understand the requirements of the sport, gather the relevant information about the performance and then analyse the skills to identify any skill deficiencies
- during the error correction phase, a coach will provide qualitative feedback (knowledge of performance) that the athlete can use to improve their technique, and they will also create training drills to correct any technique deficiencies.

4.8.2 Show me

Practice question (8 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.9; © VCAA*

The coach of an under-nine baseball team suggests that the players use a longer and heavier bat so that they can hit the ball further. After three weeks, the players' performance did not show improvement.



a. Based on your understanding of biomechanical principles, **discuss** why changing the length and weight of the bat did not improve performance. Your response should include reference to:
- angular velocity
- mass
- force
- levers. (4 marks)

b. The team's pitcher, Michael, is also having problems with his *accuracy* and asks the coach for some tips on pitching strikes instead of balls. **Discuss** the stages of a qualitative movement analysis the coach could use to *improve* the pitcher's throwing technique. including *specific examples* for each stage. (4 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Discuss — presents a clear, considered and balanced argument
- **Key terminology** — *accuracy*, *improve*, *specific examples*
- **Key concepts** — biomechanical principles, angular velocity, mass, force, levers, stages of a qualitative analysis
- **Marking scheme** — 8 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

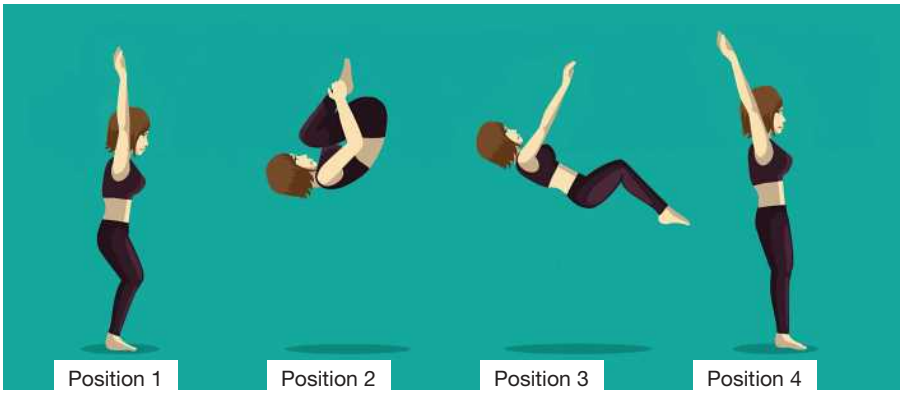
a. In theory, the *advantage* of having a longer bat is that it *increases* the resistance arm of the third-class lever, *decreasing* its mechanical advantage and producing a greater range of motion and a *speed advantage*. But a longer bat requires more force to swing at the same or greater angular velocity due to its greater mass. The under-nine students cannot deliver the *increased force* due to their smaller musculature. This *decreases* the angular velocity, so they don't hit the ball further.
Award 1 mark for identifying the effect of having a longer bat
Award 1 mark for identifying what happens to the bat's mechanical advantage
Award 1 mark for identifying that a longer bat requires more force in relation to angular velocity because of its larger mass
Award 1 mark for identifying why the under-nine students will not improve

b. During the preparation stage of a qualitative movement analysis, Michael's coach would need to *research* the correct pitching technique, *watch footage* of the world's best pitchers and organise a venue and equipment (e.g. camera, balls) to prepare for the observation stage. Footage is then collected during the observation stage by making a *digital recording* of the performance and making notes based on observations. The coach would then *watch* the footage and *evaluate* the technique during the evaluation stage, using the research criteria and knowledge from his experience in the game, noting *areas of strength* and *areas for improvement*. Finally, the coach would work with Michael during the error-correction stage to provide feedback and *strategies/drills to improve* Michael's technique. Perhaps Michael needs to follow through more, or release at a better angle.
Award 1 mark for identifying the preparation stage and some resources required
Award 1 mark for identifying the observation stage and how it could be carried out
Award 1 mark for identifying the evaluation stage and what the coach notes
Award 1 mark for identifying the error-correction stage and what information might be provided to the athlete

4.8.3 Let me do it

Question 1 (9 marks)

FIGURE 4.52 The position of a gymnast as they perform and land a somersault.



a. A gymnast can successfully perform and land a somersault, as seen in figure 4.52.
Explain how they are using the following biomechanical principles to achieve success throughout their performance in each position.

- Position 1 — Newton's Third Law
- Positions 2 and 3 — Conservation of angular momentum
- Position 4 — Impulse **(8 marks)**

b. The gymnastics coach notices that the gymnast is sometimes landing awkwardly and falling backward. They identify that this is due to the gymnast not tucking tightly enough and they develop some strategies to assist. **Name** the stage of qualitative movement analysis during which these strategies would be implemented. **(1 mark)**

4.9 Review

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4.9.1 Summary

Linear and angular concepts of human movement

- Linear and angular concepts of human movement include:
  - inertia and force
  - distance, displacement, speed, velocity and acceleration
  - mass and inertia
  - momentum and impulse
  - summation of forces
  - torque.

Newton's laws of motion

- Newton's First Law of Motion — an object will remain in its state of motion (at rest or at a constant velocity) unless acted upon by an unbalanced external force.
- Newton's Second Law of Motion — when a force is applied to an object, it will accelerate in the direction the force is applied, directly proportional to the size of the force and inversely proportional to the mass $\left(a = \frac{F}{m}\right)$.
- Newton's Third Law of Motion — for every force, there is an equal and opposite reaction force.

Levers

- A lever is a rigid bar made up of an axis, force and resistance.
- Mechanical advantage is a measure of the force or speed amplification generated by a lever.
- Third-class levers are built to amplify speed and so have a mechanical advantage of less than 1. The further below 1 the mechanical advantage of the lever is, the more the lever magnifies speed and the faster the end of the lever will move.

Projectile motion

- A projectile is an airborne object that is only under the influence of gravity and air resistance.
- Three factors affect projectile motion:
  - angle of release
  - height of release
  - speed of release.

Equilibrium and stability

- Equilibrium is when all forces are balanced.
- Stability is the resistance to the disruption of equilibrium.
- Balance is the ability to maintain and control equilibrium while stationary (static) or while moving (dynamic).
- Factors that can affect stability include:
  - centre of gravity
  - base of support
  - line of gravity
  - friction
  - mass.

Qualitative movement analysis

- Qualitative analysis involves observing a movement and using a set of principles to provide feedback about the effectiveness of the movement.
- There are four stages to a qualitative movement analysis: preparation, observation, evaluation and error correction.
- During the preparation phase, the coach identifies critical features of the tasks to be performed, compiles information about the performer and outlines how they will complete the observation and provide feedback to the athlete.
- During the observation phase, the data is collected.
- The purpose of the evaluation is to analyse the performance to determine strengths and weaknesses that has been collected.
- The information from the analysis is used to provide feedback to the athlete and develop a strategy to correct errors in their technique.

4.9.2 Key terms

angular displacement the change of angle between the initial and final position
angular distance the angle between the initial and final position
angular motion takes place when a body moves along a circular path
angular speed the change in angular distance over time
angular velocity the change in angular displacement over time, which indicates how quickly an object rotates
balance the ability to control the state of equilibrium
centre of mass the position where the weight of the object is evenly distributed
displacement the difference between the initial position and final position of an object
distance the length of space between two points
dynamic equilibrium the state in which a body is in motion with a constant velocity
eccentric force a force that is off-centre or not directly through an object's centre of mass
force the product of mass and acceleration
force summation the correct timing and sequencing of body parts to produce maximal force
general motion the combination of linear and angular motion
impulse the product of force and time
inertia the resistance of a body to a change in its state of motion
linear motion occurs either in a straight line or curved path
mass the quantity of matter found within a particular body
moment of inertia a measure of an object's resistance to change in its rate of rotation
momentum the product of mass and velocity; for example, a body with greater mass moving faster will have greater momentum than a lighter object moving slower
motion the change in position of a body in relation to time
Newton's First Law of Motion states that an object will stay at rest or continue to travel in the same direction at a constant velocity unless acted on by an unbalanced force
Newton's Second Law of Motion states that the rate of acceleration of a body is proportional to the force applied to it and in the direction in which the force is applied
Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction
speed the rate of motion (distance/time)
stability the degree to which a body resists changing its equilibrium
static equilibrium the state in which a body has zero velocity and zero acceleration. A body is in equilibrium when the sum of all forces and the sum of all movements acting on the body are zero
torque a force that is applied at a distance away from the centre of mass, that causes the object to rotate
velocity the rate of the speed at which an object moves its position

4.9 Exam questions

4.9 Section A – Multiple Choice questions

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.7;* © VCAA

A tennis racquet that rotates during a forehand stroke experiences

A. linear velocity.
B. angular velocity.
C. linear displacement.
D. an increase in mass.

Question 2 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.10;* © VCAA

If a gymnast goes from a full layout position to a tuck position, what will happen to their angular momentum?

A. It will stop.
B. It will increase.
C. It will decrease.
D. It will remain the same.

Question 3 (1 mark)

An elite cricket player has to modify his technique to prepare for the Twenty20 games. His aim is to be able to hit more balls over the fielders' heads.

The most appropriate method of error correction would be:

A. manual guidance and feedback.
B. mechanical guidance, visual model and feedback.
C. feedback and over-compensation/exaggeration.
D. feedback, visual model and modified practice.

Question 4 (1 mark)

In which of the following events is being stable the least important?

A. Skateboarding in a straight line
B. Paddling on a stand-up paddle board
C. Sumo wrestling
D. The start of a 100-metre sprint

Question 5 (1 mark)

If a gymnast moves from a fully extended position to a tucked position while rotating in the air, their angular velocity will:

A. stop.
B. decrease.
C. increase.
D. remain the same.

Question 6 (1 mark)

A shot-put cannot be thrown as far as a tennis ball when thrown with the same force. Which of Newton's laws does this concept relate to?

A. Newton's First Law of linear motion
B. Newton's Second Law of linear motion
C. Newton's Third Law of linear motion
D. Newton's Third Law of angular motion

Question 7 (1 mark)

Which of Newton's laws supports this scenario? A basketball player shoots the ball. The ball will travel at a constant velocity unless an external force (such as gravity or air resistance) acts on the ball.

A. Newton's First Law of angular motion
B. Newton's First Law of linear motion
C. Newton's Third Law of linear motion
D. Newton's Third Law of angular motion

Question 8 (1 mark)

Which of the following angles of release of projectile motion is inappropriate for the sport?

	Angle	Sport
A	<45 degrees	Long jump
B	>45 degrees	Shot-put
C	>45 degrees	A netballer shooting
D	45 degrees	A golfer driving as far as possible on a flat driving range

Question 9 (1 mark)

A junior basketballer keeps missing shots at the hoop despite a good trajectory. In fact, every shot appears to be an 'air ball' (that is, the ball is not even making the distance to the ring). To improve his shot, the basketballer must:

A. increase the speed of release.
B. decrease the speed of release.
C. increase the angle of release.
D. decrease the angle of release.

Question 10 (1 mark)

A tennis player is choking the tennis racquet by holding it further up the handle (towards the strings). This will:

A. decrease mechanical advantage.
B. increase mechanical advantage.
C. improve the lever for speed.
D. require more force to swing.

4.9 Section B – Short answer questions

Question 1 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.2;* © VCAA

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.

Discuss how a pitcher could successfully use the principle of summation of momentum to produce maximal force while pitching.

Question 2 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.4;* © VCAA

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.



Player A



Player B

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.

Question 3 (2 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.10;* © VCAA

The cyclist ahead is accelerating away from the other cyclist.

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.



Question 4 (7 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.7.b,c;* © VCAA

The graph below shows the serve accuracy data of two badminton players over four training sessions.



How may a coach benefit from using qualitative movement analysis data instead of quantitative serve accuracy data?

After training session 1, Player 2 reported that they were uninterested in attending another session; however, following training session 2, Player 2 was excited to come back.

Referencing the data in the graph and the stages of learning, **analyse** the link between motor skill development, participation and performance.

Question 5 (3 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.9;* © VCAA

The sport of skateboarding will be featured for the first time at the Tokyo Olympic Games. One of the two disciplines on the skateboarding program at the Tokyo Olympic Games will be the street skateboarding competition.

This competition will be held on a street-like course featuring stairs, handrails, kerbs, benches, walls and slopes. A variety of tricks will be performed, such as sliding the skateboard along the kerbs or handrails. Competitors will complete 45-second runs on the same course with approximately one hour between runs. Their five best tricks will be scored.

The image below shows a skateboarder performing a trick.



From a biomechanical perspective, **describe** how a skateboarder could manipulate their centre of gravity, base of support and line of gravity to improve stability when performing the trick shown above.

Continue to build your exam skills

Access the Unit 3 Area of Study 1 Review at the end of Topic 4. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

AREA OF STUDY 1 How are movement skills improved?

OUTCOME 1

On completion of this unit, the student should be able to analyse primary data collected from participation in physical activity, sport and exercise to develop and refine movement skills from an individual and coaching perspective, by applying biomechanical and skill-acquisition principles.

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

REVIEW CONTENT SEQUENCE

U3 AOS1 Extended response — Build your exam skills
U3 AOS2 Practice examination online only
U3 AOS3 Practice school-assessed coursework online only

U3 AOS1 Extended response — Build your exam skills

An essential skill in the Physical Education course is to be able to answer an extended response question that integrates a number of key knowledge points.

The Unit 3 and 4 VCAA examination will include a question that requires you to respond to a stimulus, such as a case study on a particular sport or images or data that may have been collected while participating in physical activity. This question is generally worth 8 marks.

This type of question requires you to show how concepts are interrelated. A high-scoring response will show the connections between the key knowledge, rather than simply discussing each concept independently. To be eligible for a high score, all of these key knowledge areas should be addressed and linked to the information provided in the stem of the question. You will need to determine what is important in the stimulus to inform your response.

These questions are marked holistically, and marks are awarded based on:

- how the response has been structured
- how well the key knowledge has been understood
- the connection between the stimulus material and the response.

Tell me

To address these questions, it is important to remember:

- the demands of different types of skills as they relate to the classifications of discrete, continuous, fine motor, gross, open, closed, simple and complex, as well as the degree to which the skills are mentally and physically fatiguing
- the type of learner as defined by their stage of learning, age, past experience and sociocultural background
- biomechanical principles, which are essential for successful skill performance, relate to force production, conservation of momentum, mechanical advantage of levers, projectile motion and balance and stability
- how the design of practice (distribution, variability and type of practice) best meets the needs of the learner in question and the skill they are attempting to master
- the relationship between the relative experience of the learner and the most applicable type and frequency of feedback

- the relative strengths and weaknesses of both the direct approach to coaching and the constraint-based approach to coaching and when best to employ them
- how important psychological factors, such as confidence, motivation, optimal arousal and concentration, impact performance
- to recommend relevant strategies for developing psychological skills/traits that support skill learning
- to make regular and appropriate use of data to support your answer. Data can be qualitative, such as a written description of a skill performance, or quantitative, such as measurements relating to velocity, angles, weight, height and distance.

Show me

Practice question (6 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

A football coach is trying to teach an under-13 AFL football team how to kick a set shot for goal. He gives each player 10 shots from a cone placed directly in front and just 30 metres out from goal to test their *accuracy*.

The results are below:

Child	Score out of 10	% accuracy
Player 1	0	0
Player 2	2	20%
Player 3	3	30%
Player 4	2	20%
Average accuracy	1.75/10	17.5%

The coach also observes that his players are struggling to make the distance on many of their shots and he begins to formulate some new practice drills. One of the drills involves players kicking to a coach who is standing behind the goal to act as a target and using a long run-up before kicking to increase the distance on the kicks.

Discuss how the data for the under-13 players can be used to improve their kicking. Include an **explanation** of how a drill involving a run-up at the goal can increase kicking distance, and the *advantage* of this approach.

Your response should include reference to:

- feedback
- force summation principles
- the direct and constraint-based approaches to coaching

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Discuss — present a clear, considered and balanced argument
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *accuracy*, *advantage*
- **Key concepts** — feedback, force summation principles, the direct and constraint-based approaches to coaching
- **Marking scheme** — 6 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response

The *accuracy* of the under-13 players kicking 10 shots 30 metres out from the goal was *very low*, with an *average accuracy of 17.5%*. This indicates the drill was *not effective* at helping players *improve their kicking* as they were struggling to make the distance. By *shortening the distance* and having the *coach stand behind the goal as a target*, the players can develop their ability to kick towards a target when stationary and *increase their accuracy*. This is an example of the direct instruction approach and will also allow *specific feedback* to be given from the coach to the individual player. The coach is not using the constraint-based approach for this skill; despite being more enjoyable, it would *not allow* the under-13 players the opportunity to *master their kicking accuracy*, especially if trying to kick while moving, or to receive individual feedback.

The coach would have included a drill with a long run-up before kicking the ball so that the players could *summate more momentum when kicking*. Force summation involves the *correct sequencing and timing of body parts* to produce *maximal force*. That is, they should *first move the slower, heavier body parts* (e.g. the glutes and upper leg), followed by the *lighter, faster body parts* (e.g. the lower leg and foot). The movement of each part should be timed so that the *next body part moves once the previous one reaches maximal velocity*; the previous body part must *stabilise once it passes momentum*, so that the momentum is not lost. This will help the players apply more force to the football and kick further. This direct instruction approach will help players to *develop their kicking skills with specific feedback provided* to each player as they kick. With time, this will also help them *improve their accuracy when kicking towards a goal at a distance*. The coach has not taken a constraint-based approach as it would take the under-13 players longer to master the skill of correctly sequencing the movement of their body parts to produce maximal force, and make it harder to provide individual feedback.

For both drills, the direct instruction approach allows the coach to provide *qualitative feedback* on each player's kicking relative to their *strengths and weaknesses and how they can improve*. The coach would also be able to collect *quantitative feedback* to determine if the *accuracy of the players' kicking is improving*. While both types of feedback are useful, *quantitative data* cannot say how a *player can improve*.

Marking guide

High range response	• The response is well-written and cohesive, continually linking the concepts to the stimulus • Knowledge of results (quantitative feedback) is linked to the data in the table and knowledge of performance (qualitative feedback) is linked to players not making the distance. There is detailed discussion of how each type of feedback can be used to improve players' goal kicking • Force summation is discussed as a way to increase the players' kicking distance and the concept of body parts, sequencing, timing, stabilisation and/or feedback are discussed in detail • Direct instruction is identified as the approach used and the benefits of this style of coaching are acknowledged, including faster initial skill development compared to when using the constraint-based approach. Some information on the role of constraint-based coaching is included • Continuous attempts are made to interrelate the response

Mid range response	• The response makes some links between the concepts and the stimulus but they are not extensive • Knowledge of results (quantitative feedback) and knowledge of performance (qualitative feedback) are identified as feedback strategies but they have not been linked strongly to the stimulus or the data in the table • Force summation is discussed as a way to increase the players' kicking distance and at least some of the concepts of body parts, sequencing, timing, stabilisation and feedback are identified • Direct instruction is identified as the approach used but with little comparison to a constraint-based approach • There is an attempt to interrelate concepts
Low range response	• There is little link between the concepts and the stimulus • At least one type of feedback, either knowledge of results (quantitative feedback) or knowledge of performance (qualitative feedback), is identified • Force summation is discussed as a way to increase the players' kicking distance but no details are provided • Direct instruction and/or the constraint-based approach have been mentioned but with no relevance to the question • No attempt is made to interrelate concepts or link to the stimulus

Let me do it

Extended response questions

learn on

Question 1 (8 marks)

Source: Adapted from *VCE 2021, Physical Education Exam, Section B, Q.4;* © VCAA

A young child is learning how to complete a double somersault in diving. The child uses the springboard to enter a tuck position to perform the two somersaults and then changes their body position to a layout position before entering the water.

The coach used both blocked and distributed practice within one training session to improve the child's skill development.

FIGURE 1 A young chlid in **(a)** a tuck position and **(b)** a layout position

(a)



(b)



Based on your understanding of the practice strategies listed above, explain how the young child performs their dive as part of their training with reference to:

- biomechanical principles
- Newton's Third Law of motion
- conservation of angular momentum.

Question 2 (10 marks)

Australian Jakara Anthony is a world champion mogul skier. Mogul skiing involves skiing down a 250-metre course of snow moguls (bumps) as fast as possible. Jakara takes approximately 20 seconds to complete the course. The competitors are scored and rated on a combination of factors including time to finish the course, mogul-turn technique and the quality of jumps/aerials.



Evaluate the effectiveness of Jakara's technique in reaching a high level of velocity and achieving a competitive race time and explain how she would train and improve with reference to:

- the biomechanical principles of stability and impulse
- feedback
- practice amount and distribution.

Hey students! Now that you have completed the Extended Response, access the following in learnON

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Practice SAC

Receive immediate feedback

Find all this and MORE in jacPLUS



Hey teachers! Now access learnON to assign the quarantined school-assessed coursework

Assign the quarantined school-assessed coursework

Track your students' results

Identify strengths and weaknesses

Find all this and MORE in jacPLUS



UNIT 3

AREA OF STUDY 2

How does the body produce energy?

OUTCOME 2

On completion of this unit, the student should be able to 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.

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TOPIC SEQUENCE

5 Acute physiological responses to exercise 190

6 The interplay of energy systems 227

7 Muscular fatigue and nutritional and hydration strategies 287

UNIT 3 AREA OF STUDY 2 REVIEW

Extended response — Build your exam skills 338

Practice examination ..... online only

Practice school-assessed coursework ..... online only



5 Acute physiological responses to exercise

5.1 Overview

Hey students! Bring these pages to life online

Watch videos

Engage with interactivities

Answer questions and check results

Find all this and MORE in jacPLUS



LEARNING SEQUENCE

5.1 Overview
5.2 Oxygen uptake at rest, during physical activity and during recovery
5.3 Acute responses of the cardiovascular system
5.4 Acute responses of the respiratory system
5.5 Acute responses of the muscular system
5.6 Key skills
5.7 Review

5.1.1 Introduction

Whenever an individual engages in exercise, the body responds physiologically to meet the increased energy demands of the activity. These immediate short-term responses that last only for the duration of the activity are referred to as acute responses. Acute responses can vary depending on the intensity and duration of the exercise. For example, the acute responses to anaerobic activities are mostly related to changes within the muscle, whereas changes to all body systems occur during aerobic activities.

This topic examines the cardiovascular, respiratory and muscular systems and the role of each in supplying oxygen and energy to the working muscles.

FIGURE 5.1 The cardiovascular, respiratory and muscular systems respond acutely to exercise, ensuring adequate oxygen and energy supply to working muscles.

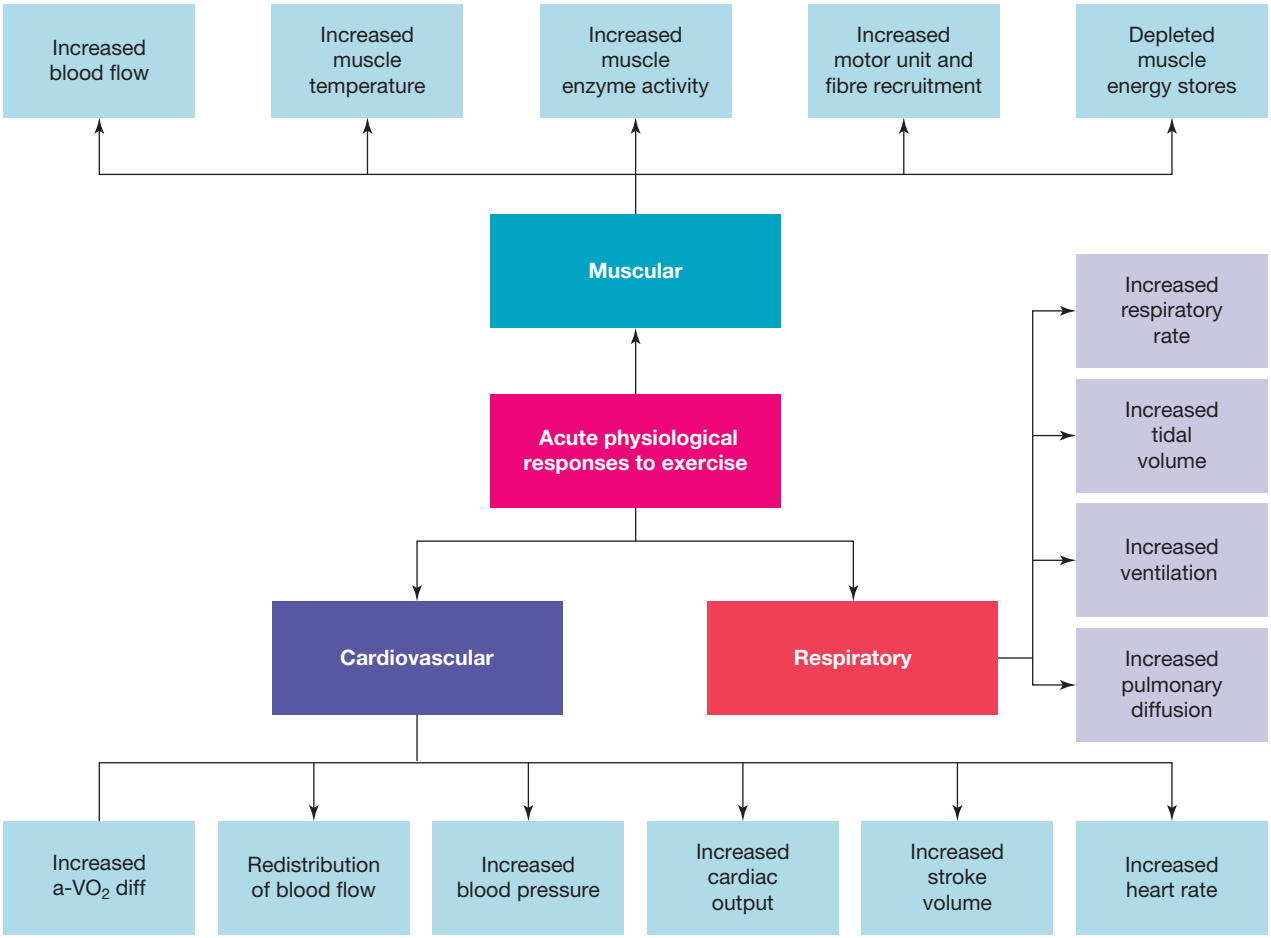


5.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• oxygen uptake at rest, and during physical activity and recovery, including oxygen deficit, steady state and excess post-exercise oxygen consumption (EPOC)	• explain the changes in oxygen supply and demand at rest, and during sub-maximal and maximal exercise	**5.2**
• acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems	• participate in laboratory activities to collect and analyse data on the range of physiological responses the body experiences during exercise	**5.3** **5.4** **5.5**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

5.1.3 Topic preview



5.2 Oxygen uptake at rest, during physical activity and during recovery

Key knowledge	Key skill
• oxygen uptake at rest, and during physical activity and recovery, including oxygen deficit, steady state and excess post-exercise oxygen consumption (EPOC)	• explain the changes in oxygen supply and demand at rest, and during sub-maximal and maximal exercise

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

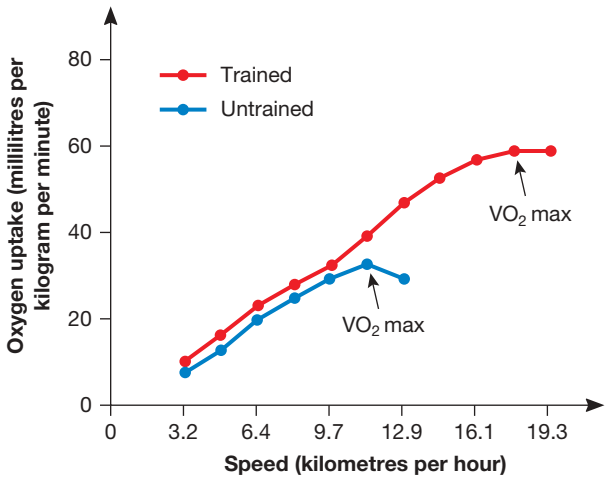
5.2.1 Increased oxygen uptake

Oxygen uptake (VO_2) refers to the amount of oxygen transported to, taken up by and used by the body for energy production. At rest, the body consumes oxygen at a rate of approximately 0.25 litres per minute. When exercise begins, oxygen uptake increases as the working muscles use more of the oxygen made available by the combined efforts of the circulatory and respiratory systems. In fact, there is a linear relationship between oxygen uptake and exercise intensity (see figure 5.2) that is similar to the one between heart rate and exercise intensity. That is, as exercise intensity increases, oxygen uptake increases in direct proportion. This is because the body requires more oxygen to perform at higher intensities. This linear increase continues until a maximum level of oxygen uptake is attained — the **maximum oxygen uptake (VO_2 max)**. No further increase in oxygen uptake can be achieved beyond this maximal value, which is usually around 2–3.5 (absolute value) litres per minute.

oxygen uptake (VO_2) the amount of oxygen transported to, taken up by and used by the body for energy production

maximum oxygen uptake (VO_2 max) the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production

FIGURE 5.2 The relationship between exercise intensity and oxygen uptake



Source: Reprinted by permission from JH Wilmore, DL Costill & WL Kenney, *Physiology of sport and exercise*, 4th ed., Human Kinetics, Champaign, IL, 2008

TABLE 5.1 Comparison of respiratory rate, tidal volume and ventilation at rest and during exercise

	Respiratory rate (breaths/minute)	Tidal volume (L/breath)	Ventilation (L/min)
Rest	12	0.5	6
Submaximal exercise	30	2.5	75
Maximal exercise	45	4.0	180

Oxygen uptake at rest

Oxygen is required for the aerobic resynthesis of ATP. When at rest, the body's need for ATP is relatively small. Minimal oxygen consumption is required to keep body processes going and for minor movements. At rest, the average person consumes about 0.3 litres of oxygen per minute and will usually use a mixture of carbohydrates and fats for energy. The body stores minimal amounts of oxygen. This means that the amount of oxygen entering your bloodstream is directly proportional to the amount used by your tissues for oxidative metabolism. As the body moves from a rest state to an exercise state, the consumption of oxygen increases to allow greater levels of ATP to be produced at the muscle level.

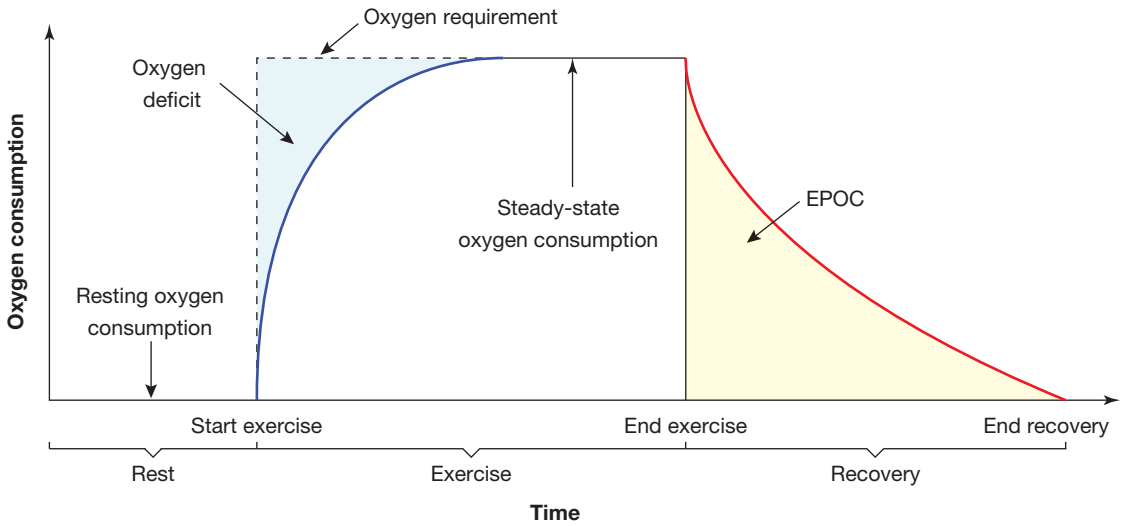
Oxygen deficit

When exercise begins, oxygen uptake increases as the body attempts to meet the increased oxygen demand of the working muscles that results from their need to produce more energy for ATP resynthesis. The respiratory and cardiovascular systems play the major role when increasing oxygen uptake and transport to the working muscles.

However, any time during exercise performance when intensity increases, there is a discrepancy (shortfall) between the required amount of oxygen and the oxygen supplied. This discrepancy is referred to as the **oxygen deficit** (see figure 5.3). Because of this discrepancy between supply and demand, there is increased reliance on the anaerobic pathways for ATP resynthesis during times of oxygen deficit.

oxygen deficit the state in which there is a discrepancy (shortfall) between oxygen supply and the oxygen needed to meet the energy requirements of the activity. The anaerobic pathways must supplement the energy demands of the activity.

FIGURE 5.3 Oxygen deficit, steady state and EPOC



Source: Reprinted by permission from JH Wilmore, DL Costill & WL Kenney, *Physiology of sport and exercise*, 4th ed., Human Kinetics, Champaign, IL, 2008

The oxygen deficit occurs because the respiratory and circulatory systems take some time to adjust to the new oxygen demand (even at low exercise intensities) and, consequently, the amount of oxygen supplied lags behind the amount needed until these systems make the necessary adjustments required to increase oxygen supply (see table 5.2).

TABLE 5.2 Adjustments to the different systems as oxygen deficit occurs

Respiratory system	• Increased respiratory rate (breaths per minute) • Increased tidal volume (depth of breathing)
Cardiovascular system	• Increased heart rate (number of times the heart beats per minute) • increased stroke volume (amount of blood ejected from the heart per beat)

on Resources

Video eLesson Oxygen deficit (eles-2759)

Steady state

Steady state is when oxygen supply equals oxygen demand. It may take anywhere between a few seconds and 1 minute or more, depending on the intensity of the exercise, for oxygen supply or uptake to increase sufficiently to meet the oxygen demands of the exercise. If and when oxygen supply does equal the oxygen demand of the exercise, an aerobic steady state (see figure 5.3) is attained. The increased supply in oxygen enables a greater proportion of ATP to be resynthesised aerobically.

However, if the exercise intensity increases again, the demand for ATP resynthesis and oxygen also increases. Once again, during the short delay before oxygen uptake increases sufficiently for supply to equal demand, the anaerobic pathways must supplement the energy supply. As oxygen uptake increases to the required level, a second aerobic steady state is achieved.

steady state the state in which oxygen supply equals oxygen demand so that virtually all the required ATP to maintain the current exercise intensity is being supplied aerobically.

excess post-exercise oxygen consumption (EPOC) the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest

Excess post-exercise oxygen consumption (EPOC)

After the cessation of exercise, oxygen uptake or consumption does not immediately return to resting levels. Rather, oxygen consumption remains temporarily elevated. This elevated oxygen consumption, which exceeds that normally experienced at rest, is referred to as **excess post-exercise oxygen consumption (EPOC)** (see figure 5.3).

on Resources

Interactivity Oxygen deficit, steady state and EPOC (int-6800)

Factors responsible for elevated EPOC

A number of factors are associated with EPOC, and they can only be understood by looking at the chemical and physical changes that occur in muscle cells during exercise. These changes increase the levels of oxygen consumption and ATP, and they continue for some time after exercise has ceased, including during the recovery phase, when oxygen consumption remains elevated.

The factors associated with the amount and duration of EPOC include:

- elevated muscle temperature
- increased use of mitochondria
- increased ATP production
- restoring CP stores
- lactate production during exercise.

EXAM TIP

Ensure you can confidently explain why relative VO_2 is the preferred way to report VO_2 max.

5.2.2 Factors affecting maximum oxygen uptake

Maximum oxygen uptake, or VO_2 max, represents the maximum amount of oxygen that can be taken up by, transported to and used by the body for energy production. This value is commonly used to determine an athlete's capacity to perform in aerobic (endurance) activities.

Maximum oxygen uptake is affected by a number of factors, including body size, gender, genetics, age and training status (aerobic or cardiorespiratory fitness levels).

Body size

Oxygen uptake is related to body size; a larger, heavier person requires more oxygen than a smaller person (see figure 5.4). It is for this reason that VO_2 max is usually expressed relative to body size in mL/kg/min — so that individuals can be compared, particularly in relation to their aerobic fitness levels, irrespective of differences in body size.

FIGURE 5.4 Oxygen uptake is related to body size — a larger, heavier person requires more oxygen than a smaller person.



Gender

Females tend to have lower oxygen uptake values compared with males of similar age and athleticism. Maximum oxygen uptake values for untrained females can be as great as 20–25 per cent lower than for untrained male individuals. However, when comparing trained athletes, the gap tends to close to about 10 per cent.

Several factors contribute to females having a lower maximum oxygen uptake than do males, including:

- Females typically have a higher percentage of body fat and lower percentage of muscle mass. Body fat does not consume oxygen, unlike muscle tissue.
- Females have lower blood volumes and lower levels of red blood cells and haemoglobin compared with males. This reduces the oxygen-carrying capacity of females as compared with males, as oxygen binds to haemoglobin when being transported around the body.
- Females typically have a smaller lung size and volume and a smaller heart size and volume (due to their on-average smaller body size) than males, thereby reducing their oxygen intake and transport capacity.

Genetics

There is significant evidence to suggest that aerobic capacity is largely genetically determined, with some studies suggesting that heredity may account for up to 25–50 per cent of the variance seen between individuals. Training, however, can result in substantial improvement in maximum oxygen uptake values.

Age

Maximum oxygen uptake tends to decline with increasing age (see figure 5.5). It peaks during late adolescence and early adulthood and then declines from that point. The average rate of decline is generally accepted to be about 1 per cent per year or 10 per cent per decade after the age of 25. However, training and/or maintaining a physically active lifestyle can both increase maximum values and decrease the rate of decline that occurs with increasing age. Usually, the age-related decline in maximum oxygen uptake can be accounted for by a reduction in maximum heart rate, maximal stroke volume and maximal a-VO_2 difference.

FIGURE 5.5 Maximum oxygen uptake tends to decline with increasing age.



Training status (aerobic or cardiorespiratory fitness level)

Aerobic training can substantially increase maximum oxygen uptake values for both males and females (see figure 5.6). Average maximum oxygen uptake relative values for non-athletes and athletes in different sports can be seen in table 5.3.

FIGURE 5.6 Aerobic training can substantially increase maximum oxygen uptake values for both males and females.



TABLE 5.3 Maximum oxygen uptake values (mL/kg/min) for various population groups

Group	Age	Males	Females
Non-athletes	10–19 20–29 30–39 40–49 50–59 60–69 70–79	47–56 43–52 39–48 36–44 34–41 31–38 28–35	38–46 33–42 30–38 26–35 24–33 22–30 20–27
Baseball/softball	18–32	48–56	52–57
Basketball	18–30	40–60	43–60
Bicycling	18–26	62–74	47–57
Canoeing	22–28	55–67	48–52
Gymnastics	18–22	52–58	36–50
Racquetball	20–35	55–62	50–60
Rowing	20–35	60–72	58–65
Skiing, alpine	18–30	57–68	50–55
Skiing, Nordic	20–28	65–94	60–75
Soccer	22–28	54–64	50–60
Speed skating	18–24	56–73	44–55
Swimming	10–25	50–70	40–60
Track and field, discus	22–30	42–55	—
Track and field, running	18–39 40–75	60–85 40–60	50–75 35–60
Track and field, shot put	22–30	40–46	—
Volleyball	18–22	—	40–56
Weightlifting	20–30	38–52	—

Source: Reprinted by permission from JH Wilmore, DL Costill & WL Kenney, *Physiology of sport and exercise*, 4th ed., Human Kinetics, Champaign, IL, 2008

5.2 Activity

5.2 Quick quiz on | **5.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 8	2, 3, 6	4, 5, 7, 9, 10

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TEST your understanding

1. **Define** the term *maximum oxygen uptake*. Explain why it is best expressed relative to body weight.
2. **List** and briefly **summarise** the factors that can affect maximum oxygen uptake.
3. **Discuss** the relationship between oxygen uptake (consumption) and energy production.
4. **Explain** why Nordic (cross-country) skiers would have higher maximum oxygen uptake values than weightlifters of a similar age (see table 5.3).
5. **Explain** why an oxygen deficit occurs at the beginning of any exercise bout.
6. **Discuss** the factors that could determine the size of the oxygen deficit that accrues.
7. **Explain** what is meant by the expression ‘oxygen is the body’s exercise currency’.

APPLY your understanding

8. When is a steady state achieved during an exercise bout? **Identify** what this signifies in terms of energy supply to the working muscles.
9. **Explain** the factors responsible for EPOC.
10. **Explain** the changes in oxygen demand and supply during submaximal exercise.

5.2 Exam questions

Question 1 (2 marks)

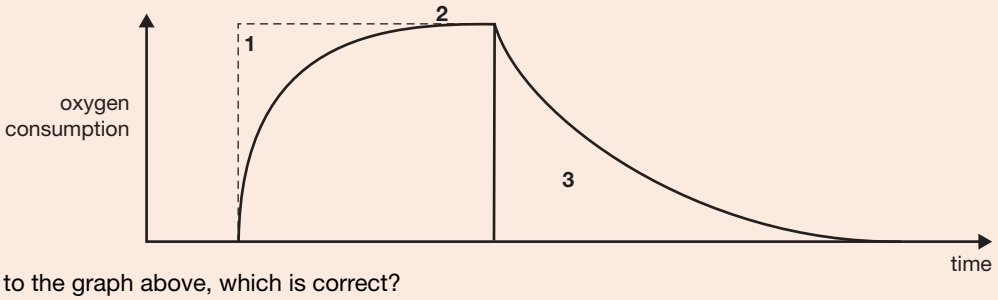
Source: *VCE 2018, Physical Education Exam, Section B, Q.2;* © VCAA

Ventilation is the product of tidal volume and respiratory rate.

Describe the relationship between ventilation and oxygen consumption when moving from a resting state to exercising, and **explain** why the relationship occurs.

Question 2 (1 mark)

Source: *VCE 2010, Physical Education Exam, Section A, Q.14;* © VCAA



In relation to the graph above, which is correct?

A. 1 = EPOC, 2 = oxygen deficit, 3 = steady state
B. 1 = EPOC, 2 = steady state, 3 = oxygen deficit
C. 1 = oxygen deficit, 2 = EPOC, 3 = steady state
D. 1 = oxygen deficit, 2 = steady state, 3 = EPOC

Question 3 (1 mark)

Source: *VCE 2009, Physical Education Exam, Section B, Q.10.a.iv;* © VCAA

In the table below, the VO_2 (L/min) has been recorded at rest, during 5 minutes of sub-maximal treadmill running and 5 minutes after the completion of running.

Values were recorded every minute and the data is shown below.

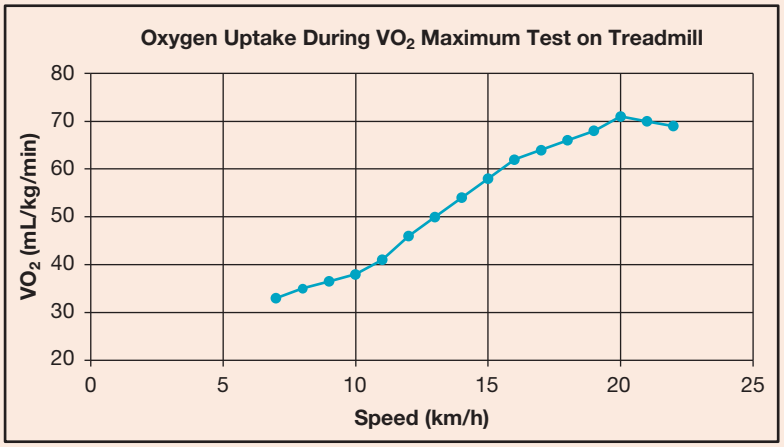
	VO_2 (L/min)
rest	0.5
exercise 1 min	1
exercise 2 min	1.2
exercise 3 min	1.8
exercise 4 min	2.0
exercise 5 min	2.0
recovery 1 min	1.7
recovery 2 min	1.4
recovery 3 min	1.1
recovery 4 min	0.7
recovery 5 min	0.5

Identify when the person experiences excess post-exercise oxygen consumption.

Question 4 (5 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.6.b,c;* © ACHPER

Taylor is an elite triathlete who completes a VO_2 maximum test on a treadmill. The results are presented in the graph below.



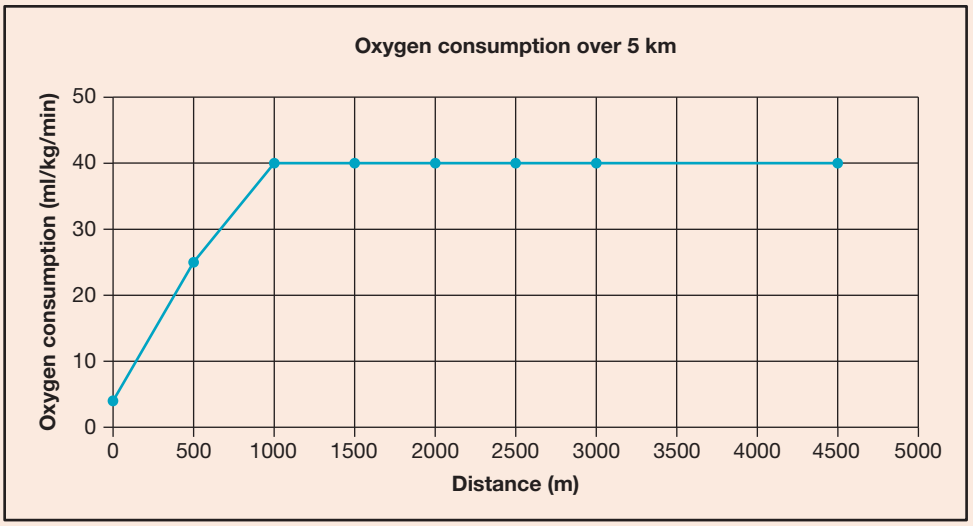
a. VO_2 maximum test results can be presented as either absolute or relative data.
Identify the type of data appearing in Taylor's results and **justify** why the data has been presented this way. **(3 marks)**

b. There is a decrease in oxygen consumption after 20 km/h yet there is also an increase in speed.
Explain how this is possible. **(2 marks)**

Question 5 (4 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.8.a,b;* © ACHPER

The graph below demonstrates oxygen consumption for the first 4.5 km of a 5 km house carnival race for a Year 12 student, Ashleigh, who undertakes a sprint finish in the final 500 m.



Source: Author's own

a. **Draw** a line on the graph predicting oxygen consumption over the final 500 m. **(1 mark)**

b. **Label** and **shade** (where relevant) steady state and periods of oxygen deficit. **(3 marks)**

More exam questions are available in your learnON title.

5.3 Acute responses of the cardiovascular system

Key knowledge	Key skill
• acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems	• participate in laboratory activities to collect and analyse data on the range of physiological responses the body experiences during exercise

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

5.3.1 Cardiovascular responses

Numerous cardiovascular (heart, blood and blood vessels) responses occur when we start exercising. All are designed to facilitate the rapid and efficient delivery of increased amounts of oxygen to the working muscles in order to meet the body's increased demand for energy. **Acute responses** of the cardiovascular system to exercise include:

- increased heart rate
- increased stroke volume
- increased cardiac output
- increased blood pressure
- redistribution of blood flow to working muscles
- increased arteriovenous oxygen difference.

acute responses the body's immediate, short-term responses that last only for the duration of the training or exercise session and for a short time afterwards (recovery)

heart rate (HR) the number of times the heart contracts or beats per minute

resting heart rate the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult

maximum heart rate (MHR) the highest heart rate value achieved in an all-out effort to the point of exhaustion

EXAM TIP

When asked to list or identify cardiovascular acute responses, you cannot use both stroke volume and cardiac output.

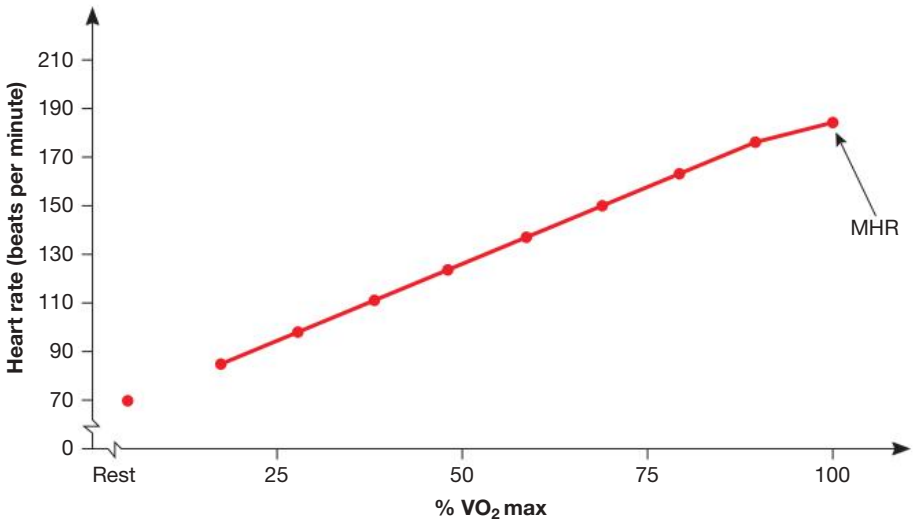
5.3.2 Increased heart rate

Heart rate (HR) refers to the number of times the heart contracts or beats per minute (bpm). **Resting heart rate** refers to the number of heartbeats per minute while the body is at rest. For an untrained adult, this is usually somewhere between 60 and 80 beats per minute. Once an individual begins to exercise, their heart rate increases as a response to the extra energy required by the body. The increase in heart rate helps to increase oxygen delivery to the working muscles and aids in the removal of waste products from the muscles and body.

The heart rate increases directly in proportion (linearly) with increases in exercise intensity until near-maximal intensity is reached (see figure 5.7). The greater the intensity of exercise, the greater the increase in heart rate. Heart rate continues to increase until **maximum heart rate (MHR)** is reached. MHR can be defined as 'the highest heart rate value achieved in an all-out effort to the point of exhaustion' (Wilmore et al., 2008).

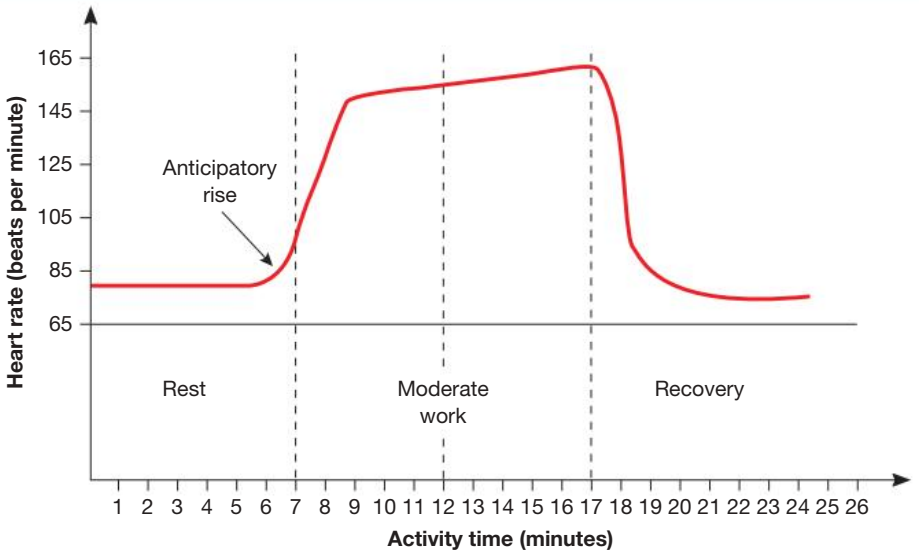
The heart rate rises above resting values just before the start of exercise. This is called an anticipatory response. The anticipatory increase in heart rate that occurs prior to beginning exercise is largely due to the release of epinephrine (adrenaline). Figure 5.8 depicts the heart rate response to exercise before, during and after moderate-intensity exercise.

FIGURE 5.7 The heart rate increases directly in proportion (linearly) with increases in exercise intensity.



Source: Reprinted by permission from JH Wilmore, DL Costill & WL Kenney, *Physiology of sport and exercise*, 4th ed., Human Kinetics, Champaign, IL, 2008

FIGURE 5.8 Heart rate response to exercise before, during and after moderate-intensity exercise



CONCEPT CONNECTOR

Record your resting heart rate, then jog on the spot as quickly as you can for 2 minutes. After the 2 minutes has elapsed, record your heart rate, along with how you felt.

Answer these questions using key terms from this topic.

- If you stopped before the 2 minutes, does this mean you're unfit?
- How would you know if you've reached your maximum heart rate?

on Resources

Interactivity Maximum heart rate calculator (int-6796)

Video eLesson Heart rate response (eles-2760)

5.3.3 Increased stroke volume

Stroke volume (SV) is defined as the amount of blood ejected from the left ventricle with each beat (contraction) of the heart. Stroke volume increases during exercise, plateauing at between 40 and 60 per cent MHR. Stroke volume (millilitres) for athletes at different levels of training can be seen in table 5.4.

TABLE 5.4 Stroke volumes (SV) for untrained and trained athletes

Subjects	SV at rest (mL)	SV max (mL)
Untrained	60–80	110–130
Trained	70–90	110–150
Highly trained	80–110	160–220

5.3.4 Increased cardiac output

Cardiac output (Q̇) is the amount of blood ejected from the left ventricle of the heart per minute. It is the product of heart rate multiplied by stroke volume:

Cardiac output (Q̇) = stroke volume (SV) × heart rate (HR)
Cardiac output (Q̇) = SV × HR

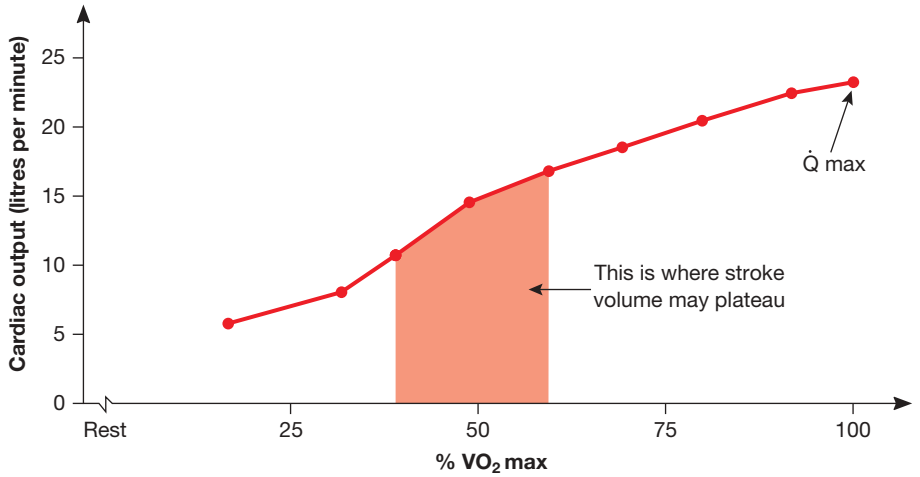
Q̇ = litres (L)
HR = beats per minute (bpm)
SV = millilitres (mL)

stroke volume (SV) the amount of blood ejected from the left ventricle with each beat (contraction) of the heart

cardiac output (Q̇) the amount of blood ejected from the left ventricle of the heart per minute;
Q̇ = heart rate (HR) × stroke volume (SV)

Cardiac output predictably increases during exercise. Under resting conditions, the average adult male's cardiac output is about 4–6 litres per minute; but this varies in proportion to the size of the individual. During exercise, cardiac output increases as a result of increases in both heart rate and stroke volume. This increase in cardiac output is designed to bring about an increase in oxygen delivery to the working muscles and heart. During maximal exercise intensities, average cardiac output can be 20–25 litres per minute, although among highly trained endurance athletes, cardiac output may be as high as 35–40 litres per minute, giving these athletes a major physiological advantage (see figure 5.9).

FIGURE 5.9 Cardiac output responses to exercise: cardiac output increases in direct proportion to increasing exercise intensity.



Source: Reprinted by permission from WL Kenney, JH Wilmore & DL Costill, *Physiology of sport and exercise*, 5th ed., Human Kinetics, Champaign, IL, 2011

As exercise begins there is an increase in cardiac output. This increase in cardiac output continues until the person reaches their MHR. Both heart rate and stroke volume contribute to the increase in cardiac output.

Increases in cardiac output beyond 40–60 per cent of MHR are the result of an increase in heart rate. In VCE Physical Education we say that:

- during submaximal intensity exercise the increase in cardiac output is the result of an increase in both heart rate and stroke volume
- as exercise intensity increases towards maximal/high intensity (beyond 40–60% MHR) the further increase in cardiac output is the result of an increase in heart rate.

Aerobic exercise and cardiac output, stroke volume and heart rate

The relationship between cardiac output, stroke volume and heart rate during submaximal and maximal aerobic exercise can be seen in table 5.5.

TABLE 5.5 Heart rate, stroke volume and cardiac output at rest, during submaximal and higher intensity exercise

Intensity	Heart rate (beats per minute)	Stroke volume (millilitres per beat)	Cardiac output (litres/minute)
Rest	70	70	4.9
Submaximal	140	120	16.8
Maximal	200	120	24.0

At rest, an individual has the lowest heart rate, stroke volume and cardiac output. These increase when working at submaximal intensity (a moderate pace). At maximal intensity (a fast pace), heart rate and cardiac output increase further, but stroke volume does not. During high-intensity exercise, heart rate contributes primarily to the further increases in cardiac output, whereas stroke volume tends to plateau when exercise intensity reaches around 40–60 per cent of the individual's maximal exercise capacity.

EXAM TIP

Ensure you can define cardiac output and discuss the relationship between cardiac output, stroke volume and heart rate during submaximal and higher intensity continuous exercise.

5.3.5 Increased blood pressure

Blood pressure is the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: **systolic blood pressure** and **diastolic blood pressure**.

blood pressure the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: systolic blood pressure and diastolic blood pressure.

systolic blood pressure the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure values.

diastolic blood pressure the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.

Blood pressure is usually expressed as:

$$\text{blood pressure} = \frac{\text{systolic}}{\text{diastolic}} \text{mmHG}$$

During dynamic whole-body exercise, such as jogging or cycling, blood is pumped more forcefully and quickly out of the heart, increasing the pressure on the artery walls. This results in an increase in systolic blood pressure — it may reach levels as high as 180–200 mmHg during the heaviest workloads, although the decrease in peripheral resistance caused by the vasodilation of the blood vessels of the exercising muscles offsets or buffers this rise in systolic pressure. Diastolic blood pressure changes little during exercise, with increases of more than 10 mmHg considered abnormal. The minimal change in diastolic blood pressure is accounted for by the decrease in peripheral resistance.

During resistance-type exercise (e.g. lifting weights), large increases in both systolic and diastolic blood pressure are evident. With high-intensity resistance training, blood pressure can reach values as high as 480 over 350 mmHg.

5.3.6 Redistribution of blood flow to working muscles

Under resting conditions, only about 15–20 per cent of total systemic blood flow is directed to the skeletal muscles. The rest is mainly distributed to the organs of the body (e.g. heart, liver, kidneys, intestines, brain). However, under exercise conditions, the majority of the blood (80–90 per cent) may be redirected to the working muscles (see figure 5.10). This is achieved by the capillaries and arterioles supplying the working muscles expanding in diameter (a process known as **vasodilation**). At the same time, blood flow to the organs of the body is reduced by the **vasoconstriction** (narrowing) of the capillaries and arterioles that supply blood to these organs.

vasodilation the process whereby blood vessels increase their internal diameter as a response to an increased demand for oxygen delivery to muscle tissue

vasoconstriction the process where blood vessels narrow or constrict as a response to a decreased demand for oxygen delivery to muscle tissue

arteriovenous oxygen difference (a-VO_2 diff) a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.

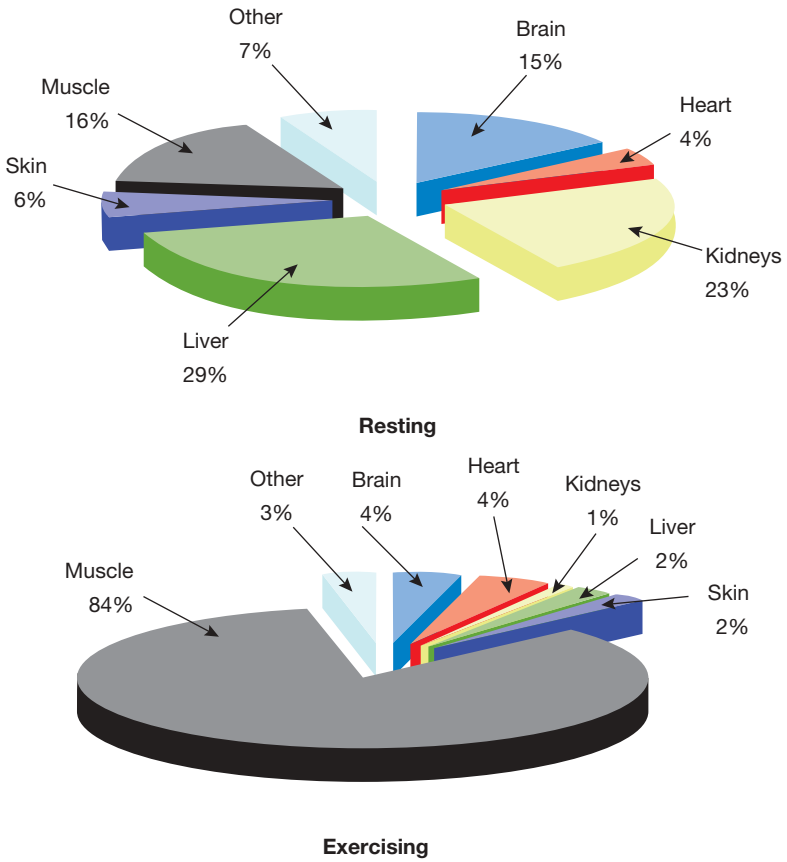
5.3.7 Increased arteriovenous oxygen difference

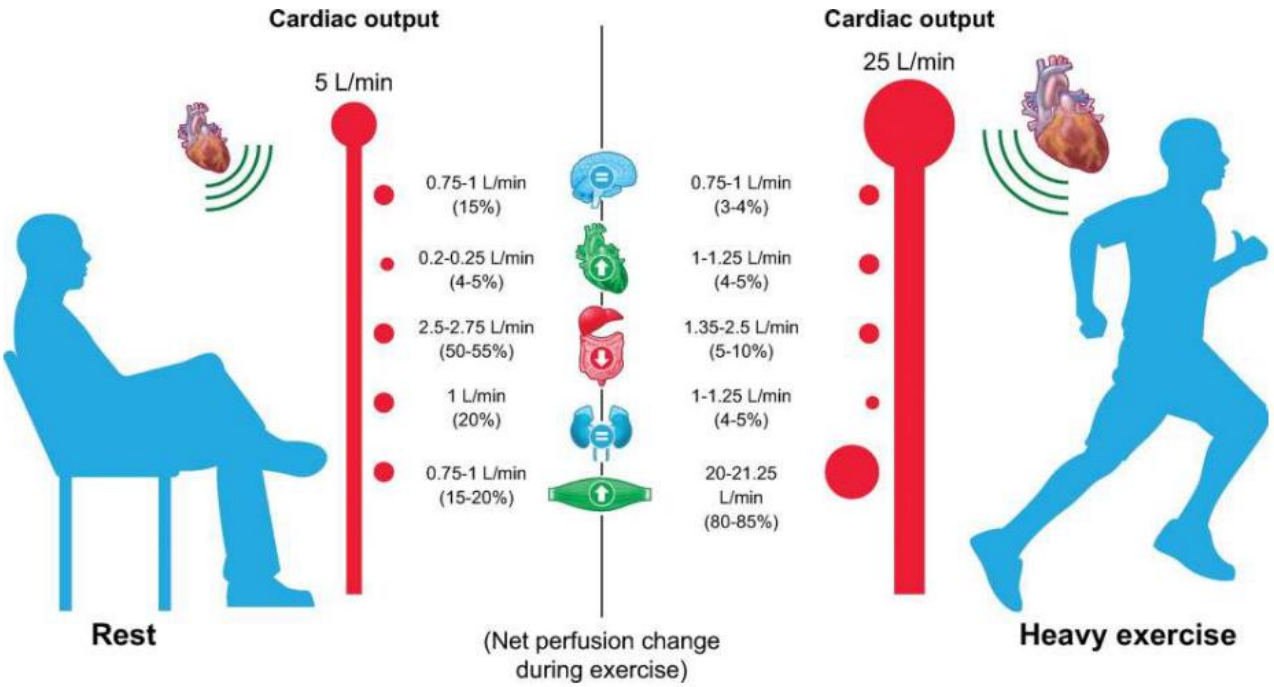
The **arteriovenous oxygen difference (a-VO_2 diff)** is a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. This is measured in millilitres per 100 millilitres of blood. At rest, the arteries contain an oxygen concentration of approximately 20 millilitres per 100 millilitres of blood (200 millilitres of oxygen per litre of blood), while the veins typically contain about 15 millilitres per 100 millilitres. Thus, the a-VO_2 difference at rest is about 5 millilitres per 100 millilitres of blood:

$$\text{a-VO}_2\text{ diff} = \frac{20\text{ mL}}{100\text{ mL}} - \frac{15\text{ mL}}{100\text{ mL}}$$

$$\text{a-VO}_2\text{ diff} = \frac{5\text{ mL}}{100\text{ mL}}$$

FIGURE 5.10 Distribution of cardiac output during rest and exercise.





Source: Reprinted by permission from J Hoffman, *Physiological aspects of sport training and performance*, Human Kinetics, Champaign, IL, 2002

During exercise, the body has a higher cardiac output to supply the muscles with more oxygen. However, this does not mean blood supply to the brain has reduced. As a result, the a-VO_2 difference increases to as high as 15–18 millilitres per 100 millilitres of blood — almost a threefold increase over the value at rest (see figure 5.11).

FIGURE 5.11 The arteriovenous oxygen difference **(a)** at rest and **(b)** during intense aerobic exercise

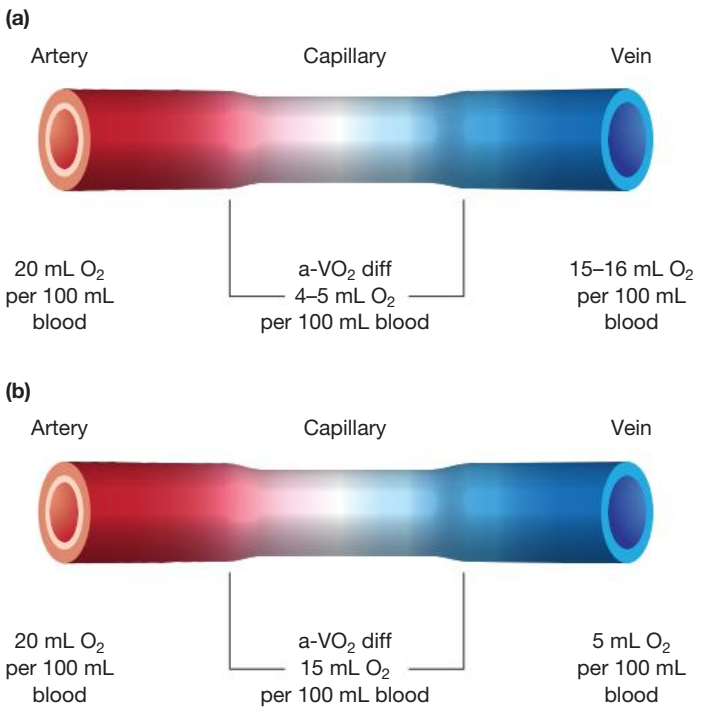


TABLE 5.6 Summary of acute responses to exercise

Body system	Acute response	Nature of response
Cardiovascular system	• Increased heart rate	• Increases linearly with increasing exercise intensity up to an approximate maximum that is calculated by subtracting the individual's age (years) from 220
	• Increased stroke volume	• Maximal value reached during submaximal exercise
	• Increased cardiac output	• Increases from 5–6 L/min at rest to 20–25 L/min or more during maximal exercise
	• Increased blood pressure	• Increased systolic pressure
	• Redistributed blood flow to working muscles	• At rest 15–20 per cent of total blood flow directed to working muscles; during exercise 80–90 per cent of total blood flow directed to working muscles
	• Increased arteriovenous oxygen difference	• Increases can be almost threefold over the value at rest

doc-41956

PRACTICAL ACTIVITY Heart rate responses to exercise

Goal

To measure your heart rate during different activities.

Instructions

1. Working with a partner, measure and record both of your resting heart rates. Your teacher will show you how to do this manually or with a heart rate monitor.
2. Perform the following physical activities, recording both heart rates immediately after completing each activity. Allow your heart rate to return to its resting value between each activity.
   - Walking for 2 minutes
   - Jogging for 2 minutes
   - Performing step-ups on a bench for 2 minutes
   - Performing bent-knee sit-ups for 2 minutes

Primary data/Reflection

TABLE 1 Heart rate results

	Heart rate (bpm)	
	You	Your partner
Resting		
Walking for 2 minutes		
Jogging for 2 minutes		
Step-ups on a bench for 2 minutes		
Bent-knee sit-ups for 2 minutes		

- What observations did you make about your body as you completed each activity?
- Were there any similarities or differences between your heart rate and that of your partner for the different activities? What could explain this?

- Consider the factors that may have influenced the changes in heart rate during and after physical activity, such as exercise intensity, duration and individual fitness level. How do these factors contribute to the cardiovascular response to exercise?

Questions

1. Graph the results you obtained for both yourself and your partner. Describe any trends.
2. Identify the exercise that resulted in the highest heart rate. How do you account for this?
3. Discuss the relationship between your heart rate and the intensity of the exercise.

doc-41957

PRACTICAL ACTIVITY Blood pressure response to exercise

Goal

To measure your blood pressure during different activities

Equipment

Electronic blood pressure monitors

Instructions

1. Your teacher will show you how to put on and use the electronic blood pressure monitor.
2. Complete the following activities, and with the aid of a partner, record your blood pressure each minute for 5 minutes.
   - Sitting at rest
   - Standing at rest
   - Lying at rest
   - Cycling on an exercise bike at a moderate intensity

Primary data/Reflection

TABLE 1 Blood pressure results for the different activities

Time (min)	Sitting	Standing	Lying	Cycling
0				
1				
2				
3				
4				
5				

- How did you feel as you completed each activity?
- Consider the factors that may have influenced the changes in blood pressure during and after physical activity, such as exercise intensity, duration and individual fitness level. How do these factors contribute to the cardiovascular response to exercise?
- Reflect on any challenges or limitations encountered during the blood pressure measurement process. Were there any sources of error or variability that could have affected the accuracy of the readings?

Questions

1. Graph the blood pressure data you obtained. Make sure to show the values for both systolic and diastolic blood pressure on the one graph.
2. What effect did different body positions have on your blood pressure when you were at rest? Explain how you account for any differences observed.
3. What happened to your blood pressure during exercise? At what point in the activity did blood pressure reach its maximum value? Did your blood pressure plateau at any point?

4. Did the changes in your blood pressure during exercise match what you expected to happen based on your understanding of blood pressure responses to exercise? Explain.
5. Explain what might have happened to your blood pressure if you had been asked to perform a maximum bench press test? How would this blood pressure response differ to that experienced during the 5 minutes of moderate-intensity cycling? Explain why this difference occurs.

5.3 Activity

5.3 Quick quiz on | **5.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 8	6, 11, 12	4, 5, 7, 9, 10

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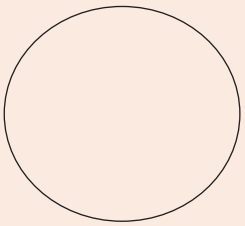
TEST your understanding

1. **Define** what is meant by the terms *heart rate, stroke volume* and *cardiac output*.
2. **Outline** the method for estimating the maximum attainable heart rate.
3. **Explain** why females tend to have lower stroke volumes than males.
4. a. **Explain** the mechanisms that are responsible for the increase in stroke volume that accompanies exercise.
   b. **Explain** why stroke volume plateaus at exercise intensities approaching 40–60 per cent of maximum exertion levels. Discuss why this might not be the case with highly trained athletes.
5. **Calculate** the cardiac output of an individual who has a heart rate of 80 beats per minute and a stroke volume of 75 millilitres per beat.
6. Refer to figure 5.7 and answer the following questions:
   a. Figure 5.7 shows a linear relationship between heart rate and exercise intensity, as indicated by the straight line. **Explain** what is meant by a linear relationship between heart rate and exercise intensity.
   b. At what intensity of exercise does stroke volume reach maximum levels? **Explain** your answer.
   c. **Explain** why trained athletes have higher stroke volumes than untrained individuals.
7. **State** the component of blood pressure that is most affected by exercise. **Explain** why this is the case.
8. **Explain** the difference between vasodilation and vasoconstriction. **Explain** how these processes result in increased blood flow and oxygen delivery to working muscles.
9. **Explain** what is meant by the arteriovenous oxygen difference. **Explain** why this increases during exercise.

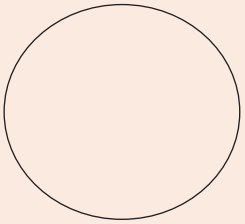
APPLY your understanding

10. Use the circles below to draw pie charts that show the approximate distribution of blood flow to the *muscles* and *organs* at rest and at the 10-minute mark of a submaximal run.

Blood distribution at rest

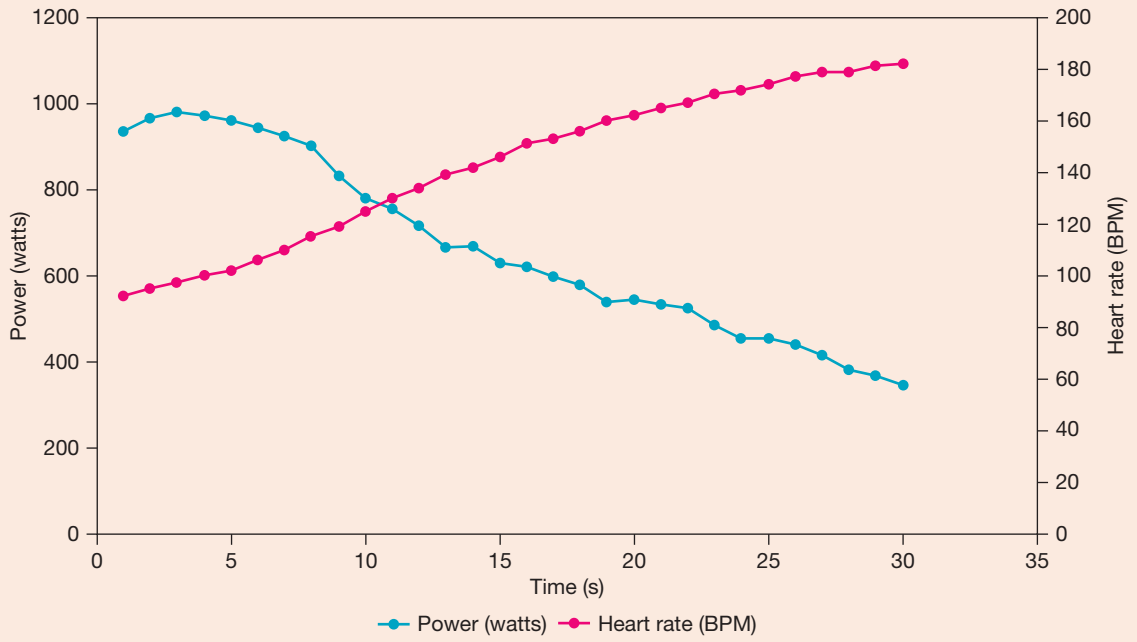


Blood distribution at the 10-minute mark



11. **Calculate** the estimated maximum heart rate for a 16-year-old male.
12. The data below was taken from a Wingate test.
    The following questions will relate to this test and the data collected from the test.

    During a Wingate test, a participant is required to pedal as fast as possible for 30 seconds.
    It is a test to measure the anaerobic power of the lower body.



a. A change in heart rate is an example of an acute response to exercise. **Define** the term *acute response*.
b. **Identify** the role of the acute response seen on the graph above (from the Wingate test).
c. **Identify** two other acute cardiovascular responses that would be occurring during this test.

5.3 Exam questions

Question 1 (2 marks)

List one acute cardiovascular response and **describe** how it results in increased oxygen uptake during exercise.

Question 2 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.2;* © VCAA

Heart rate responses were taken at regular intervals during a 20-minute continuous run. For the time period between three and seven minutes, heart rate readings were between 110 bpm and 113 bpm.

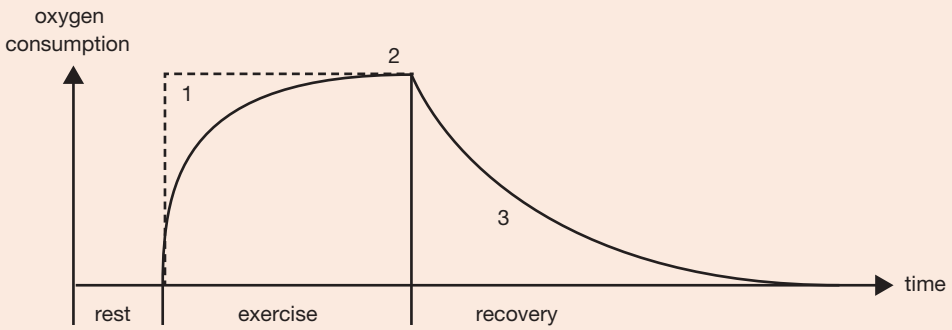
Which one of the following physiological statements could explain these readings?

A. The ATP resynthesis rate is finite.
B. The anaerobic threshold is being met.
C. Oxygen supply is equal to oxygen demand.
D. The lactate inflection point (LIP) has been surpassed.

Question 3 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.12;* © VCAA

Oxygen consumption during and after exercise



The graph above represents oxygen consumption during and after exercise.

The area indicated by the number 1 is known as

A. excess post-exercise oxygen consumption (EPOC).
B. oxygen deficit.
C. oxygen debt.
D. steady state.

Question 4 (4 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.10.d;* © VCAA

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

Define 'cardiac output' and **explain** the relationship between the two cardiac factors that contribute to the measurement of cardiac output when an individual moves from rest to maximal intensity activity.

Question 5 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section B, Q.4.d;* © VCAA

As a result of aerobic training, an individual is likely to see an increase in left ventricle volume and stroke volume. These changes are accompanied by a decrease in resting heart rate and a decrease in heart rate at sub-maximal exercise intensities.

Explain the relationship between VO_2 max, cardiac output and a-VO_2 diff, and their effect on aerobic capacity.

More exam questions are available in your learnON title.

5.4 Acute responses of the respiratory system

Key knowledge	Key skill
• acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems	• participate in laboratory activities to collect and analyse data on the range of physiological responses the body experiences during exercise

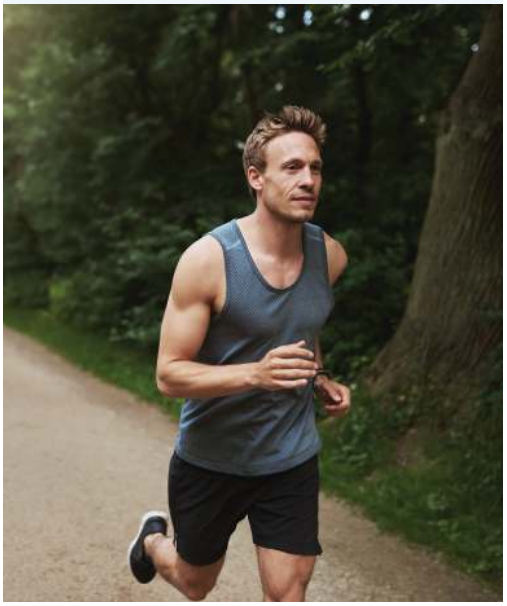
Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

5.4.1 Respiratory system responses

Acute responses of the respiratory system to exercise are designed to facilitate an increase in the availability of oxygen and the removal of carbon dioxide. These responses include:

- increased respiratory rate (breathing rate)
- increased tidal volume
- increased ventilation
- increased pulmonary diffusion.

FIGURE 5.12 When we engage in exercise, certain changes occur immediately within the respiratory system. These responses are designed to meet the increased energy demands imposed on the body.



Increased respiratory rate (breathing rate)

Respiratory rate refers to the number of breaths taken per minute. At rest, the average respiratory rate is around 12 breaths per minute. When exercise begins, breathing rates rise sharply and can increase to as high as 35–50 breaths per minute. This increase in respiratory rate is triggered by the increase in carbon dioxide concentrations in the blood, which stimulates the respiratory control centre in the brain.

Increased tidal volume

The depth of breathing (**tidal volume (TV)**) increases from around 0.5 litres per breath at rest to as high as 3–5 litres per breath at maximal workloads.

Increased ventilation

Ventilation is the amount of air inspired or expired per minute by the lungs. It is the product of respiratory rate multiplied by tidal volume.

$$\underset{\text{(L/min)}}{\text{ventilation (V)}} = \underset{\text{(breaths/min)}}{\text{respiratory rate}} \times \underset{\text{(L/breath)}}{\text{tidal volume}}$$

At rest, ventilation is around 5–6 litres per minute. During maximal exercise, it may increase beyond 180 litres per minute for males, and 130 litres per minute for females. This is 25 to 35 times greater than resting values. It should be noted that both tidal volume and ventilation are generally higher for males because of their larger average lung volume.

respiratory rate the number of breaths taken per minute

tidal volume (TV) the amount of air inspired and expired by the lungs per breath

ventilation the amount of air inspired or expired per minute by the lungs. Ventilation (V) = respiratory rate × tidal volume.

CONCEPT CONNECTOR

Count the number of breaths you take (your respiratory rate) over 15 seconds. Now spend 1 minute completing as many star jumps on the spot (or similar activity) as possible, and then count your breaths again for 15 seconds. This will show you how your respiratory rate (breathing rate) increases after exertion.

Mechanisms responsible for increased ventilation

With its rapid onset, the initial adjustment of ventilation to the increased oxygen demands of exercise is neural in nature, controlled by the respiratory control centres in the brain, with additional neural input from receptors within the exercising muscles. As exercise progresses, further adjustments in ventilation are controlled primarily by changes in the chemical status of arterial blood. Increased muscle metabolism due to exercise results in the production of greater levels of carbon dioxide and hydrogen ions, which are sensed within the blood by chemoreceptors located in the brain and lungs. This in turn stimulates the respiratory control centres, further increasing both the rate and depth of breathing (in other words, an increase in ventilation).

pulmonary diffusion the movement of oxygen and carbon dioxide from areas of high concentration to areas of low concentration between the alveoli and the surrounding capillaries

Increased pulmonary diffusion

Pulmonary diffusion is the process of gaseous exchange that takes place within the lungs. Pulmonary diffusion has two major functions:

- to replenish oxygen supply through diffusion from alveolar to pulmonary capillaries
- to remove carbon dioxide from returning venous blood.

At rest, oxygen diffusion capacity is about 21 millilitres of oxygen per minute. During maximal exercise, the oxygen diffusion capacity may increase by up to three times the resting rate.

FIGURE 5.13 Pulmonary diffusion helps remove carbon dioxide from the blood and replenish oxygen.

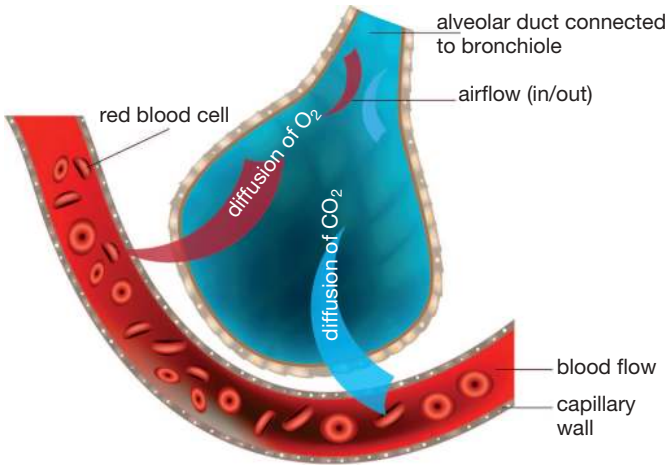


TABLE 5.7 Summary of acute responses to exercise

Body system	Acute response	Nature of response
Respiratory system	• Increased respiratory rate (breathing rate)	• Increases from 12 breaths per minute to as many as 35–40 per minute
	• Increased tidal volume	• Increases from around 0.5 litres per breath at rest to as high as 5 litres per breath at maximal workloads
	• Increased ventilation	• Increases from around 5–6 L/min at rest to beyond 108 and 130 L/min during exercise (for males and females, respectively)
	• Increased oxygen uptake	• Increases from 0.3–0.4 L/min at rest to maximal values of 2.0–3.5 L/min during exercise
	• Increased pulmonary diffusion	• Increases by up to three times the resting rate

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PRACTICAL ACTIVITY Acute respiratory responses to exercise

Goal

To observe and record the effects of exercise on the respiratory system.

Instructions

1. Measure your resting respiratory rate by counting the number of breaths you take in 1 minute.
2. Perform the first activity below, then measure your respiratory rate for 10 seconds immediately after you complete each activity. Multiply this value by 6 to get your respiratory rate per minute and record it in a table.
3. Allow your breathing rate to return to your resting value before doing the next activity.
   - Standing still for 2 minutes
   - Lying down for 2 minutes
   - Walking for 2 minutes
   - Jogging for 2 minutes
   - Performing step-ups on a bench for 2 minutes
   - Resting for 1 minute after the bout of step-ups
   - Resting for 2 minutes after the bout of step-ups
   - Performing bent-knee sit-ups for 2 minutes

Primary data/Reflection

TABLE 1 Respiratory rate

	Respiratory rate (breaths/minute)
Rest	
Standing still	
Lying down	
Walking	
Jogging	
Step-ups	
1 minute after completing step-ups	
2 minutes after completing step-ups	
Sit-ups	

- What observations did you make about your respiratory rate as you completed the different activities?
- Describe your experience during the physical activity. How did your breathing pattern change as you increased your intensity?
- Reflect on your recorded respiratory rate immediately after completing the exercises. Were you surprised by the result? Why or why not?

Questions

1. Graph your results using the data collected.
2. Which activity resulted in the highest respiratory rate? How do you account for this?
3. Did standing still or lying down result in the highest respiratory rate? Explain.
4. Explain why respiratory rate increases so much during exercise.
5. Explain why your respiratory rate remains elevated above normal resting values for a period after stopping strenuous exercise.

5.4 Activity

5.4 Quick quiz on | **5.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 5	2, 6	3, 7

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TEST your understanding

1. **Define** the terms *respiratory rate*, *tidal volume*, *ventilation*, *pulmonary diffusion*, *oxygen uptake* and *maximum oxygen uptake.*
2. An individual sets out on a 3-kilometre run. **Predict** the likely acute respiratory system responses to this exercise bout.
3. Using your prior knowledge of the respiratory system, **explain** how gases diffuse into and out of the lungs and blood vessels.
4. What causes increased ventilation?
   - **A.** Increased heart rate
   - **B.** Increased levels of carbon dioxide in the blood
   - **C.** Increased tidal volume
   - **D.** Decreased heart rate
5. Pulmonary diffusion occurs between which structures?
   - **A.** Lungs and muscles
   - **B.** Lungs and heart
   - **C.** Lungs and capillaries
   - **D.** Muscles and capillaries

APPLY your understanding

6. **Calculate** the ventilation of an individual who has a respiratory rate of 15 breaths per minute and a tidal volume of 0.5 litres per breath.
7. **List** two acute respiratory responses to exercise and **explain** how they assist with the performance of the athlete.

5.4 Exam questions

Question 1 (1 mark)

Define the term *tidal volume*.

Question 2 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section B, Q.3.a;* © VCAA

State the formula for ventilation. In your response, do not use abbreviations.

Question 3 (2 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.2;* © VCAA

Ventilation is the product of tidal volume and respiratory rate.

Describe the relationship between ventilation and oxygen consumption when moving from a resting state to exercising, and **explain** why the relationship occurs.

Question 4 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.8.b;* © VCAA

The Ironman Triathlon consists of a 3.86 km swim, a 180.25 km bicycle ride and a 42.20 km marathon, raced in that order. Races generally last eight hours for world-class performers.

List one acute response and **describe** how it results in increased oxygen uptake during exercise.

Question 5 (2 marks)
Explain *pulmonary diffusion* and how it changes during exercise to increase oxygen consumption.

More exam questions are available in your learnON title.

5.5 Acute responses of the muscular system

Key knowledge	Key skill
• acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems	• participate in laboratory activities to collect and analyse data on the range of physiological responses the body experiences during exercise

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

5.5.1 Muscular system responses

Acute muscular system responses to exercise are those that occur in the working muscles themselves. These responses vary according to the type, intensity and duration of the exercise. Muscular acute responses include:

- increased motor unit and muscle fibre recruitment
- increased arteriovenous oxygen difference
- increased muscle temperature
- increased muscle enzyme activity
- increased oxygen use
- decreased muscle substrate levels (ATP, creatine phosphate, glycogen and triglycerides).

Increased motor unit and muscle fibre recruitment

When an individual engages in any physical activity, there is a need for muscular contractions to take place. When exercise begins, an increase in motor unit recruitment must occur so that more muscle fibres are activated to contract. The greater the force or effort required, the greater the number of motor units recruited, and the greater the number of muscle fibres activated.

Increased arteriovenous oxygen difference

During exercise, working muscles extract much more of the available oxygen from the blood, via myoglobin and mitochondria. As much as 75 per cent of the available oxygen is extracted and, as a result, the arteriovenous oxygen difference increase (see figure 5.11).

Increased muscle temperature

Increased blood flow to the muscles, coupled with the heat generated as a by-product of the increased production of ATP during exercise, results in an increase in muscle temperature.

Increased muscle enzyme activity

Enzyme activity increases during exercise to produce the increased amount of ATP required by the muscles. This is because enzymes assist in the chemical reactions that resynthesise ATP. For example, the enzyme ATP synthase converts ADP and phosphate into ATP. Enzymes are involved in all of the chemical processes that produce energy via the three energy pathways.

Increased oxygen use

The cells within the muscle extract and use more oxygen from the blood during exercise because of the increased demand for ATP. This greater extraction and use of oxygen by the exercising muscle contributes to the increase in the arteriovenous oxygen difference that has been previously referred to.

Decreased muscle substrate levels

Muscular stores of ATP, creatine phosphate, glycogen and triglycerides begin to deplete during exercise because they are sources of fuel for the production of ATP. The depletion of these energy stores, particularly creatine phosphate and glycogen, contributes to the fatigue experienced during exercise and physical activity.

Increased ATP production in the mitochondria

The mitochondria are the site of aerobic metabolism within the muscle. During exercise, there is an increase in ATP resynthesis within the mitochondria.

Increased transport of oxygen by myoglobin

Myoglobin carries oxygen within the muscle. During exercise, there is an increase in oxygen being carried by myoglobin.

FIGURE 5.14 During high-intensity exercise, muscular stores of ATP and creatine phosphate deplete as they provide energy for the production of ATP.



TABLE 5.8 Summary of acute responses to exercise

Body system	Acute response	Nature of response
Muscular system	• Increased motor unit and muscle fibre recruitment	• More motor units recruited and muscle fibres activated
	• Increased blood flow in the muscles	• Increases from 15–20 per cent of total blood flow at rest up to 80–90 per cent during exercise
	• Increased muscle temperature	• As a result of increased blood flow and ATP production
	• Increased muscle enzyme activity	• In order to produce the increased amounts of ATP required by the muscles during exercise
	• Increased oxygen extraction and utilisation	• Muscle cells extract and use more oxygen during exercise
	• Decreased muscle substrate levels	• ATP, creatine phosphate, glycogen and triglycerides deplete

5.5 Activity

5.5 Quick quiz on | **5.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	4	2, 3

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TEST your understanding

1. **Draw** a simple diagram (using appropriate icons to represent each muscular system change) that summarises the major acute muscular system responses to exercise.
2. Using your knowledge of different types of muscle fibres, **explain** how each of the muscle fibre types might respond to different types of exercise (anaerobic and aerobic).
3. **State** one acute muscular response that will occur during a 100-metre sprint and assist with performance. **Explain** how the stated acute response assists with performance.

APPLY your understanding

4. **Discuss** the adaptations that occur in fast-twitch muscle fibres compared to slow-twitch muscle fibres.

5.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.4;* © VCAA

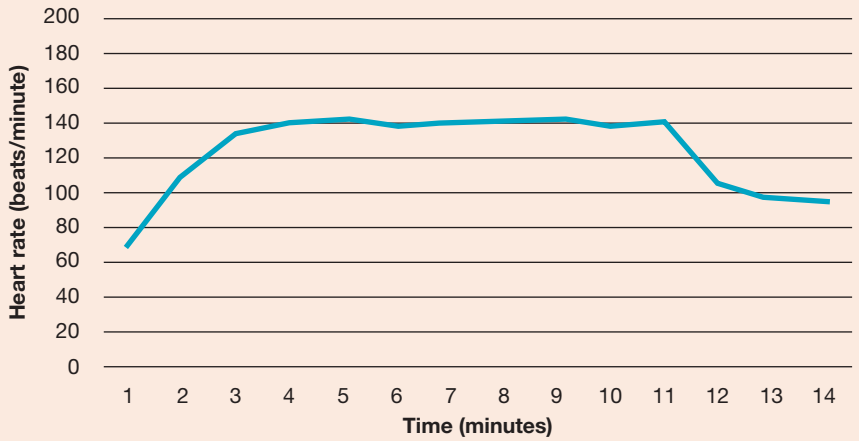
During exercise, skeletal muscle capillaries dilate in order to

A. increase their surface area to enable greater diffusion to occur.
B. decrease the removal of metabolic by-products.
C. decrease the use of intramuscular substrates.
D. increase ventilation and stroke volume.

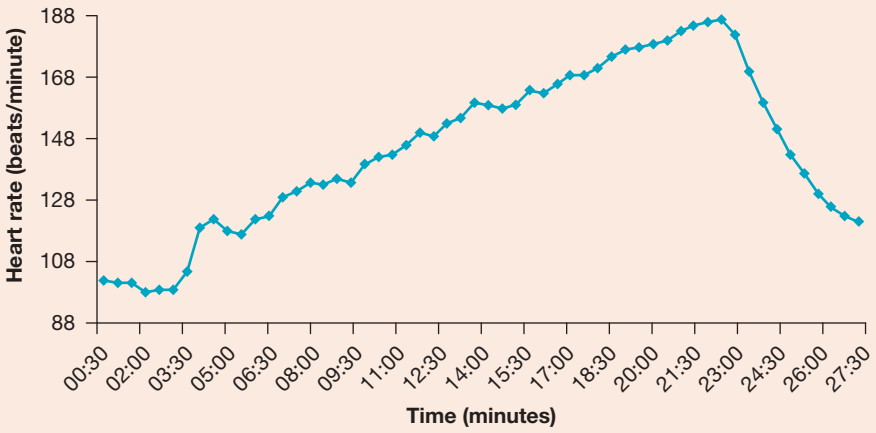
Question 2 (1 mark)

The data below is taken from two exercise conditions.

Exercise condition 1: heart rate data collected during a submaximal 10-minute jog followed by a 4-minute recovery.



Exercise condition 2: VO_2 max test. The work period was 23 minutes and the recovery duration was 5 minutes.



Select the answer below that best describes the substrate use in the two exercise conditions over the first 14 minutes.

A. Both have equal reduction in intramuscular glycogen and triglycerides.
B. There would be a greater reduction in intramuscular triglycerides during the VO_2 max.
C. There would be a greater reduction in intramuscular triglycerides in the submaximal run.
D. There would be a greater reduction in muscle glycogen during the submaximal run.

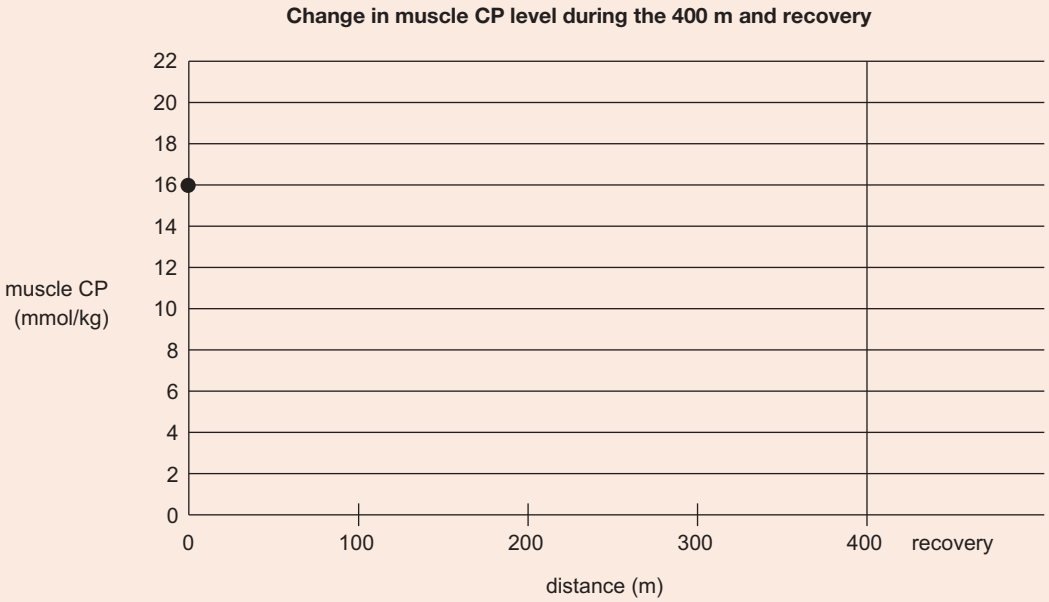
Question 3 (2 marks)

Explain the change in a-VO_2 difference during the VO_2 max test.

Question 4 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.3.d;* © VCAA

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.



Question 5 (2 marks)

With reference to two muscular acute responses to exercise, **outline** the similarities and differences in muscular changes during a 10-minute submaximal run as compared to the VO_2 max test.

More exam questions are available in your learnON title.

5.6 Key skills

Key skills

- explain the changes in oxygen supply and demand at rest, and during sub-maximal and maximal exercise
- participate in laboratory activities to collect and analyse data on the range of physiological responses the body experiences during exercise

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

5.6.1 Tell me

To address these key skills, it is important to remember:

- increased demand for oxygen during physical activity leads to changes in the respiratory system, cardiovascular system and in the muscles
- examples of changes that occur (i.e. increased stroke volume)
- how each specific change results in increased oxygen delivery
- some changes that occur during anaerobic exercise are not related to oxygen consumption
- the supply of oxygen does not always meet the demand
- heart rate and oxygen consumption share a linear relationship, so changes in oxygen consumption can be predicted based on changes to heart rate.

5.6.2 Show me

Practice question (4 marks)

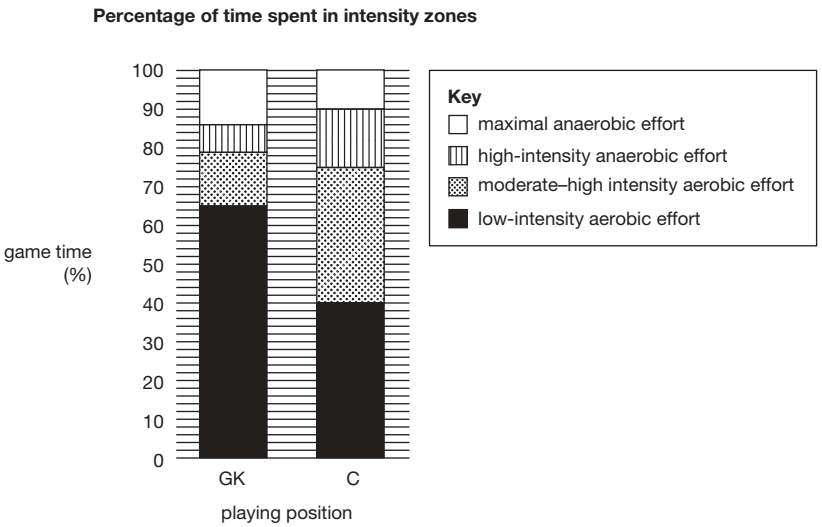
KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: *VCE 2023, Physical Education Exam, Section B, Q.3;* © VCAA

Asher is an active 13-year-old boy who has started playing netball. He rotates between goalkeeper (GK) and centre (C) positions.

The graph below shows the percentage of game time Asher spent in each intensity zone.



Source: Adapted from CM Young, PB Gastin, N Sanders, L Mackey & DB Dwyer, 'Player load in elite netball: match, training and positional comparisons', *International Journal of Sports Physiology and Performance*, vol. 11, no. 8, 2016, p. 1076

a. Other than *increased* respiratory rate, **list** two acute respiratory responses experienced by Asher when playing centre. (2 marks)

b. **Select one** of the acute respiratory responses from **part a** and **describe** how it would assist Asher's *performance* in the *centre position*. (2 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
- **List** — arrange related content sequentially
  Describe — provide a detailed account in an accurate way
- **Key terminology** — *performance*, *centre position*
- **Key concepts** — acute respiratory responses, respiratory rate
- **Marking scheme** — 4 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a. *Increased ventilation*, *increased pulmonary diffusion*
Award 2 marks for any two respiratory responses (e.g. increased pulmonary diffusion, increased ventilation).

b. An *increase* in *ventilation* enabled a *greater volume* of air and more oxygen to enter the lungs. The *increase* in *oxygen* would have enabled Asher to work at a higher aerobic intensity.
Award 1 mark for providing some detail about the acute response.
Award 1 mark for linking it to the increase in oxygen and aerobic metabolism.

5.6.3 Let me do it

Question 1 (8 marks)

Describe the changes in oxygen demand and supply from rest to submaximal exercise and the relationship between oxygen uptake and exercise intensity.

Your answer should be completed in paragraphs and contain the following terms:

- oxygen
- demand
- supply
- steady state
- oxygen deficit
- linear relationship
- submaximal
- heart rate
- anaerobic
- aerobic and VO_2 max

5.7 Review

Hey students! Now that it's time to revise this topic, go online to:

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5.7.1 Topic summary

Oxygen uptake at rest, during physical activity and during recovery

- As the intensity of exercise increases, there is an increase in oxygen consumption.
- At the start of exercise, oxygen demand is greater than supply.
- The cardiovascular and respiratory systems make the changes necessary to supply more oxygen to the working muscles. Once these changes have occurred, oxygen supply will meet demand and steady state will occur.
- Oxygen supply remains elevated following exercise. This is called EPOC.
- VO_2 is the unit that is used to measure oxygen consumption.

Acute responses of the cardiovascular system

- Blood vessels and the heart make up the cardiovascular system.
- Several changes occur in the cardiovascular system during exercise, including increased cardiac output and increased heart rate. These changes help to transport more oxygen to the working muscles.

Acute responses of the respiratory system

- Several respiratory changes occur to increase the intake of oxygen during exercise.
- Ventilation increases and so does the amount of oxygen that is transferred to the blood via pulmonary diffusion.

Acute responses of the muscular system

- Changes within the muscle help to increase the use of oxygen during exercise.
- These changes include:
  - an increase in enzyme activity
  - increased transport of oxygen by myoglobin
  - increased ATP resynthesis within the mitochondria.

on Resources

Interactivities Understanding acute response terms (int-6801)
Acute responses to exercise (int-6802)

5.7.2 Key terms

acute responses the body's immediate, short-term responses that last only for the duration of the training or exercise session and for a short time afterwards (recovery)
arteriovenous oxygen difference (a-VO_2 diff) a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.

blood pressure the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: systolic blood pressure and diastolic blood pressure.
cardiac output ($\dot{Q}$) the amount of blood ejected from the left ventricle of the heart per minute; $\dot{Q}$ = heart rate (HR) × stroke volume (SV)
diastolic blood pressure the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.
excess post-exercise oxygen consumption (EPOC) the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest
heart rate (HR) the number of times the heart contracts or beats per minute
maximum heart rate (MHR) the highest heart rate value achieved in an all-out effort to the point of exhaustion
maximum oxygen uptake (VO_2 max) the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production
oxygen deficit the state in which there is a discrepancy (shortfall) between oxygen supply and the oxygen needed to meet the energy requirements of the activity. The anaerobic pathways must supplement the energy demands of the activity.
oxygen uptake (VO_2) the amount of oxygen transported to, taken up by and used by the body for energy production
pulmonary diffusion the movement of oxygen and carbon dioxide from areas of high concentration to areas of low concentration between the alveoli and the surrounding capillaries
respiratory rate the number of breaths taken per minute
resting heart rate the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult
steady state the state in which oxygen supply equals oxygen demand so that virtually all the required ATP to maintain the current exercise intensity is being supplied aerobically.
stroke volume (SV) the amount of blood ejected from the left ventricle with each beat (contraction) of the heart
systolic blood pressure the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure values.
tidal volume (TV) the amount of air inspired and expired by the lungs per breath
vasoconstriction the process where blood vessels narrow or constrict as a response to a decreased demand for oxygen delivery to muscle tissue
vasodilation the process whereby blood vessels increase their internal diameter as a response to an increased demand for oxygen delivery to muscle tissue
ventilation the amount of air inspired or expired per minute by the lungs. Ventilation (V) = respiratory rate × tidal volume.

5.7 Exam questions

5.7 Section A – Multiple choice questions

Question 1 (1 mark)

State the major body systems that respond immediately to the transition from rest to exercise.

A. Cardiovascular, skeletal and muscular
B. Respiratory, skeletal and muscular
C. Cardiovascular, respiratory and muscular
D. Cardiovascular, digestive and nervous

Question 2 (1 mark)

Cardiac output is the product of which two factors?

A. Heart rate and stroke volume
B. Blood volume and heart rate
C. Tidal volume and heart rate
D. Stroke volume and blood volume

Question 3 (1 mark)

Cardiac output at rest and during maximal exercise would be approximately:

A. 1 to 2 L/min and 4 to 5 L/min, respectively.
B. 1 to 2 L/min and 40 to 45 L/min, respectively.
C. 11 to 12 L/min and 24 to 35 L/min, respectively.
D. 5 to 6 L/min and 20 to 25 L/min, respectively.

Question 4 (1 mark)

Which two factors, when multiplied, result in ventilation?

A. Tidal volume and maximal oxygen uptake
B. Respiratory rate and total lung capacity
C. Respiratory rate and tidal volume
D. Residual volume and respiratory volume

Question 5 (1 mark)

The relationship between exercise intensity and oxygen uptake is:

A. exponential until maximal uptake is obtained.
B. linear until maximal uptake is obtained.
C. non-linear.
D. non-linear until maximal uptake is obtained.

Question 6 (1 mark)

From rest to submaximal exercise, the arteriovenous difference:

A. increases.
B. remains the same.
C. decreases.
D. is close to zero.

Question 7 (1 mark)

At the start of exercise, the body's oxygen transport systems do not immediately supply the required quantity of oxygen to the active muscles. This is known as:

A. steady state.
B. oxygen debt.
C. oxygen deficit.
D. EPOC.

Question 8 (1 mark)

During exercise, capillaries and arterioles:

A. vasoconstrict to increase oxygen to the working muscles.
B. vasodilate to decrease oxygen to the non-essential organs.
C. remain the same to increase oxygen to the non-essential organs.
D. vasodilate to increase oxygen to the working muscles.

Question 9 (1 mark)

An elite female alpine skier would have a VO_2 max of approximately:

A. 65 to 70 mL/kg/min.
B. 50 to 55 mL/kg/min.
C. 50 to 55 L/min.
D. 50 to 55 mL/min.

Question 10 (1 mark)

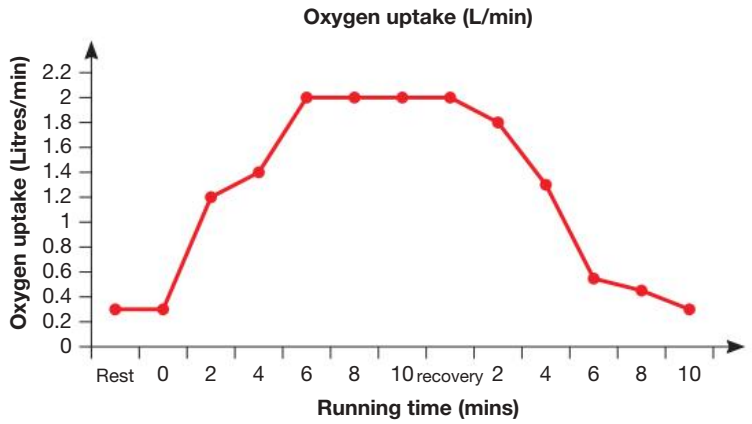
An acute muscular response during high-intensity exercise could be:

A. decreased stores of ATP and creatine phosphate.
B. increased tidal volume.
C. increased cardiac output.
D. decreased muscle enzyme activity.

5.7 Section B – Short answer questions

Question 1 (9 marks)

The graph shows the oxygen uptake of a male athlete running on a treadmill for 12 minutes at 22 °C.



a. **Explain** why the athlete's oxygen uptake has increased at the 2- and 4-minute marks of exercise. **(1 mark)**

b. **State** whether the athlete's heart rate and stroke volume would increase, decrease or stay the same at 2 and 4 minutes. **(2 marks)**

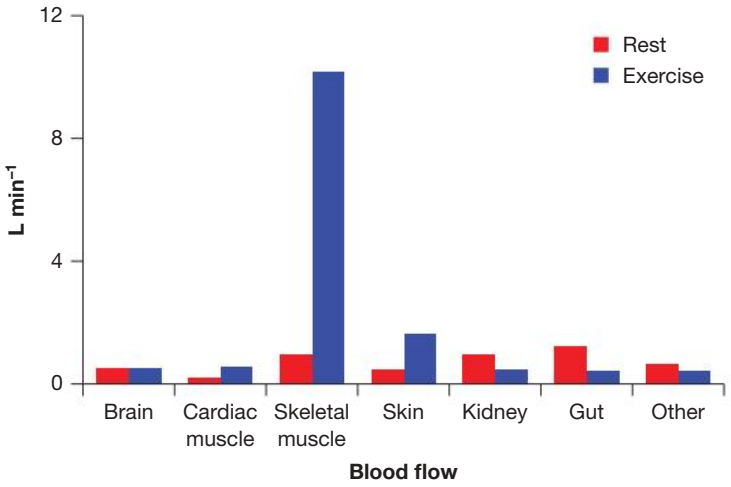
c. Does the athlete achieve steady state during their run? Use data from the graph to **justify** your answer. **(2 marks)**

d. On the graph, shade in the area of excess post-exercise oxygen consumption (EPOC). **(1 mark)**

e. **Outline** three factors that causes EPOC. **(3 marks)**

Question 2 (7 marks)

The graph below indicates blood flow to various organs of the body at rest and during exercise.



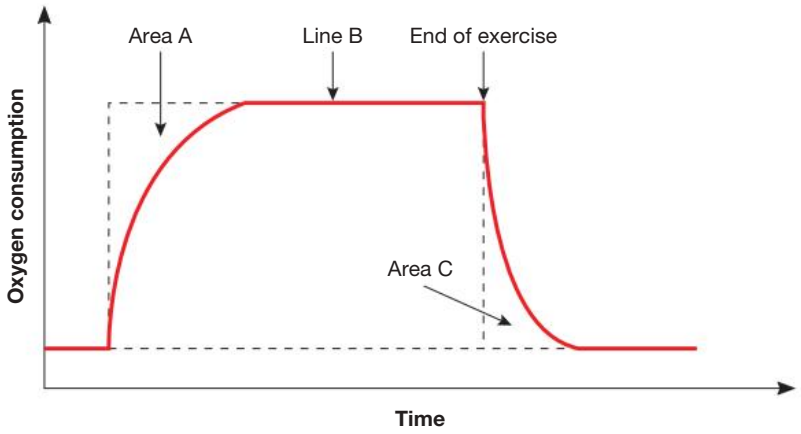
a. Use the data to suggest the amount of blood (in L or mL) that is redistributed to the skeletal muscles during exercise. **(1 mark)**

b. Other than skeletal muscle, **indicate two** areas to which blood flow increases during exercise. For each of these two areas, **outline** the reason for this redistribution in blood flow. **(4 marks)**

c. **Explain** the physiological response that allows the increase in blood flow to skeletal muscle during exercise. **(2 marks)**

Question 3 (9 marks)

Use the graph below to answer the following questions.



a. What do the following areas of the graph represent? **(3 marks)**

b. Why does Area A occur at the beginning of exercise? **(1 mark)**

c. **Describe** the circumstances that allow Line B to occur. **(2 marks)**

d. Name one strategy that an athlete can undertake in order to reduce the size of Area A. **(1 mark)**

e. **Explain** why the strategy listed in **part d** above can reduce the size of Area A. **(2 marks)**

Question 4 (2 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.11.b;* © VCAA

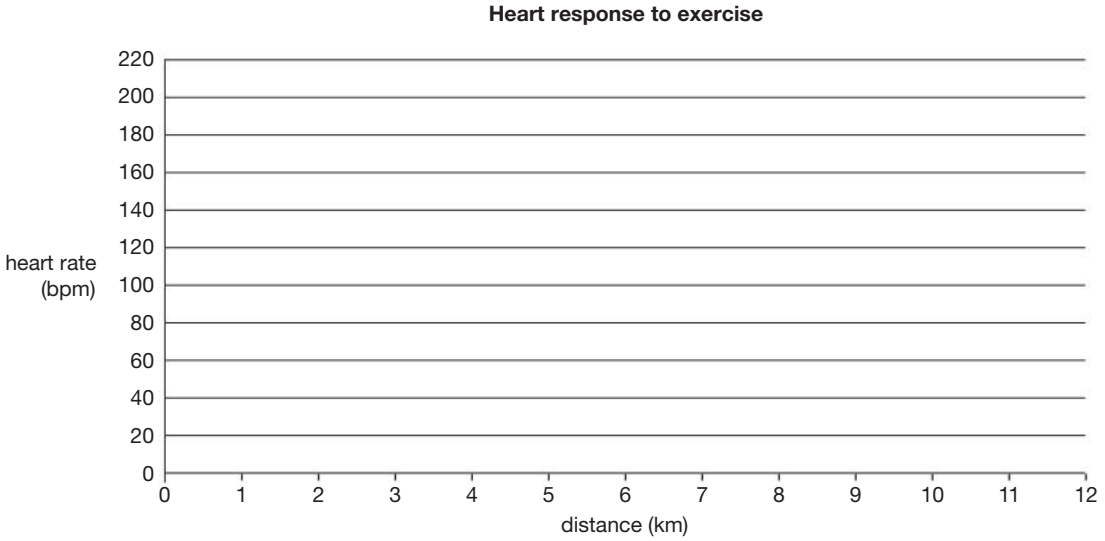
Describe the acute physiological responses that occur at the beginning of exercise.

Question 5 (11 marks)

Source: *VCE 2012, Physical Education Exam, Section B, Q.9*; © VCAA

A 20-year-old male completes a 10-km run as part of his pre-season football training. He wears a heart rate monitor to record changes in his heart rate and records a resting heart rate of 60 bpm. He knows that 160 bpm means he is working in his aerobic training zone. It takes him 1 km before he reaches a steady state at 80% of heart rate max. The 10-km course is relatively flat and he maintains this intensity throughout the run. As part of his routine, he works maximally for the last 500 m and then completes an active recovery for 2 km.

a. On the axes below, draw and label a graph that demonstrates your understanding of the heart rate response to this training session. On your graph, include
- periods of O_2 deficit
- steady state
- periods of excess post-exercise oxygen consumption (EPOC). **(4 marks)**



b. Provide an explanation for the shape of the graph in **part a** from 0 to 1 km. **(2 marks)**

c. How will the EPOC of the footballer be affected by him running at maximal intensity for the last 500 m instead of maintaining a steady state until the end of the run? **(2 marks)**

d. Provide an appropriate strategy for overloading this training session. **(1 mark)**

e. **Suggest** an alternative aerobic training method and explain how it could be manipulated to make training more specific to the needs of a football game. **(2 marks)**

Continue to build your exam skills

Access the Unit 3 Area of Study 2 Review at the end of Topic 7. This includes:
- Practice extended response
- Practice examination
- Practice school-assessed coursework.

6 The interplay of energy systems

6.1 Overview

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LEARNING SEQUENCE

6.1 Overview
6.2 Adenosine triphosphate
6.3 Fuels — chemical and food
6.4 Energy systems characteristics
6.5 The ATP–CP system and recovery
6.6 The anaerobic glycolysis system and recovery
6.7 The aerobic system and recovery
6.8 Energy systems interplay
6.9 Key skills
6.10 Review

6.1.1 Introduction

Energy is required for a variety of processes in the human body, including growth, repair of body tissue, the transportation of substances between cells and muscle contraction. The intensity and time over which muscular contractions can be sustained is determined by the energy system used to create the energy. Understanding the characteristics of the body's three energy systems and how they recover will enable you to determine each system's combined contribution to movement at rest and to specific movements at varying intensities. This knowledge is essential for understanding how to analyse movement through the lens of exercise physiology, and for developing the skills to design and implement successful training programs that are specific to an athlete's needs.

FIGURE 6.1 How is energy being produced? What energy systems are enabling each of the players' movements? Is the amount of energy required the same for each player?



6.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery	**6.2** **6.3** **6.4** **6.5** **6.6** **6.7**
• the interplay of energy systems in relation to the intensity and duration of various physical activity, sport and exercise	• participate in physical activity, sport and exercise to describe, using appropriate terminology, the interplay and relative contribution of the 3 energy systems	**6.8**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

6.1.3 Topic preview



6.2 Adenosine triphosphate

Key knowledge	Key skill
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

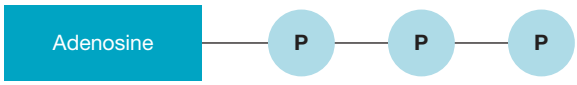
Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

6.2.1 ATP

Adenosine triphosphate (or ATP as it is more commonly referred to) is the chemical energy 'currency' of all body cells, including muscle cells. It powers all the cell's metabolic activities, including, in the case of muscle cells, the ability to contract. An ATP molecule consists of adenosine and a chain of three inorganic phosphate groups bound together by high-energy chemical bonds as seen in figure 6.2.

The energy that powers the mechanisms involved in muscular contraction is obtained from the catabolism (breaking down) of ATP. However, the body stores only a very small quantity of this 'energy currency' within the cells, enough to power only 1–2 seconds of maximal exercise. As most sporting activities last longer than this, the body must replace or resynthesise ATP on an ongoing basis. Understanding how the body does this is the foundation for understanding energy systems.

FIGURE 6.2 An ATP molecule



The phosphate 'tail' of ATP is the actual 'power source' that the cell catabolises (breaks down). Available energy is contained in the bonds between the phosphates and is released when they are broken. Usually only the outer phosphate is removed from ATP to yield energy. When this occurs, ATP is converted to **adenosine diphosphate** (or ADP) and inorganic phosphate (or Pi — a free floating phosphate molecule) (see figure 6.3).

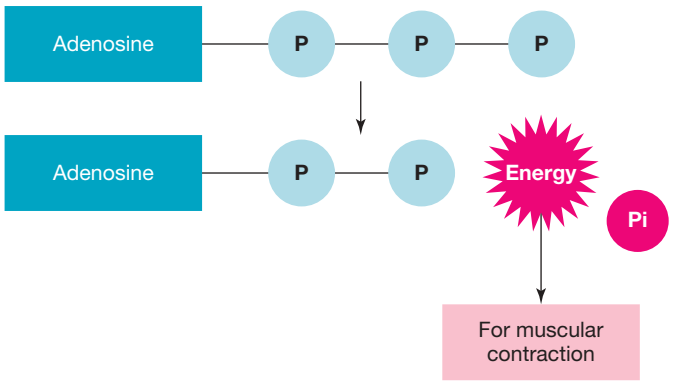
adenosine triphosphate (ATP) a high-energy molecule stored in muscle cells and other parts of the body. It is the energy currency for biological work.

adenosine diphosphate (ADP) a by-product that results when ATP breaks down and loses one of its phosphate groups, which are located at the end of the molecule

The energy released during the breakdown of ATP to ADP and Pi is used to power cell processes such as the mechanisms involved in muscular contraction. This can be represented by the formula:

$$ATP \leftrightarrow ADP + Pi + Energy.$$

FIGURE 6.3 Energy is released during the breakdown of ATP to ADP and Pi.



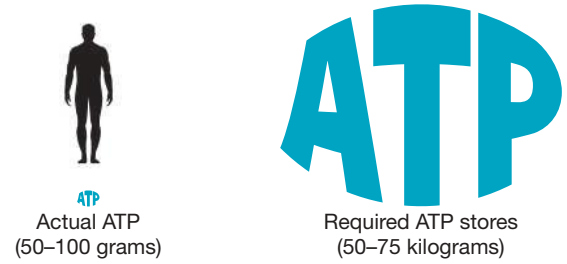
on Resources

Video eLesson Breakdown of ATP (eles-0469)

6.2.2 Replenishing ATP stores

While the breakdown of ATP is required in order to provide the energy that powers the mechanisms involved in muscular contraction, muscular stores of ATP are very limited. It is estimated that the total quantity of ATP in the average human body is about 0.1 mole, or approximately 50–100 grams. Yet estimates put the daily energy requirement of an average person upward of 100–180 moles of ATP, which is equivalent to 50–75 kilograms of ATP (see figure 6.4).

FIGURE 6.4 The amount of ATP in the human body is much less than what is required in a 24-hour period.

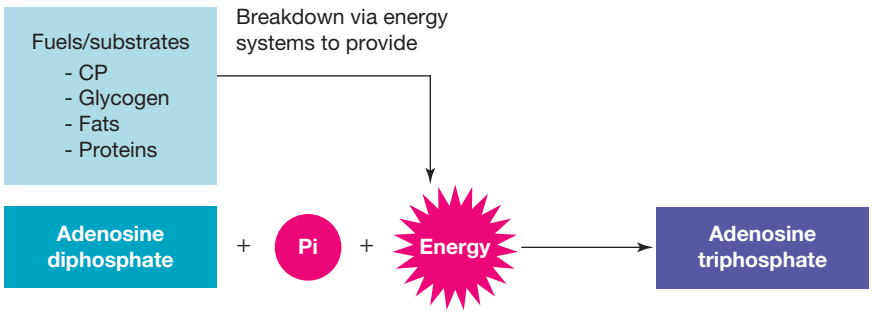


The limited stores of ATP within the body are used up within about 1–2 seconds of maximal intensity activity. If it were not for the fact that ATP stores are constantly replenished during activity, muscular contraction could not continue. Once intramuscular ATP stores begin to deplete, chemical reactions within the muscle start to replenish ATP stores, allowing the muscles to keep working.

The replenishment of the limited stores of ATP occurs via a process known as phosphorylation. This is a biochemical process that involves the addition of a phosphate group to an organic compound or molecule. In this particular circumstance, it involves the addition of a phosphate group to ADP to form ATP. In other words, ATP is replenished or resynthesised from ADP and Pi.

However, this resynthesis requires energy to connect the phosphate group back to ADP to create ATP (ADP + Pi + Energy ↔ ATP). This energy can be obtained from the breakdown of several energy fuels or substrates that are also present within the muscle. These fuels or substrates include creatine phosphate (also known as phosphocreatine), forms of carbohydrate (glycogen), fats and protein. These fuels can provide the energy required for the resynthesis of ATP during physical activity for as long as sufficient stores of the fuels or substrates are available (see figure 6.5).

FIGURE 6.5 The resynthesis of ATP from ADP and an inorganic phosphate (Pi) molecule requires energy available from the breakdown of energy fuels.



The energy required for ATP resynthesis to occur can be released from these energy fuels via three distinct yet closely integrated metabolic pathways or energy systems. If ATP resynthesis occurs via energy systems or pathways that require the presence of oxygen, it is referred to as **aerobic metabolism** and uses the aerobic system. If it occurs via energy systems or pathways that do not require oxygen, then it is referred to as **anaerobic metabolism** and uses the ATP–CP and anaerobic glycolysis systems.

aerobic metabolism when ATP resynthesis occurs via energy pathways that require the presence of oxygen

anaerobic metabolism when ATP resynthesis occurs via energy pathways that do not require the presence of oxygen

EXAM TIP

Remember that aerobic is with air (oxygen), anaerobic is without.

on Resources

Video eLesson ATP breakdown and resynthesis (eles-0454)

6.2 Activity

6.2 Quick quiz on | **6.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 6	4, 5	1, 3

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TEST your understanding

1. **Explain** what is meant by 'ATP is the energy currency of the cell'.
2. **Draw** a diagram to show the basic structure of ATP.
3. **Explain** how ATP differs from ADP.

APPLY your understanding

4. a. **Create** a list of each of the exercises you completed in your previous training session. This could be a session you undertook individually or within a team setting.
   For variety you may need to include exercises you completed in the warm up and cool down phase.
   Where possible, also include the intensity they were completed at, i.e. submaximal or maximal.
   b. **Identify** the type of metabolism (anaerobic or aerobic) that was the main contributor to each exercise in your list. To achieve this, you may need to investigate the characteristics of each type of metabolism in subtopic 6.4.
   c. Choose one of the exercises from your list and **discuss** why either anaerobic or aerobic metabolism was the main contributor to your performance.
5. The word 'rate' refers to how fast we produce ATP and 'yield' refers to how much ATP we need.
   With reference to the 50-metre sprint and the 60-second jog, **compare** the rate (fast or slow) and yield (high or low) of ATP that is required for both sports.
6. To resynthesise or produce ATP, we require energy from fuels. **Identify** the fuels that can be used by the body to produce ATP?

6.2 Exam question

Question 1 (1 mark)

Outline one difference between anaerobic and aerobic metabolism.

Question 2 (1 mark)

Identify the high-energy molecule stored in muscle cells and other parts of the body.

A. Adenosine triphosphate (ATP)
B. Adenosine diphosphate (ADP)
C. Phosphorylation
D. Aerobic metabolism

Question 3 (1 mark)

Energy for ATP resynthesis can be obtained from the breakdown of several substrates including:

A. creatine, glycogen, fibre and amino acids.
B. phosphocreatine, glycogen, fats and calcium.
C. creatine, glycogen, fats and protein.
D. phosphocreatine, glycogen, fats and protein.

More exam questions are available in your learnON title.

6.3 Fuels — chemical and food

Key knowledge	Key skill
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

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Several fuels or substrates can be used to provide the energy required for the resynthesis of ATP from ADP and Pi. These include creatine phosphate (a chemical fuel) and carbohydrates, fats and protein (food fuels). Chemical fuels are formed in the body itself; they cannot be consumed. Conversely, food fuels are eaten as part of our diet.

6.3.1 Creatine phosphate as a fuel source

Creatine phosphate (CP), or phosphocreatine (PC) as it is also known, is a chemical compound; and, like ATP, it is stored in limited quantities within muscle cells. Also like ATP, CP is a high-energy substance that stores and releases energy via the high-energy bond that binds the creatine and phosphate together (see figure 6.6). When this bond is broken, energy is released that enables ATP to be resynthesised from ADP and Pi. The bond is broken via a simple and short anaerobic (without oxygen) chemical reaction, which allows the fastest rate of ATP resynthesis. As such, CP is the primary supplier of ATP during short duration, explosive exercise, such as field events in athletics (see figure 6.7).

creatine phosphate (CP) a chemical compound found in muscle cells that is capable of storing and releasing energy that can be used to resynthesise ATP from ADP and Pi

FIGURE 6.6 The chemical compound creatine phosphate (CP) consists of creatine and phosphate bound together by a high-energy bond.



FIGURE 6.7 Creatine phosphate is the primary supplier of ATP in field events such as **(a)** launching a shot put or **(b)** taking off to clear the high jump bar.



Creatine in the diet

Approximately 50 per cent of the **creatine** stores within our bodies are obtained through the foods we eat, while the other 50 per cent are manufactured in the kidneys and liver. Roughly 95 per cent of the human body's total creatine is located in skeletal muscle. The rest is located in the brain or heart. Approximately one-third is found within our bodies in its free form as creatine, while the remainder is bound with phosphate to form CP.

creatine an organic substance that occurs naturally in humans and helps to supply energy to muscle

carbohydrates naturally occurring compounds that consist of carbon, hydrogen and oxygen

glycogen the storage form of glucose; a chemical fuel found in the muscles and in larger quantities in the liver

6.3.2 Carbohydrates as a fuel source

Carbohydrates are the most versatile fuel source available to supply energy for ATP resynthesis. **Glycogen** can provide the energy for ATP resynthesis under both anaerobic (no oxygen required) and aerobic (oxygen required) conditions. As such, glycogen can be the primary fuel source for ATP resynthesis at a variety of intensities, including during submaximal efforts and periods of extended or repeat high intensity, such as when playing team sports. At rest and during low-intensity exercise, carbohydrates contribute approximately one-third of the body's energy requirements, with fats providing the other two-thirds. When exercising continuously, we have around 90–120 minutes of stored glycogen in our muscle and liver for ATP resynthesis.

Carbohydrates in the diet

Carbohydrates are found in many of the foods we eat (see figure 6.8). Traditionally, they have been divided into two groups:

- simple carbohydrates or sugars, made up of one or two glucose molecules. Simple carbohydrates (e.g. watermelon) are metabolised by the digestive system quickly and provide an immediate release of energy.
- complex carbohydrates or starches, made up of many hundreds of glucose molecules. Complex carbohydrates (e.g. pasta) are metabolised by the digestive system slowly and provide a more gradual, sustained release of energy.

FIGURE 6.8 What relevance does the time of energy release have to athletes and their nutritional needs in performance and recovery?



Watermelon Rice Pasta

When carbohydrates are digested, they are broken down into **glucose** for transportation via the circulatory system (blood) and then stored as glycogen in the muscles and liver. Any excess carbohydrates can be stored as fat in the form of triglycerides within adipose tissue around the body.

Carbohydrates should make up approximately 55–65 per cent of total daily energy intake, although athletes in heavy training and competition may require a higher percentage intake (60–80 per cent) to ensure adequate levels in the body each day for training and competition needs.

glucose the simplest form of carbohydrate and the basic ingredient for anaerobic and aerobic glycolysis

fats (lipids) an essential component of a balanced diet; should comprise about 20–25 per cent of daily food intake

6.3.3 Fats as a fuel source

Fats are the most concentrated form of energy for ATP resynthesis. Gram for gram, fats provide more energy than carbohydrates; they provide 9 kilocalories per gram compared to the 4 kilocalories per gram provided by carbohydrates. Despite this, fats are primarily used during rest and low-intensity exercise.

During exercise, the percentage of fats being used as an energy source decreases as the exercise intensity increases. This is because, metabolically speaking, fats are more difficult to break down. Because breaking down fats requires a longer chain of chemical reactions, their rate of energy release is much slower compared to carbohydrates. As such, carbohydrates are the preferred fuel source during extended high-intensity activity during which ATP resynthesis must keep pace with the rapid rate of ATP use. However, fats as an energy source become important when stores of carbohydrate (stored in the muscle and liver as glycogen) start to deplete during continuous endurance exercise (usually after 90–120 minutes of continuous activity).

Fats in the diet

Fats (or lipids) are found in many different foods. They can be divided into:

1. saturated fats
2. unsaturated fats.

Saturated fats are found in animal foods such as dairy products (e.g. milk, cheese) and meat products (see figure 6.9). This type of fat contains a substance called cholesterol, which has been implicated in cardiovascular disease. When blood cholesterol levels rise, blood vessels may become lined with cholesterol deposits, leading to cardiovascular problems.

Unsaturated fats (see figure 6.10) come in two forms.

1. polyunsaturated fats — found in most vegetable oils (e.g. sunflower oil) and oily fish (e.g. tuna)
2. mono-unsaturated fats — found in foods such as olive oil, avocados and nuts.

Both types of unsaturated fat help lower the total cholesterol level and contain essential fatty acids that the body cannot produce itself.

FIGURE 6.9 Examples of foods containing saturated fats



Fats in the body

Fats are broken down through digestion and made available to the bloodstream as **free fatty acids** and glycerol. They are stored intramuscularly (within the muscles) as **triglycerides**, with excess amounts stored subcutaneously (under the skin) within adipose tissue (body fat) around the body, where they act as a substantial energy reservoir.

FIGURE 6.10 Examples of foods containing unsaturated fats



6.3.4 Protein as a fuel source

Under normal circumstances, protein contributes only minimal energy for ATP resynthesis (estimates put this figure at no more than 5–10 per cent). However, in extreme circumstances (such as starvation or ultra-endurance events), when the body has severely depleted its supplies of carbohydrate and fat, proteins can become a viable source of energy for the replenishment of ATP. However, due to the complex reactions required to break down protein, this fuel source produces ATP for muscular contractions at a slower rate compared to carbohydrates.

Protein in the diet

Animal foods such as meat, poultry, fish, eggs and dairy products are rich in **protein** (figure 6.11) and contain all the essential **amino acids**. Plant foods such as cereals, grains, lentils, beans and peas are also good sources of protein, although they do not contain all the essential amino acids.

Protein is broken down through digestion into amino acids, of which there are two types:

1. essential amino acids — cannot be made by the body, so must be consumed as part of the diet
2. non-essential amino acids — can be manufactured from other amino acids in the body.

Excess protein (amino acids) is converted to fats and stored within adipose tissue.

Proteins are important in the formation, growth and repair of body tissue, especially muscle tissue and cells. They also help in the production of red blood cells, hormones and enzymes. As such, proteins play a vital role in the post-exercise recovery process, and adequate consumption helps the body to return to pre-exercise conditions sooner. Protein's role in recovery will be further explored in topic 7.

free fatty acids a broken-down, transportable form of fats

triglycerides the stored form of fats found in adipose tissue and skeletal muscle

protein an essential component of a balanced diet. Protein allows for muscle growth and repair, fights disease, assists in chemical reactions and transports materials

amino acids the building blocks of protein. Protein is broken down through the process of digestion into amino acids.

Nutritionists recommend that proteins contribute about 15 per cent of a person's average daily food intake. Athletes in training may require slightly more protein in their diet, especially athletes involved in strength and power sports.

FIGURE 6.11 Examples of protein-rich foods



6.3.5 Protein and carbohydrates

Protein and carbohydrates make excellent partners for post-exercise nutrition. When consumed together, they stimulate a greater release of insulin. Put more simply, the addition of protein amplifies the insulin response, promoting absorption and accelerating the recovery of muscle glycogen levels. This is an important consideration for endurance athletes who, in training and competition, regularly use a significant amount of their glycogen stores for ATP production. Insulin is important because it:

- plays a key role in the dynamics of protein synthesis
- stimulates protein synthesis and helps to reduce protein breakdown.

The consumption of protein is therefore essential on two fronts:

- to increase the absorption of carbohydrates, accelerating the replenishment of muscle glycogen
- to provide the basic building blocks for muscle repair.

Examples of healthy snacks that include both protein and carbohydrates:

- yoghurt
- milk drinks
- fruit smoothies
- lean meat or cheese sandwiches.

6.3.6 Summary of food fuels

The elite athlete will adjust their percentage food fuel intake in consultation with a coach/dietician to ensure their needs are met. For example, the elite athlete may require a greater level of protein intake if they need to build and repair muscle. Most elite athletes will have a greater intake of fuel than will the general population, due to their higher energy requirements.

Table 6.1 provides a summary of the food fuels that are used to provide energy for ATP resynthesis.

TABLE 6.1 Food fuels, and the differing energy release that they provide

	Food sources	Transport form	Storage form in muscle	Excess
Carbohydrates	**Gradual release of energy:** most fruits and vegetables (except potatoes and watermelon), grainy breads, pasta, peas, lentils, milk and yoghurt **Fast release of energy:** sugar, honey, potatoes, watermelon, many breakfast cereals, most white rice and white bread	Glucose	Glycogen	• Liver — glycogen • Converted into fats — adipose tissue
Fats (lipids)	**Saturated fats:** meat products and dairy products **Unsaturated fats:** vegetable oils, oily fish (e.g. tuna), olive oil, nuts and avocado	Free fatty acids and glycerol	Triglycerides	Adipose tissue
Protein	**Animal foods:** meat, poultry, fish, eggs and dairy products **Plant foods:** cereals, grains, lentils, beans and peas	Amino acids	Amino acids	Adipose tissue

on Resources

Interactivity Summary of food fuels (int-6790)

Weblink Fuels for resynthesis of ATP

EXAM TIP

Remember that glycogen can provide the energy for ATP resynthesis under both anaerobic (no oxygen required) and aerobic (oxygen required) conditions.

6.3 Activity

6.3 Quick quiz on | **6.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 4	3, 7	1, 5, 6

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TEST your understanding

1. **Explain** the role of glycogen in providing energy for physical activity.
2. **List** the percentages of carbohydrate, fat and protein that are recommended as part of the daily dietary intake?
3. How would the dietary intake of food fuels differ for a weight-lifter **compared** with a long-distance runner?

4. Complete the following table by **recalling** information about the relationship between food fuels, the storage form of these food fuels and the energy system or systems that use each food fuel.

Food fuel	Storage form	Associated energy system or systems
Carbohydrates		
Fats		
Protein		

5. Carbohydrates and fats are the main food fuels used to supply energy for ATP resynthesis. **Explain** under which conditions proteins would be used to supply energy for physical activity.

APPLY your understanding

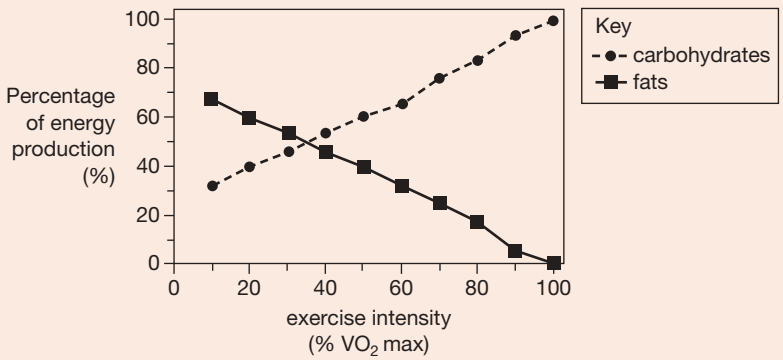
6. Record your total dietary intake for a continuous 3-day period. Record this intake in an appropriate table form. **Assess** the percentages of carbohydrate, fat and protein in your diet each day and for the 3-day period overall. Using your own dietary knowledge as a guide, **explain** how you could improve your diet to meet your energy needs. Write a brief report on your findings.
7. Glycogen stored in the muscle and liver can deplete during continuous endurance exercise after approximately 90–120 minutes. **Investigate** one sporting event in which glycogen depletion is likely to occur. In doing so, **outline** the event requirements such as type of exercise, intensity and duration.

6.3 Exam question

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.13*; © VCAA

The graph below shows the percentage of energy contributed by carbohydrates and fats as exercise intensity changes.



Source: Adapted from SK Powers & ET Howley, *Exercise physiology*: *theory and application to fitness and performance*, McGraw-Hill, New York, 2009, p. 61

Which one of the following statements is correct?

A. As the exercise intensity increases, the contribution of fats to energy production increases.
B. As the exercise intensity increases, the contribution of carbohydrates to energy production increases.
C. At 60% VO_2 max, there is a higher contribution from fats than from carbohydrates to energy production.
D. At 50% VO_2 max, there is an even contribution between fats and carbohydrates to energy production.

Question 2 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.12;* © ACHPER

Phosphocreatine is a form of

A. amino acid.
B. food fuel.
C. complex carbohydrate.
D. simple carbohydrate.

Question 3 (4 marks)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.2;* © ACHPER

Glycogen breakdown can occur with or without the presence of oxygen.

In the table below, **identify one** advantage and **one** disadvantage for each type of breakdown.

	Advantage	Disadvantage
With Oxygen		
Without Oxygen		

Question 4 (3 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.9;* © *VCAA*

Discuss the role of fats in energy production at rest and during exercise.

Question 5 (3 marks)

Explain the benefit of consuming a post-exercise snack that contains a combination of carbohydrates and protein.

More exam questions are available in your learnON title.

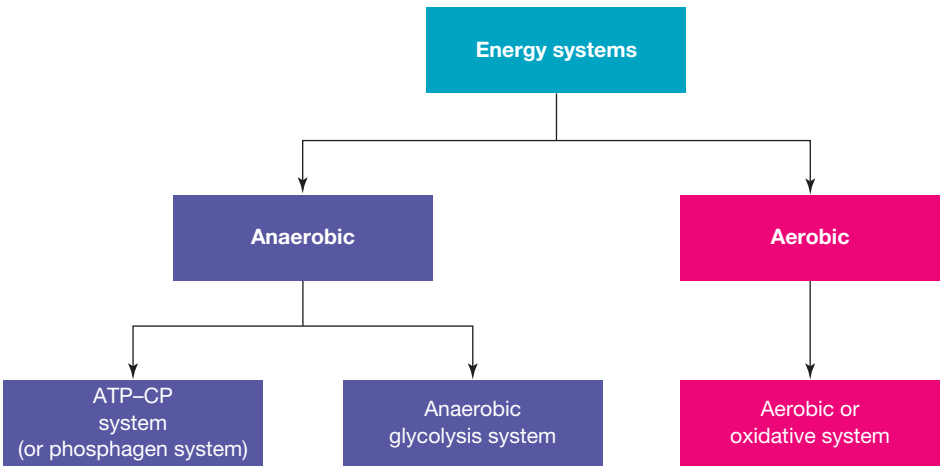
6.4 Energy systems characteristics

Key knowledge	Key skill
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

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The energy that is required for ATP resynthesis to occur can be obtained via three distinct yet closely integrated metabolic pathways or energy systems that operate simultaneously to satisfy the energy requirements of the muscle. Two of these energy systems are anaerobic pathways and the third is an aerobic pathway, as shown in figure 6.12.

FIGURE 6.12 The body relies on three energy systems — two anaerobic systems and one aerobic system.



The **ATP–CP energy system** refers to the processes involved in the breakdown of stored phosphagens — ATP and CP — without oxygen being involved. This system is also commonly referred to as the ATP–PC system, the phosphate energy system, the phosphocreatine (PC) system or the phosphagen system.

The **anaerobic glycolysis energy system** involves the metabolism of carbohydrates (glycogen) to lactic acid through a series of chemical steps that do not require oxygen.

The **aerobic energy system** (or oxidative system) involves the complete metabolism of primarily carbohydrates (glycogen) and/or fats (triglycerides) in the presence of oxygen.

ATP–CP energy system provides energy for the resynthesis of ATP through the breakdown of creatine phosphate (CP) without oxygen being involved

anaerobic glycolysis energy system provides energy for the resynthesis of ATP through the breakdown of glycogen through a series of chemical steps that do not require oxygen

aerobic energy system provides energy from the breakdown of carbohydrates and/or fats in the presence of oxygen

6.4.1 ATP resynthesis: demand, rate and yield

At all times, all three energy systems contribute to the resynthesis of ATP during physical activity. How each system works alongside the other energy systems is referred to as the **interplay of energy systems**. To determine which of the three energy systems is the major or primary supplier of energy for ATP resynthesis at any point in time during an activity, and which energy system is the major contributor over the duration of a total activity or event, it is necessary to understand the concept of **ATP demand**.

During any activity, ATP resynthesis (supply) must be able to meet the ATP demand of the activity. Two factors determine the ATP demand of an activity:

1. exercise duration — how long the activity lasts for
2. exercise intensity — how hard the exercise is performed (often measured using heart rate per minute).

Exercise intensity determines the **rate** of ATP use and, consequently, resynthesis during the activity. Exercise duration determines the total amount or **yield** of ATP that needs to be resynthesised over the course of the activity. Generally speaking, as exercise duration increases, the intensity at which it can be performed decreases.

interplay of energy systems the energy systems simultaneously working together, but at different rates, to supply the ATP required for an activity

ATP demand refers to how much ATP is required during an activity and the rate at which it is expended and, therefore, needs to be resynthesised

rate refers to how quickly ATP is resynthesised

yield the total amount of ATP that is resynthesised during an exercise bout or from a specific fuel within the bout

To help illustrate the concept of ATP demand, rate and yield, let us consider two different activities.

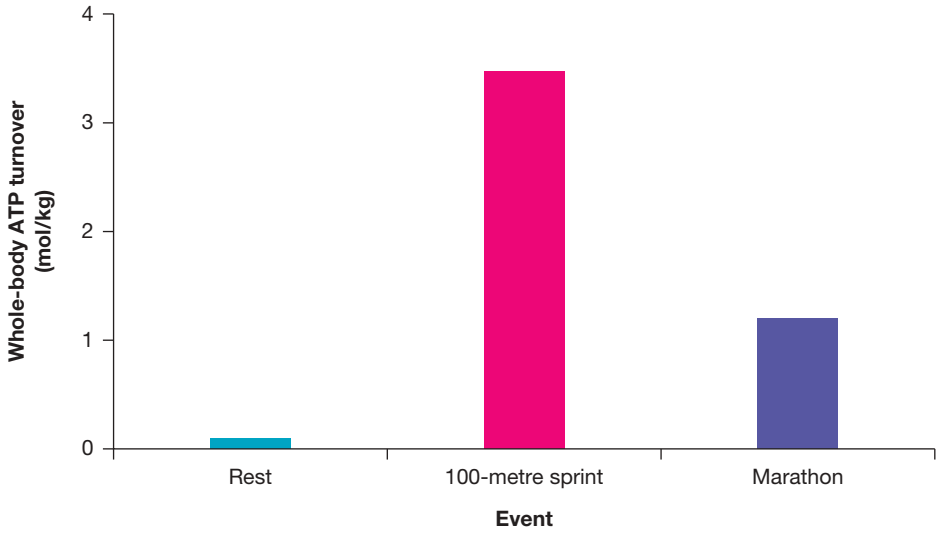
100-metre sprint

- Completed in around 10 seconds, the 100-metre sprint is a high-intensity activity. The rate of ATP expenditure is very rapid because the leg muscles need to contract powerfully and very quickly. Consequently, the rate of ATP resynthesis must also be very rapid to keep pace with the demand. However, because of this event's short duration (less than 10 seconds), the yield (total amount) of ATP required is low.

Marathon

- Taking around 2 hours and 15 minutes to complete, a marathon is a submaximal-intensity activity. The rate of ATP expenditure is much lower compared to in the sprint, since the muscles do not need to contract as forcefully or as quickly. However, due to the marathon's much longer duration, the yield (total amount) of ATP required is much, much greater (see figure 6.13).

FIGURE 6.13 The 100-metre sprint and the marathon place different ATP demands on the athlete. Note that ATP turnover during a 100-metre sprint is estimated to be almost three times greater than during a marathon.



Source: Adapted from JR Poortmans, *Principles of exercise biochemistry,* 3rd ed. rev., Karger Publishing, 2004

6.4.2 Meeting ATP demands

The two anaerobic energy systems (ATP–CP and anaerobic glycolysis) supply energy for ATP resynthesis at a rapid rate, but only for a short period of time, with a much smaller yield compared to the aerobic system. Therefore, these anaerobic systems are used for ATP resynthesis during high-intensity, short-duration exercise, for which muscles need a rapid supply of ATP.

The aerobic system, on the other hand, supplies energy for ATP resynthesis at a much slower rate than the anaerobic pathways, but with a much greater yield. The aerobic system is therefore the major supplier of energy for ATP resynthesis when the body is at rest, and during longer-duration exercise performed at submaximal intensity. While the rate of energy production via the aerobic system is much slower compared to the two anaerobic systems, it produces far more energy for ATP resynthesis for a given amount of 'fuel'.

Yield of ATP

Yield of ATP is the amount of ADP that can be resynthesised into ATP. The higher amount of ATP available means more ATP can be broken down, providing larger amounts of energy for muscle contraction.

In terms of ATP yield:

- the ATP–CP system can produce only 0.7 moles of ATP from 1 mole of CP
- the anaerobic glycolysis system can produce only 2 moles of ATP from 1 mole of glucose
- the aerobic system can produce 36–38 moles of ATP from 1 mole of glucose
- the aerobic metabolism of fats produces by far the most ATP from a given amount of 'fuel'. One mole of fat can produce in excess of 100 moles of ATP.

Rate of ATP

Rate of ATP is the speed at which ADP can be resynthesised to ATP. The quicker that ADP can be resynthesised, the quicker it can be broken down again to provide energy for muscle contraction.

When considering the rate of ATP supply, the reverse applies to what was seen for ATP yield.

- The ATP–CP system can supply ATP at a maximal intensity rate of 3.6 moles per minute.
- The anaerobic glycolysis system can supply ATP at a high intensity rate of 1.6 moles per minute.
- The aerobic system can supply ATP at a slow rate of around 1 mole per minute.

These differences in the capacity of the three energy systems are summarised in table 6.2. The characteristics of food fuels is summarised in figure 6.14.

TABLE 6.2 Capacities of the three energy systems

			Aerobic system	
	ATP–CP system	**Anaerobic glycolysis system**	**Carbohydrate (glycolysis)**	**Fats (lipolysis)**
Fuel source	Creatine phosphate	Glucose Glycogen	Glucose Glycogen	Free fatty acids Triglycerides
Rate	Most rapid 3.6 moles/minute	Fast 1.6 moles/minute	Slow 1.0 mole/minute	Slowest < 1.0 mole/minute
Yield (moles of ATP per mole of fuel source)	Very small < 1	Small 2	Large 36–38 in ideal conditions	Largest 100+ free fatty acids 300+ triglycerides
Event characteristics	• Speed maximal effort of 0–10 seconds • Power-based events	• Speed of 10 seconds – 75/90 seconds • Repeated high intensity efforts • Surges above submaximal intensities	• Endurance • Submaximal intensities	• Ultra-endurance • Submaximal intensities • 4+ hours

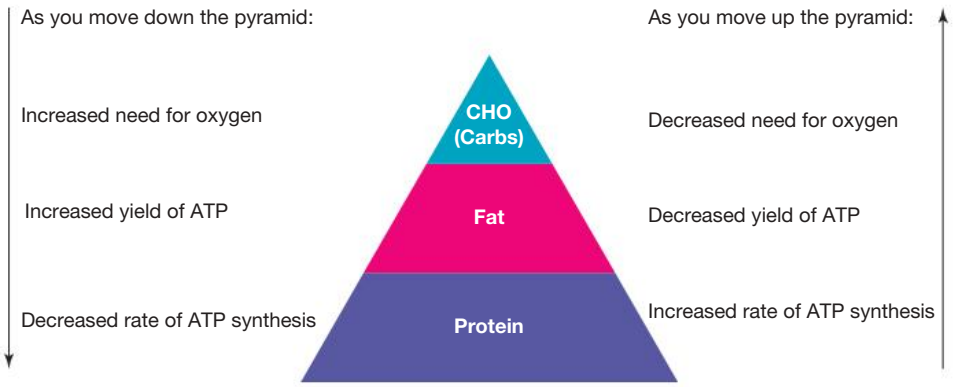
Notes about table 6.2:

- There is a trade-off between rate and yield for each of the energy systems.
- As the rate of ATP resynthesis increases, the yield decreases. This is determined by the complexity of the chemical pathway of the energy system.
- The values shown in the table are general values and can vary from individual to individual.
- The capacity to produce energy via each of the three energy systems can vary with training.
- There is a transition period where one energy system is increasing its relative contribution while another is decreasing its relative contribution (interplay of energy systems).
- Fatigue-limiting factors will determine the transition from one energy system to another.

EXAM TIP

When describing the rate and yield of each energy system, the most important information to use in your response is the qualitative information. For example, the ATP—CP system has the most rapid rate of ATP resynthesis. The exact numbers help you understand the differences but there is no need to memorise them.

FIGURE 6.14 The characteristics of the food fuels



Yield of ATP is the amount of ADP that can be resynthesised to ATP. A higher amount of ATP available means more ATP can be broken down, providing larger amounts of energy for muscle contraction. For example, fats provide a large yield of ATP compared to CHO.

EXAM TIP

IDRY (Intensity, Duration, Rate and Yield) is a useful acronym for remembering the key information you should consider and use when responding to energy system questions.

on Resources

Interactivity Capacities of the three energy systems (int-6791)

Weblink Energy system characteristics

6.4 Activity

6.4 Quick quiz on | **6.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 5, 6	8	4, 7

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TEST your understanding

1. **List** the three energy systems that are responsible for the production of energy for ATP resynthesis.
2. For each energy system, **identify** the chemical and/or food fuels that can be used by that energy system.
3. **Identify** the two factors that determine the ATP demand of an exercise bout or activity?
4. **Explain** the difference between rate and yield in terms of ATP demand.
5. **List** the three energy systems in order from fastest (1) to slowest (3) in terms of the rate at which they are capable of providing energy for ATP resynthesis.
6. **List** the three energy systems in order from lowest (1) to highest (3) in terms of the yield of ATP they are capable of producing from an equivalent amount of their fuel source.

APPLY your understanding

7. Perform the following series of physical activities, allowing adequate time for recovery (2–3 minutes) between each activity. Have a partner time how long it takes you to complete each activity, and then swap roles.
   - Dribbling from half court to perform a basketball lay up
   - A 100-metre sprint
   - 10 burpees
   - A 400-metre jog around the oval
   - 5 × 50-metre sprints (with 20 seconds recovery between each sprint)

   a. **Identify** which energy systems were involved in ATP resynthesis throughout these activities.
   b. Based on the time recorded and the prescribed intensity, **identify** which system was the major supplier of ATP for each of the 5 activities.
   c. **Justify** why it was important to record the time taken to complete each activity.
   d. **Identify** what occurred during the recovery period.
8. Observe 2 minutes of play from a basketball game. This could be in person or watching recorded footage. Make a record of three skills performed within the passage of play. **Discuss** the rate and yield required for the successful performance of each of the three skills. Ensure you use the qualitative information from table 6.2 in your response.

6.4 Exam question

Question 1 (1 mark)

Which fuel produces the greatest amount of energy per mole?

A. Liver glycogen
B. Triglycerides
C. Stored phosphocreatine (PC)
D. Muscle glycogen

Question 2 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.10;* © VCAA

The energy system with the highest yield of ATP but slowest rate is the

A. ATP–CP system.
B. aerobic system.
C. anaerobic system.
D. anaerobic glycolysis system.

Question 3 (2 marks)

Compare the rate and yield of the ATP–CP system to that of the aerobic system.

Question 4 (2 marks)

Discuss two differences between the chemical pathways of aerobic and anaerobic glycolysis.

More exam questions are available in your learnON title.

6.5 The ATP–CP system and recovery

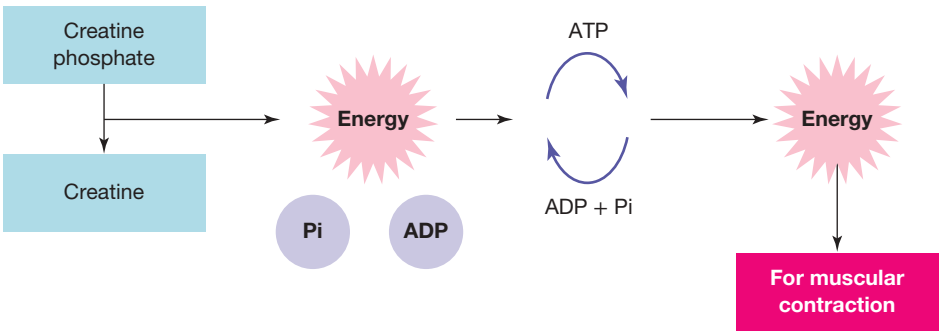
Key knowledge	Key skill
• the 3 energy systems (ATP–CP, anaerobic glycolysis and aerobic), including their fuels (chemical and food); rate and yield of each system; their contribution at rest and varying intensities; and recovery rates associated with active and passive recovery	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

6.5.1 The ATP–CP system

The ATP–CP (or ATP–PC) system is the least complicated of the three energy systems, and it produces energy for ATP resynthesis most rapidly. The ATP–CP system relies on the muscular stores of ATP and CP. When CP is broken down, energy is released and is used to resynthesise ATP. Therefore, as rapidly as ATP is broken down for muscular contraction, it is continually resynthesised from ADP and Pi by the energy released by the breakdown of CP. However, CP stores within the muscle are also limited and they deplete rapidly, particularly during high-intensity activity. This process is shown in figure 6.15.

FIGURE 6.15 The release of energy via the ATP–CP system for ATP resynthesis is quick and efficient, but short-lived.



When undertaking maximal-intensity exercise, ATP stores in the muscle will last for approximately 1–2 seconds. Thereafter, the resynthesis of ATP from the breakdown of CP will continue until the CP stores become depleted. On average, this happens after approximately 6–8 seconds of high-intensity exercise. Combined, the ATP–CP system can therefore sustain all-out (maximal) exercise for approximately 8–10 seconds. If the activity continues beyond this, the body must rely on another energy system to be the major supplier of ATP. Note, however, that while CP stores can deplete to 1–2 per cent, they never deplete fully, which means the ATP–CP system is always contributing, even if only minimally.

In conclusion, due to limited CP stores, the ATP–CP system has a finite capacity and can provide only a very limited amount (yield) of energy for ATP resynthesis, although it can supply this energy at a very rapid rate. For short duration, high-intensity activities that take up to 10 seconds to perform, such as sprints, kicks, throws and jumps, this system will be the major contributor to ATP resynthesis. However, due to the body's limited stores, it cannot continue being the primary contributor for an extended period.

6.5.2 The ATP–CP system and exercise

To further illustrate how the ATP–CP system functions, let us consider two activities in sport: one that takes just a few seconds to perform — a drive off the tee in golf — and another that takes about 10 seconds to perform — the 100-metre sprint in athletics.

The golf drive

The drive off the tee in golf is an effort of very short duration and maximal intensity (see figure 6.16). The energy required to perform this movement is primarily supplied by the ATP–CP system, which uses CP as its fuel. This system resynthesises ATP at the most rapid rate, meeting the ATP demand for this movement. After the drive off the tee, a **passive recovery** should be completed to replenish CP stores as soon as possible. A passive recovery replenishes CP stores faster than an active recovery.

FIGURE 6.16 The drive off the tee in golf is an example of a powerful movement that relies heavily on the ATP–CP system.

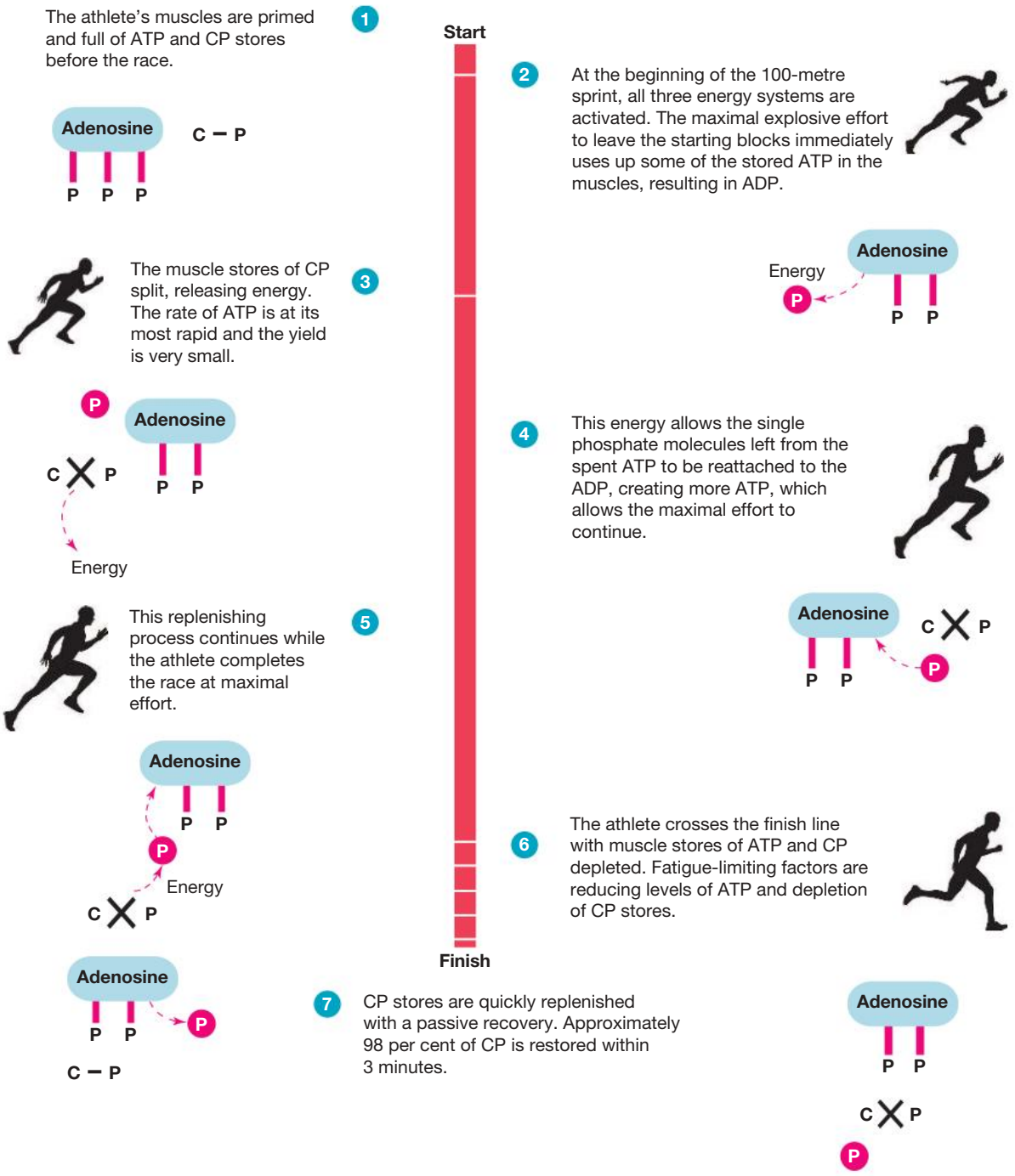


The 100-metre sprint

- At the beginning of a 100-metre sprint (see figure 6.17), all three energy systems are activated simultaneously.
- When the runner pushes off the blocks in a maximal effort, the ATP–CP system will be the primary supplier of ATP. This system provides energy at the most rapid rate, enabling this explosive effort to occur.
- Due to the short duration of this event, the ATP–CP system will continue to be the primary supplier of energy throughout the race, enabling the runner to continue to sprint at maximal intensity.
- Towards the end of the race (from about 6–10 seconds onwards), the muscles' stores of CP are greatly depleted, due to the very small yield of this system. The energy contribution from the anaerobic glycolysis system during the final few seconds of the race becomes much more significant.
- Passive recovery, such as standing or sitting down, will replenish CP stores at the fastest rate. Within 3 minutes, approximately 98 per cent of CP will have been restored.

passive recovery complete rest by standing, sitting or lying down to replenish CP at a faster rate

FIGURE 6.17 The cycle of ATP being broken down and resynthesised for powerful muscle movement centres around energy being released via the breakdown of creatine phosphate.



6.5.3 Recovery

Post-exercise **recovery** aims to overcome the effects of **fatigue** and restore the body to its pre-exercise condition. Adequate and effective recovery is essential to provide the body with the opportunity to replenish, repair and rebuild itself in readiness for the next training session or exercise bout. Without enough recovery, subsequent performances in both training and competition will be compromised.

recovery the overcoming or reversal of the fatigue experienced as the result of participation in a training session or exercise bout, where body systems repair damaged tissue and replenish energy stores

fatigue an exercise-induced reduction in the ability of muscle to produce force or power

Passive recovery

After an athlete has completed their maximal intensity, short duration activity, the ATP and CP stores must be rebuilt if the ATP–CP system is to be used as the major fuel source for the next activity.

- At the end of the activity, breathing rate is above normal and the body enters a period of excess post-exercise oxygen consumption (EPOC). Passive recovery, such as when the athlete stands, sits or lies down, will promote faster replenishment of CP.
- The extra oxygen is used to restore ATP, some of which is broken down. The resulting energy is used to combine creatine and phosphate back into CP stores within the muscle.
- During passive recovery:
  - within 30 seconds, 70 per cent of ATP and CP is restored
  - within 3 minutes, 98 per cent is restored
  - within 10 minutes, 100 per cent is restored.

It is worth noting that these restoration rates assume that CP stores have been depleted to 1–2 per cent. If a muscle has contracted maximally for only a few seconds, there would still be ample stores of CP and less restoration time would be required.

EXAM TIP

Remember that the ATP–CP system has the most rapid rate of ATP resynthesis, and it will be the primary/major contributor in maximal, explosive efforts of very short duration.

doc-41544

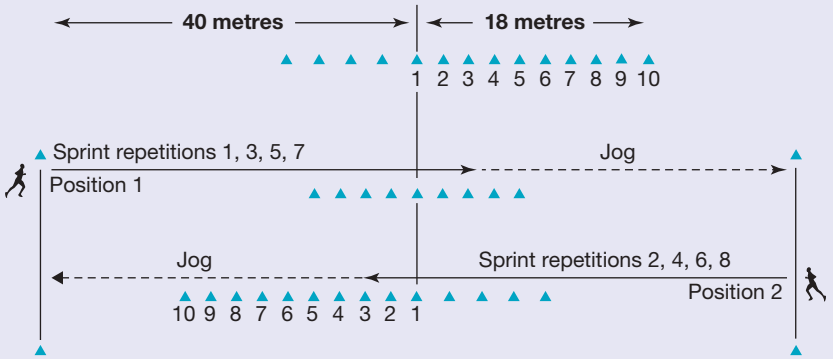
PRACTICAL ACTIVITY Phosphate recovery test

Goal

To undertake a phosphate recovery test to measure your ability to replenish CP stores.

Instructions

1. Set up the course as shown in the figure below. Place the cones numbered 1–10 every 2 metres from the centre in the formation shown.



2. Participants work in pairs, with one partner running while the other records. They then reverse roles. Each participant should be thoroughly familiar with the test protocol.
3. A timekeeper, who works with two stopwatches and a whistle, controls the test.
4. Each participant performs one of the following sets:
   - 8 × 7-second sprints, departing every 30 seconds (work-to-rest ratio of 1:3.3)
   - 8 × 5-second sprints, departing every 30 seconds (work-to-rest ratio of 1:5).
5. Participants must perform each sprint at maximum effort. The timekeeper blows the whistle to start and stop each sprint.
6. Both stopwatches are started as the sprint begins. Watch 1 is clocked off at 7 or 5 seconds (according to the set), with an appropriate whistle signal to the runner. Watch 2 continues ticking over as the participant jogs or walks to the other end of the course.
7. At 30 seconds (watch 2), the timekeeper blows the whistle to begin the next sprint. Timing of the sprint should begin on watch 1.
   Access **Phosphate recovery** in the digital documents section of the Resources panel for a sample procedure.

Primary data/Reflection

1. Record the scores on a recording sheet (see the example below).

Phosphate recovery test score

Participant's name: **Maximum number of repetitions to be completed:**

× 5/7 seconds (delete 1)
Going every 30 seconds

Repetition number	1	2	3	4	5	6	7	8	Total
Score									
Decrement									

Calculations
Best possible score_____ – total score _____ = total decrement
(Repetition × best score)

$\frac{\text{Total decrement}}{\text{Best possible score}} \times \frac{100}{1} =$ _____% of decrement score

2. Scorers must be in position to accurately read scores from the two sets of numbered cones. When the participants sprint from left to right, they are scored using the top set of numbered cones; when running right to left, they are scored using the bottom set of numbered cones.
3. The participants score points for each repetition according to the number of cones they have passed when the whistle blows to signify the end of the sprint.

Results

1. Calculate the total score by adding the points from each sprint repetition (see figure above).
2. Calculate the best possible score by multiplying the best single score by the number of repetitions.
3. Calculate the total decrement score (the value that reflects the decline in performance relative to the best possible score) by subtracting the total score from the best possible score.
4. Calculate the percentage decrement score by dividing the total decrement score by the best possible score and multiplying by 100.
5. Look up the percentage decrement score in the table below to see the rating. The lower the total decrement and percentage decrement scores, the better the result.

Rating	Percentage decrement score
Excellent	< 12
Good	12–19
Average	20–29
Fair	30–40
Poor	> 40

Source: Adapted from Dawson, Ackland, Roberts & Lawson, 1991.

Questions

1. Use your understanding of energy systems to explain the interplay between them during performance of the phosphate recovery test.
2. Use your understanding of energy systems to explain why, during the phosphate recovery test, participants' performance tends to decline over the course of the repetitions.
3. Research a range of other laboratory and/or field tests that can be used to indicate the capacity of the ATP–CP system. Explain how performance in each of these tests relates to the capacity of this system.

on Resources

Digital document Phosphate recovery (doc-1115)

Weblink Marcell Jacobs wins men's 100-metre final

6.5 Activity

6.5 Quick quiz on | **6.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	4, 5	3

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TEST your understanding

1. Describe the intensity and duration of a sporting activity in which the ATP–CP system is the major energy system.
2. Outline the advantages and disadvantages associated with the ATP–CP system.
3. Which sports would be most closely associated with the ATP–CP system? Explain your reasoning.
4. Identify one sport that would primarily rely on the contribution of the ATP-CP system and discuss the importance of this energy system for successful performance in your chosen sport.

APPLY your understanding

5. A long jump competition typically consists of each athlete having three attempts, with the best jump recorded towards each competitor's result. Each jump takes around 6 seconds and is completed at maximal intensity. Predict the impact of completing an active recovery between jumps instead of a passive recovery.

6.5 Exam question

Question 1 (1 mark)

Source: Adapted from *VCE 2017 Physical Education Exam, Section B, Q.13.c; © VCAA*

The Australian Football League (AFL) carries out a series of fitness tests at its annual draft camp to help clubs determine who is the best young talent. The Brisbane Lions selected Jarrod Berry after he performed very well at the draft camp. His results were as follows:

- 4th overall in the 6 × 30 m sprint test – 24.99 s
- 1st overall in the 20 m shuttle run – level 15.1
- 1st overall in the 3 km time trial – 9.46 min

Data: AFL news, 'Top-10 results from 2016 NAB AFL Draft Combine', 9 October 2016, www.afl.com.au

What type of recovery would be most beneficial between each of the sprints in the 6 x 30m sprint?

Question 2 (1 mark)

Source: *VCE 2013 Physical Education Exam, Section A, Q.11; © VCAA*

The ATP-CP energy system produces energy at a

A. slow rate with a low yield.
B. slow rate with a high yield.
C. fast rate with a low yield.
D. fast rate with a high yield.

Question 3 (2 marks)

Source: *VCE 2006 Physical Education Exam, Section B, Q.6.a.i (adapted); © VCAA*

At the Commonwealth Games, a VCE Physical Education student noticed that the long jumpers sat down and rested in between their jumps but the 200 m sprinters did an active recovery of stretching and light exercise after their heat.

Evaluate the physiological benefits of a passive recovery for a long jump athlete.

Question 4 (1 mark)

Source: *VCE 2012 Physical Education Exam, Section A, Q.6; © VCAA*

Which of the following is aided by a passive recovery?

A. liver glucose replenishment
B. blood glucose replenishment
C. muscle glycogen replenishment
D. muscle phosphagen replenishment

Question 5 (3 marks)

The world record time for men in the 100-metre sprint is 9.58 seconds.

a. **Identify** the energy system that would be the major contributor for this event. **(1 mark)**
b. **Justify** your response to **part a**. **(2 marks)**

More exam questions are available in your learnON title.

6.6 The anaerobic glycolysis system and recovery

Key knowledge	Key skill
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

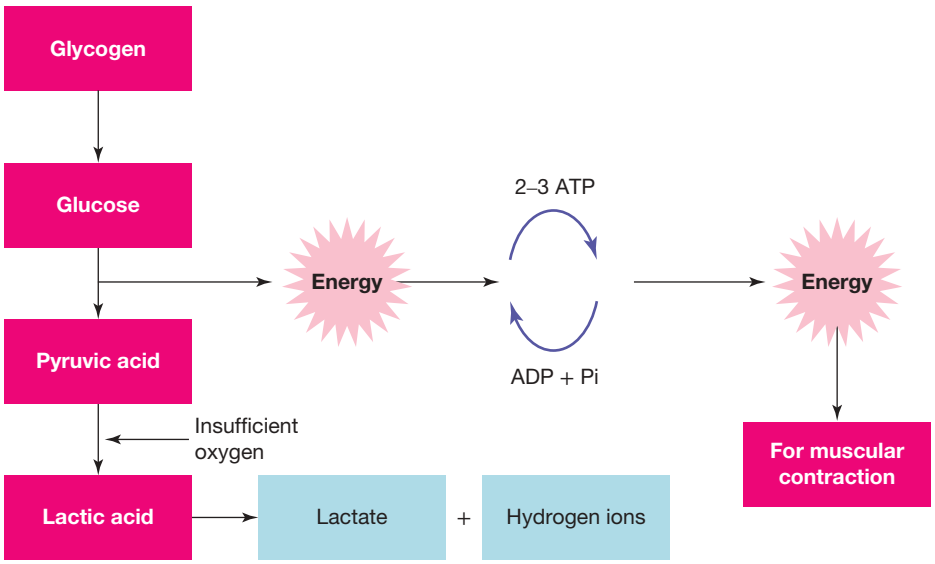
Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

6.6.1 The anaerobic glycolysis system

pyruvic acid (pyruvate) an intermediate product in the metabolism of carbohydrates, formed by the anaerobic metabolism of glucose

In the anaerobic glycolysis system, muscular stores of glycogen are converted into glucose; then, with the aid of glycolytic enzymes, this glucose is broken down into a substance called **pyruvic acid** (or pyruvate). If oxygen is not available in sufficient quantities at this stage in the metabolic pathway, then pyruvic acid is further converted to lactic acid. During this series of reactions, energy is released, which is used to resynthesise ATP from ADP and Pi. The lactic acid that is produced dissociates (separates) into lactate and hydrogen ions (H^+) within the muscle. Lactate and H^+ are by-products of the anaerobic glycolysis system. The process of anaerobic glycolysis is shown in figure 6.18.

FIGURE 6.18 The process of anaerobic glycolysis is more complex than the one involved in the ATP–CP system. It has many more chemical steps.



on Resources

Video eLesson Anaerobic glycolysis (eles-0788)

EXAM TIP

Remember there are two anaerobic systems so it is important you refer to this system as the anaerobic glycolysis system rather than the anaerobic system.

6.6.2 The anaerobic glycolysis system and exercise

The anaerobic glycolysis system resynthesises ATP at a fast rate and has a higher yield than the ATP–CP system. This increased yield means this system is the major contributor to ATP resynthesis when CP stores deplete (from around 10 seconds of maximal effort). Anaerobic glycolysis is also the main contributor in the following activity types:

- repeated short, high-intensity efforts, when there isn't enough time for CP stores to fully replenish (e.g. repeat sprint efforts in team sports)
- increasing intensity when already at submaximal levels (e.g. increasing running speed)
- working beyond maximal oxygen uptake (e.g. running uphill or surging to the finish line).

In these cases, the anaerobic glycolysis system will increase its output to meet the increased ATP demand. However, lactate and hydrogen ions (H^+) will accumulate, and the performer will be forced to either stop or decrease the intensity to the muscle, which can no longer sustain the same contraction force and speed. This fatiguing factor is known as H^+ accumulation and will be explored in topic 7. While the ATP–CP system has a finite capacity due to the depletion of CP, the anaerobic glycolysis system is finite due to the accumulation of its fatiguing by-product, H^+.

EXAM TIP

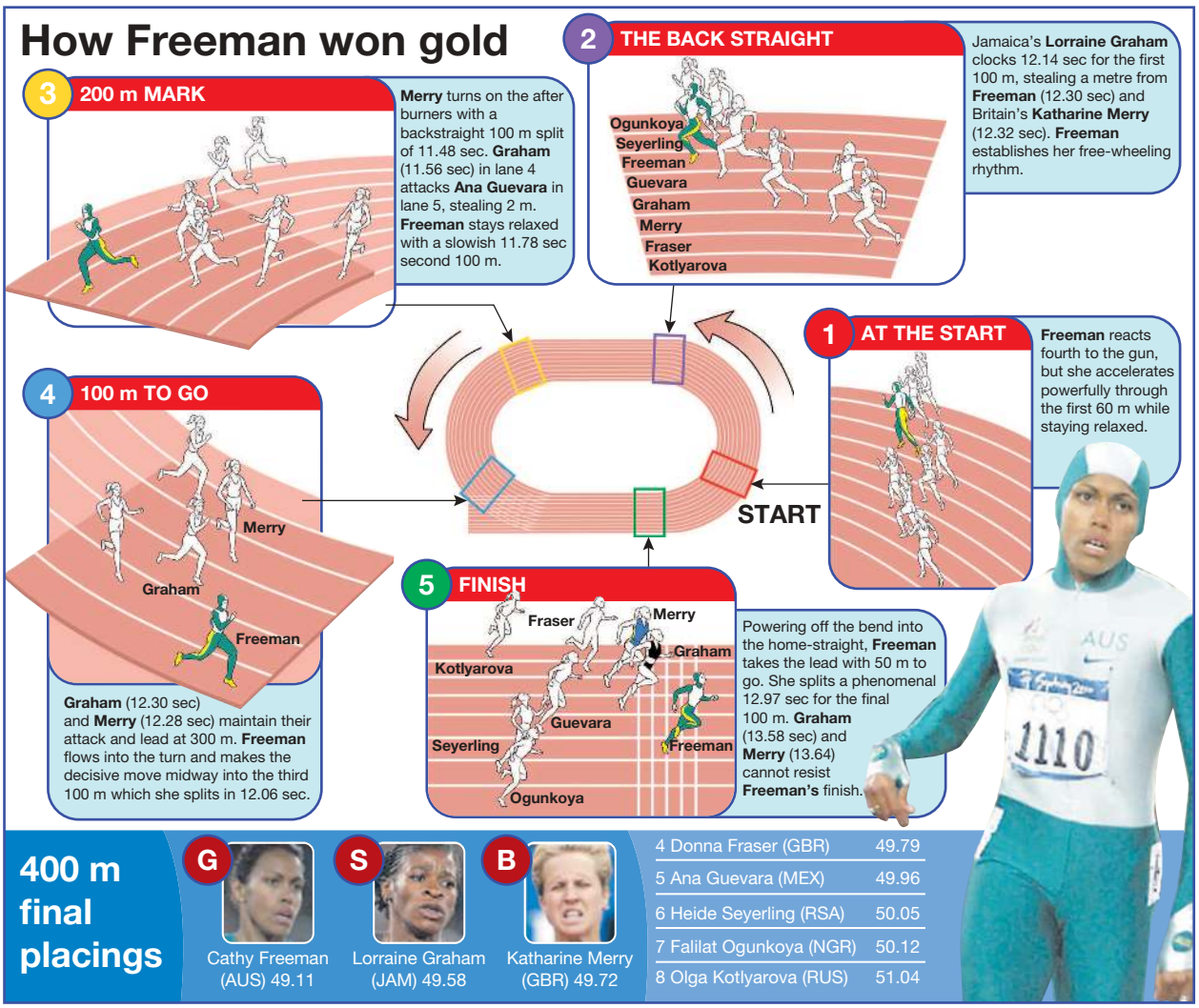
Remember the reasons for why the two anaerobic systems have a finite capacity.

- ATP–CP — limited CP stores
- Anaerobic glycolysis — hydrogen ion (H^+) accumulation.

The 400-metre athletic event

To further illustrate how this system functions, let us consider the 400-metre running event in athletics. The men's world record for the 400 metres is currently held by Wayde van Niekerk of South Africa, who set a time of 43.03 seconds in 2016, while the record for the women's 400 metres is currently 47.60 seconds, set by Marita Koch of Germany in 1985. Cathy Freeman famously won the gold medal in the 400 metres at the 2000 Sydney Olympics in a time of 49.11 seconds (see figure 6.19).

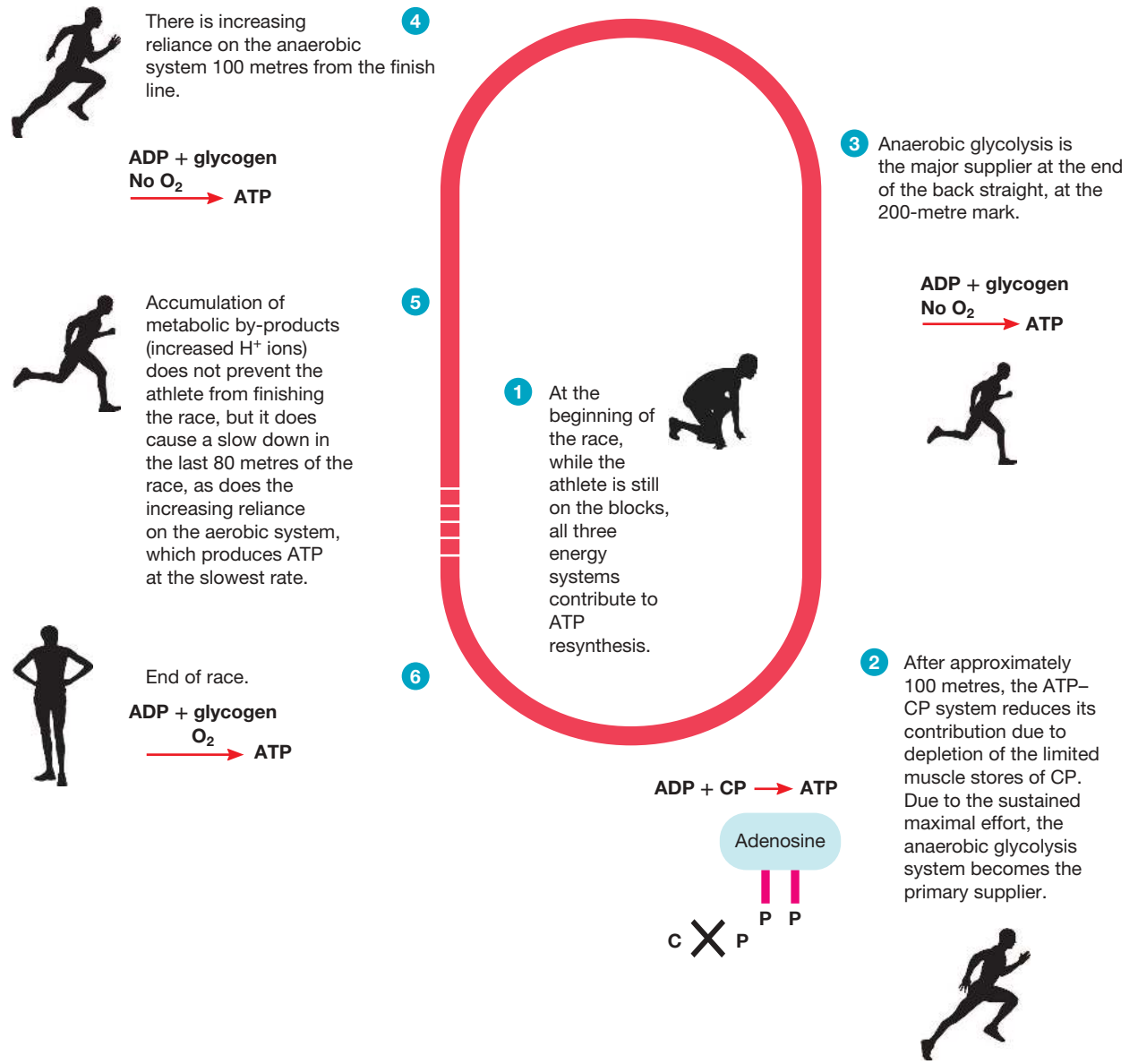
FIGURE 6.19 How Cathy Freeman won gold



- During the 400-metre athletic event, the production of ATP relies on all three energy systems, although the major supplier is anaerobic glycolysis due to the duration of 49.11 seconds (see figure 6.20).
- When the athlete pushes off the starting blocks, the ATP–CP energy system allows for an explosive start to the race, resynthesising ATP at the most rapid rate.
- However, after about 6–10 seconds, the ATP–CP system quickly loses its primary role in the production of energy for ATP resynthesis as CP stores are rapidly depleting.
- The anaerobic glycolysis system becomes the major supplier of ATP throughout the middle to later stages of the race. While this system has a slower rate than the ATP–CP system, it nevertheless produces ATP at a fast rate and can meet sprinting's high ATP demand. This allows the muscles to continue to propel the runner around the track.

- The aerobic system plays a significant role in providing energy for ATP resynthesis during the final phase of the event (the final 100 metres or so). This results in another drop in power output because the aerobic system resynthesises ATP at a slower rate compared to the anaerobic systems. Recent studies indicate that in a 400-metre event taking approximately 45 seconds to complete, the aerobic contribution to ATP resynthesis during the event could be as high as 40 per cent, with the other 60 per cent coming from the two anaerobic systems.

FIGURE 6.20 The 400-metre event is a good example of an activity that relies heavily on the anaerobic glycolysis system.



on Resources

Weblink Cathy Freeman

6.6.3 Recovery

Active recovery

Research has shown that an **active recovery** is an efficient first step in helping the body to recover from exercise, particularly from exercise where the aerobic or anaerobic glycolysis system has been the primary contributors to ATP resynthesis (see figure 6.21). After an athlete has completed a strenuous, high-intensity anaerobic exercise bout at an intensity close to or at **VO_2 max** (maximum oxygen uptake), the fastest lactate/hydrogen ions clearance is achieved by active recovery at an exercise intensity lower than the individual's **lactate inflection point (LIP)**. Rather than sitting or lying down as soon as exercise is completed, the athlete should undertake movement at a low intensity (at 50–60 per cent of maximum heart rate [MHR]), for a period of 5–10 minutes, targeting the same muscles that were used in the exercise bout. The active recovery can also take the form of light, aerobically based cross-training activities performed after the exercise session. Active recovery engages the skeletal muscle pump, causing the muscles to continue contracting but at a lower intensity than during the exercise bout. This increases the delivery of oxygenated blood to the muscles and the faster return of deoxygenated blood to the heart.

active recovery low-intensity (50–60 per cent of MHR) activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling

VO_2 max the maximum amount of oxygen per minute that can be taken in, transported and used by the body for aerobic energy production

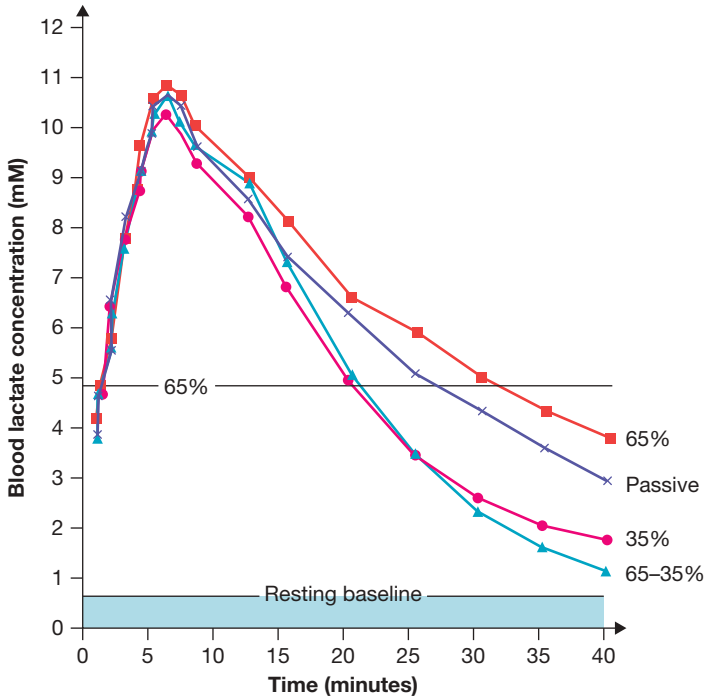
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.

metabolic by-product (or metabolite) a substance produced as a result of chemical reactions within the body associated with the production of energy for ATP resynthesis

Active recovery:

- maintains an elevated heart rate to increase blood flow to the working muscles
- provides a skeletal muscle pump to increase blood flow back to the heart
- decreases venous pooling
- assists with thermoregulation by slowly reducing core temperature
- accelerates the oxidation of **metabolic by-products** such as H^+ ions that have accumulated in the muscle.

FIGURE 6.21 Blood lactate levels following maximal exercise during passive and active recoveries after maximum oxygen uptake (VO_2 max).



Active recovery is particularly beneficial if the previous exercise was strenuous, causing lactate, H^+ and body temperature to increase considerably. In this case, **excess post-exercise oxygen consumption (EPOC)** recovery would be slow, potentially taking several hours to return to pre-exercise oxygen consumption levels, depending on the intensity and duration of the exercise bout.

Active recovery activities can be different from those performed in the exercise bout, but they should target the same muscle groups. An example would be undertaking light pool work after a game of football.

excess post-exercise oxygen consumption (EPOC) the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest

venous pooling an accumulation of blood in the veins in inactive muscles following activity

Studies have shown that active recovery can help to prevent **venous pooling** after strenuous activity. Venous pooling occurs because the active muscles are no longer acting as pumps to propel blood back to the heart. This compromises blood flow to the vital organs, including the brain, and can leave the athlete feeling dizzy.

on Resources

Video eLesson Active recovery (eles-2754)

doc-41545

PRACTICAL ACTIVITY Energy systems and push-ups

Goal

To investigate the effect of push-ups on energy systems.

Instructions

In pairs, one person completes a 60-second push-up test, while the other person records the results.

The number of push-ups completed is recorded every 10 seconds, with the six sets of results added for a total score. Swap roles and record the results for the other person.

Primary data/Reflection

TABLE 1 Push-up test results

	Splits						
	0–10	11–20	21–30	31–40	41–50	51–60	TOTAL
Person 1							
Person 2							

Questions

1. Identify the split where the highest number of push-ups was recorded for:
   a. you
   b. your partner.
2. Use your understanding of energy system characteristics to explain why this was the case.
3. What was likely to have been the major cause of fatigue in the final 20 seconds? Use data to justify your response.
4. Justify physiologically whether you should complete an active or passive recovery following this test.

6.6 Activity

6.6 Quick quiz on

6.6 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 5	2, 7	6

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TEST your understanding

1. What is the only fuel food that can be catabolised anaerobically?
2. Discuss the role of the skeletal muscle pump in an active recovery.
3. What are the by-products of anaerobic glycolysis?
4. Describe the intensity and duration of a sporting activity in which the anaerobic glycolysis system is the major supplier of ATP.
5. Outline the advantages and disadvantages associated with the anaerobic glycolysis system.

APPLY your understanding

6. Undertake a 400-metre run. Use your understanding of energy systems to explain the interplay that occurred during the performance of this test.
7. After completing a 400-metre sprint, your coach recommends that you complete an active recovery. Discuss the type of exercise, intensity and duration your coach should be recommending for you to achieve this.

6.6 Exam question

Question 1 (1 mark)

Source: *VCE 2010 Physical Education Exam, Section A, Q.8; © VCAA*

Which of the following would be most likely to cause fatigue in an 800-metre running race?

A. depletion of liver glycogen stores
B. depletion of intramuscular fat stores
C. accumulation of lactate ions in the blood
D. accumulation of hydrogen ions in the blood

Question 2 (2 marks)

The anaerobic glycolysis energy system has a finite capacity. **Discuss** what is meant by this.

Question 3 (3 marks)

Referring to figure 6.19, each of the medallists in the Olympic 400-metre final recorded their slowest split in the final 100 metres. Use your understanding of energy system characteristics to **explain** why this was the case.

Question 4 (4 marks)

a. A swimmer completes the 100-metre freestyle in 49 seconds. **State** the major energy system for this event. **(1 mark)**
b. **State** the major fuel for the 100-metre freestyle. **(1 mark)**
c. At the end of the 100-metre freestyle, an active recovery session was used. **Explain** how this facilitates a faster recovery from this event compared to passive recovery. **(2 marks)**

More exam questions are available in your learnON title.

6.7 The aerobic system and recovery

Key knowledge	Key skill
• the 3 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	• perform, observe, analyse and report on practical activities designed to explore the relationship between the energy systems during activity and recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

The **aerobic system** is the slowest energy system to contribute towards ATP resynthesis due to the complex nature of its chemical reactions. However, it is capable of producing the greatest yield of ATP energy of all three energy systems. It is also the most versatile of the three energy systems in that it can use a variety of different fuels, including carbohydrates (glycogen), fats (triglycerides and free fatty acids) and, under extreme conditions, proteins.

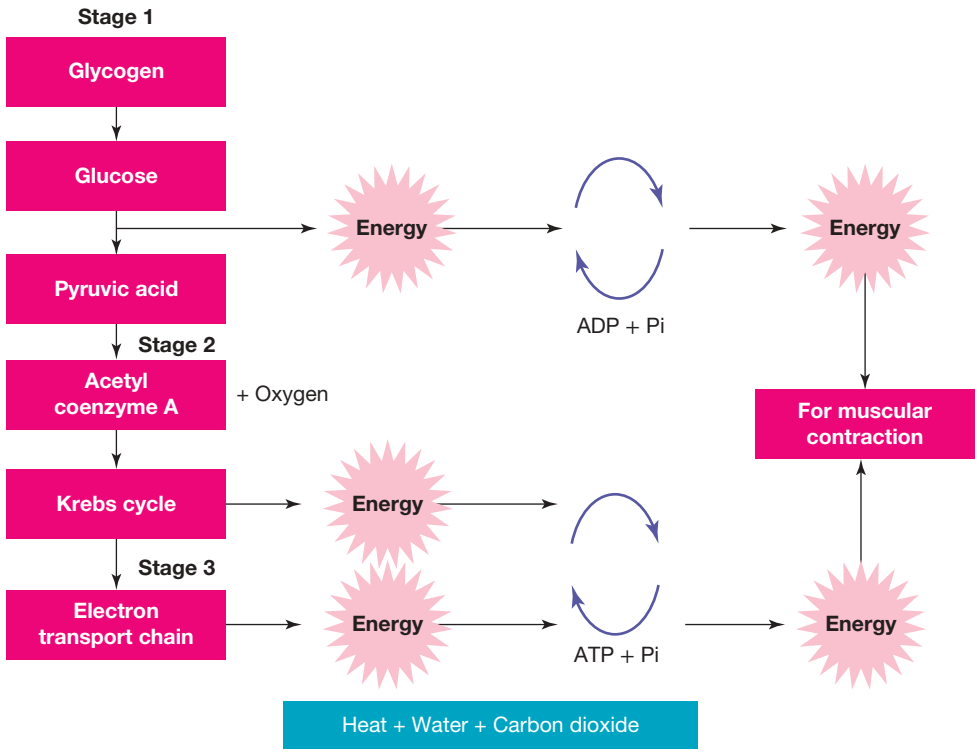
aerobic system provides energy for the resynthesis of ATP through the breakdown of various energy fuels (mainly glycogen and triglycerides) through a series of chemical steps that require oxygen

6.7.1 Aerobic energy production from carbohydrates

The aerobic metabolism of carbohydrates to produce energy for ATP resynthesis involves three processes (see figure 6.22):

1. aerobic glycolysis (increasingly referred to as slow glycolysis, as opposed to anaerobic or fast glycolysis)
2. the Krebs cycle (citric acid cycle)
3. the electron transport chain.

FIGURE 6.22 The process of aerobic metabolism of carbohydrates (glycogen) is more complex than the one involved in the anaerobic metabolism of glycogen.



EXAM TIP

It is important to know that stage 2 (the Krebs cycle) and stage 3 (the electron transport chain) occur in aerobic metabolism. However, there is no need to learn the specifics of these two processes. Knowing they occur and contribute to the yield of the aerobic system is sufficient.

on Resources

Video eLesson Aerobic metabolism of carbohydrates (eles-2756)

6.7.2 Comparing carbohydrate and fat metabolism

The aerobic system can produce ATP through either fats (fatty acids) or carbohydrates (glycogen). The key difference is that the breakdown of fats produces significantly more ATP (greater yield) compared with that obtained from an equivalent amount of carbohydrates. However, the metabolism of fats requires far more oxygen than the metabolism of the equivalent amount of carbohydrates. Therefore, if your body is to use fats as the fuel source for ATP resynthesis, it must be able to provide sufficient oxygen to meet the greater metabolic demand. If not, then the exercise intensity must decrease so that the oxygen requirement is reduced.

6.7.3 Aerobic energy production from proteins

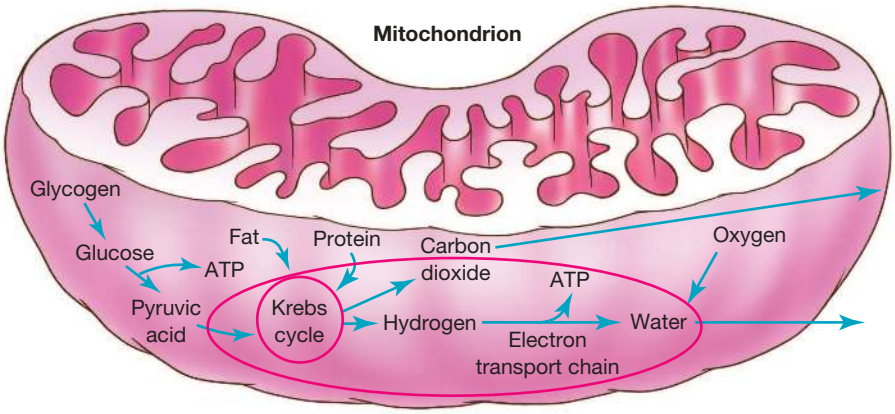
Protein is thought to make only a small contribution (usually no more than 5–10 per cent) to energy production. However, amino acids, the building blocks of protein, can be either converted into glucose or into other intermediates used by the Krebs cycle such as acetyl coenzyme A. Protein may make a more significant contribution during very prolonged exercise (e.g. ultra-marathons), perhaps as much as 15–20 per cent of total energy requirements.

The mitochondria

Stages 2 and 3 of aerobic metabolism (the Krebs cycle and the electron transport chain) occur within the **mitochondria** (see figure 6.23). The greater the number and size of mitochondria within the muscle cells, the greater the capacity for energy production.

mitochondria cell structures (organelles) that serve as the power generators of the cell, converting nutrients into ATP in the presence of oxygen (aerobically)

FIGURE 6.23 Mitochondria are cell structures that act as the power generators of the cell, converting oxygen and nutrients into ATP.



6.7.4 The aerobic system and exercise

The aerobic system is used primarily when at rest and during low- to moderate-intensity exercise, including periods of recovery between exercise bouts. When you are at rest, your body has an abundant oxygen supply, so the energy required for the resynthesis of ATP is provided almost exclusively by the aerobic energy system. It relies on the breakdown of fats to provide about two-thirds of the energy required, while the other one-third comes from the breakdown of carbohydrates. However, when exercising, the body's preferred fuel is generally carbohydrates, and the higher the exercise intensity, the greater the reliance on carbohydrates. Carbohydrates are the preferred fuel source during exercise because:

- they can be metabolised aerobically or anaerobically
- they produce energy at a faster rate than fat
- the complete oxidation of carbohydrates requires less oxygen than the complete oxidation of fat
- carbohydrate stores are more readily accessible than fat stores (triglycerides have to be reduced to glycerol and free fatty acids before they can be used to generate cellular energy).

The aerobic system, along with the other two energy systems, is also activated at the beginning of high-intensity exercise and it will become the major energy system after approximately 60 seconds of continuous maximal-intensity activity. By this time, the intensity of the activity will have decreased (it will now be submaximal exercise), and the body's supply and delivery of oxygen to the working muscles will have increased as a result of acute bodily responses to the demands of the activity. The aerobic system continues to be the major contributor to energy production for ATP resynthesis during continuous submaximal exercise that exceeds 1–2 minutes in duration. At this point, a steady state will have been reached and heart rate will plateau as the body's demand and supply of oxygen become equal. When this occurs, the aerobic system will supply the majority of ATP for muscular contractions.

6.7.5 Recovery

Active recovery, where heart rate remains at 50–60 per cent of MHR, is beneficial in accelerating the process of clearing the muscle cells of any metabolic by-products that may have been produced and accumulated during the exercise period. Despite the aerobic system being the major supplier of ATP resynthesis during endurance events, it is common for higher intensities to be reached by the performer. This increases the output from anaerobic glycolysis and with it the associated by-product of H^+ ions. During the active recovery period, the rate of oxygen consumption by the athlete remains above the required rate. The term 'excess post-oxygen consumption' (EPOC) has typically been used to describe this phase. Active recovery is suitable after aerobic type activities because it:

- maintains an elevated heart rate to increase blood flow to the working muscles
- provides a skeletal muscle pump to increase blood flow back to the heart
- decreases venous pooling
- assists with thermoregulation by slowly reducing core temperature
- accelerates the oxidation of metabolic by-products such as H^+ ions that have accumulated in the muscle.

If previous exercise was primarily aerobic where the performer remained in a steady state for the majority of the effort, EPOC recovery will be completed within several minutes. Depending on the environmental conditions and duration of the effort, recovery after aerobic exercise may also require an approach that prioritises thermoregulation and/or nutrition. These recovery methods will be explored in more depth in topic 7.

FIGURE 6.24 The aerobic system is best exemplified in any low-to-moderate-intensity longer duration event, in which it provides the majority of the required energy to resynthesise ATP.



1 Start of a 20-minute cross-country race.

Energy

P

Adenosine

P P



2 The athlete is exercising submaximally with heart rate around 70–85 per cent of maximum.

ADP + glycogen

O_2

ATP



3 Oxygen supply and demand are equal. The athlete is in a steady state. ATP is being replenished from ADP, primarily by the aerobic energy system.

ADP + glycogen

O_2?

ATP



4 Any periods of acceleration or hill work will increase reliance on anaerobic glycolysis energy supply. However, this is generally controlled by following this up with periods of lower exertion, during which time O_2 supplies become plentiful again.

ADP + glycogen

O_2

ATP



O_2

P

Adenosine

P P

5 At the end of the race, the athlete enters EPOC and the rate of oxygen consumption remains above resting levels. In most instances it is recommended that post an aerobic effort the athlete completes an active recovery of 5–10 minutes in duration. This will aid the clearance of metabolic by-products such as hydrogen ions that may have accumulated in the leg muscles.

on Resources

Weblink Cross country skiing

doc-41546

PRACTICAL ACTIVITY Multi-stage fitness test

Goal

To complete a 20-metre multi-stage fitness test to measure your aerobic power.

Instructions

1. Measure out a 20-metre section of floor space (the shuttle).
2. The participant must arrive at the end of the shuttle before the beep.
3. For the first minute, the beeps on the audio recording will sound at the rate for the participant to travel at a speed of 8.5 kilometres per hour, and will then increase in speed by 0.5 kilometres per hour each minute following.
4. When the participant fails to arrive at the end of the shuttle by the beep, they withdraw and their level is recorded.

Primary data/Reflection

- How did your performance in the 20-metre multi-stage fitness test compare to your expectations?
- Did you experience any physical discomfort or fatigue during the test? If so, how did you manage it?
- What factors do you think contributed to your performance level in the test?
- Reflecting on your performance, what are your strengths and weaknesses in terms of aerobic fitness and endurance?

Questions

1. Use your understanding of energy systems to explain the interplay between them during your performance of the 20-metre multi-stage fitness test.
2. Research a range of other laboratory and/or field tests that can be used to indicate the capacity of the aerobic system. Explain how performance in each of these tests relates to the capacity of the aerobic system.

6.7 Activity

6.7 Quick quiz on

6.7 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5	6, 7

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TEST your understanding

1. Describe the intensity and duration of a sporting activity in which the aerobic system is the major energy system.
2. Outline a specific sporting activity or situation that clearly illustrates the use of the aerobic system as the major energy system.
3. Outline the advantages and disadvantages associated with the aerobic system.
4. State one reason why carbohydrates are typically the body's preferred fuel source during exercise.
5. Where in the cell does the aerobic resynthesis of ATP take place?
6. Explain why the aerobic system is described as the most versatile of the three energy systems.

APPLY your understanding

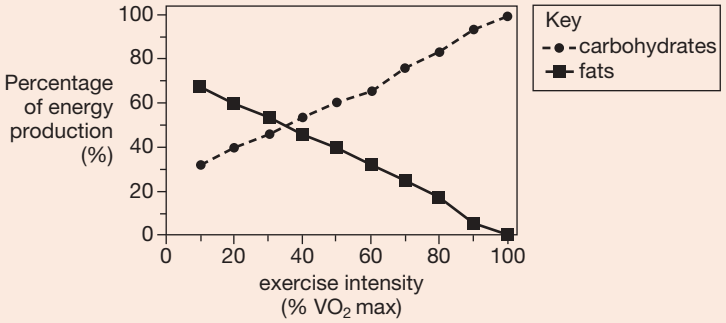
7. What type of recovery should be completed after the conclusion of the 20-metre multi-stage fitness test? Justify your response.

6.7 Exam question

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.14*; © VCAA

The graph below shows the percentage of energy contributed by carbohydrates and fats as exercise intensity changes.



Source: Adapted from SK Powers & ET Howley, *Exercise physiology: theory and application to fitness and performance*, McGraw-Hill, New York, 2009, p. 61

When comparing the rate and yield of energy (ATP) production, which one of the following statements is correct?

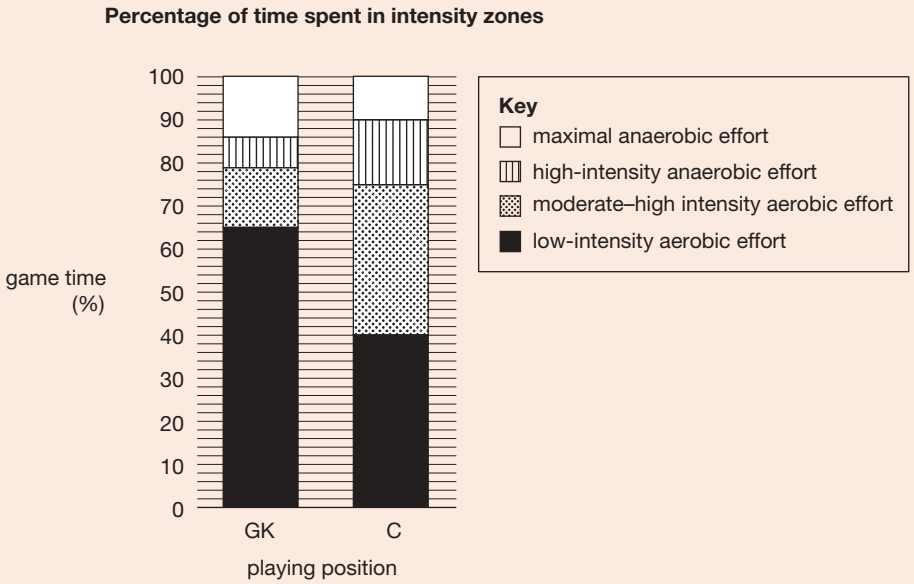
A. At 20% VO_2 max, fats produce the largest yield of ATP at the slowest rate.
B. At 40% VO_2 max, carbohydrates produce the largest yield of ATP at the slowest rate.
C. At 60% VO_2 max, fats produce the largest yield of ATP at the slowest rate.
D. At 80% VO_2 max, carbohydrates produce the largest yield of ATP at the slowest rate.

Question 2 (4 marks)

Source: Adapted from *VCE 2023, Physical Education Exam, Section B, Q.3.b;* © VCAA

Asher is an active 13-year-old boy who has started playing netball. He rotates between goalkeeper (GK) and centre (C) positions.

The graph below shows the percentage of game time Asher spent in each intensity zone.



Source: Adapted from CM Young, PB Gastin, N Sanders, L Mackey & DB Dwyer, 'Player load in elite netball: match, training and positional comparisons', *International Journal of Sports Physiology and Performance*, vol. 11, no. 8, 2016, p. 1076

Use the information provided in the graph to **explain** two differences in the aerobic requirements for Asher when he plays GK and C.

Question 3

Source: *VCE 2020, Physical Education Exam, Section B, Q.3;* © VCAA

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

State the type of recovery — active or passive — that should be undertaken after completing an endurance event and **outline** why this type of recovery would be suitable.

Question 4

Source: Adapted from *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.11.a;* © ACHPER

An International track and field competition was held in the Middle East in summer. Daytime temperatures during this competition often reached over 35 degrees Celsius and all events were held at night. The women's marathon event was held at midnight, and the average temperature throughout the event was 30 degrees. The gold medallist in the marathon finished the event in 2 hours 32 minutes, 15 minutes slower than her personal best. Thirty of the seventy athletes who started the marathon event failed to finish.

The Women's 400-metre hurdles final was at held at 10 pm and the temperature was 32 degrees Celcius. The gold medallist broke the world record in this event, running a time of 52.16 seconds. All eight competitors who started the event finished.

Complete the table below by **identifying** the primary energy system and major fuel source for each of the events listed above.

Event	400-metre hurdles	Marathon
Primary energy system		
Major fuel source		

More exam questions are available in your learnON title.

6.8 Energy systems interplay

Key knowledge	Key skill
• the interplay of energy systems in relation to the intensity and duration of various physical activity, sport and exercise	• participate in physical activity, sport and exercise to describe, using appropriate terminology, the interplay and relative contribution of the three energy systems

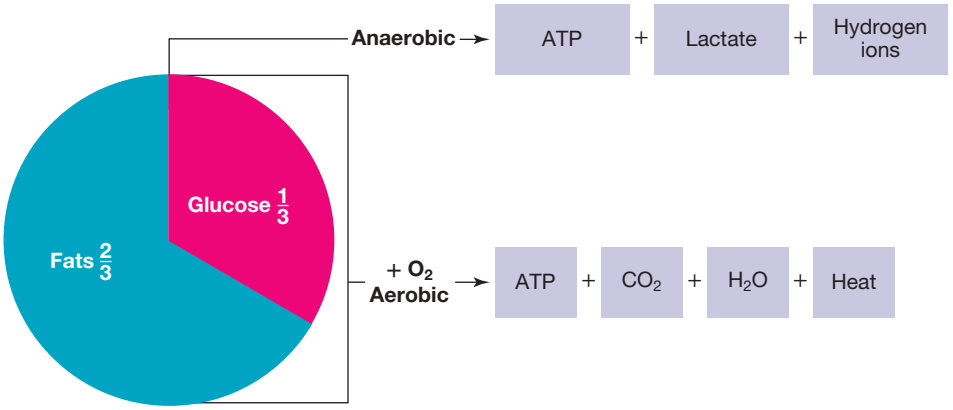
Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

This section will look at how the energy systems contribute during rest and exercise conditions. This will help with understanding how the body adapts its metabolic activity during the transition from rest to exercise.

6.8.1 ATP production at rest

When at rest, your body's demand for ATP is low and it has an abundant oxygen supply, so the energy required for the resynthesis of ATP is provided almost exclusively by the aerobic energy system. In this state, your body relies on the breakdown of fats to provide about two-thirds of the energy required with the remaining one-third coming from the breakdown of carbohydrates (figure 6.25). There is very minimal contribution from the two anaerobic systems.

FIGURE 6.25 At rest, the body relies almost exclusively on the aerobic system for energy production, with fats acting as the major food fuel.



6.8.2 ATP production during exercise

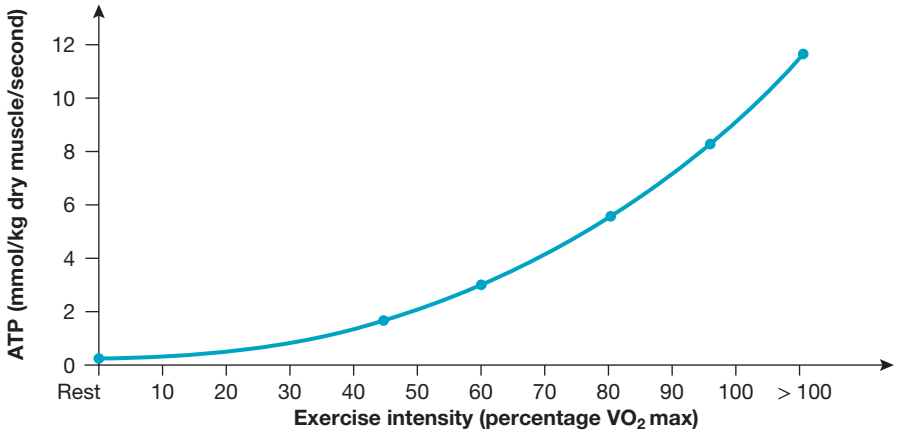
There is no exact or definitive point where one energy system drops off and another energy system becomes the major energy supplier. Rather, there is a gradual transition from one system being the major supplier to another system assuming the primary contribution to ATP resynthesis.

Energy system interplay requires an assessment of key factors such as intensity and duration to accurately determine the ATP contribution of each system overall, and at specific moments within sport and exercise.

Rest-to-exercise transitions during continuous activity

The following three rest-to-exercise transition scenarios can help to illustrate this interplay of energy systems. This will help with understanding when each of the three energy systems is called upon to provide the major portion of the ATP needed to sustain exercise at any given intensity. In looking at each scenario, it is important to recall that all the energy systems are contributing towards ATP production simultaneously throughout any exercise bout. However, the proportion of ATP contributed from each system to the metabolic demand will shift according to exercise intensity.

FIGURE 6.26 As exercise intensity increases, the rate of ATP production rises to meet the energy demand.



Source: Brown, SP, Miller, WC & Eason JM, *Exercise physiology: basis of human movement in health and disease*, Lippincott Williams & Wilkins, 2005, Section 3.2.

Maximum continuous efforts of short duration

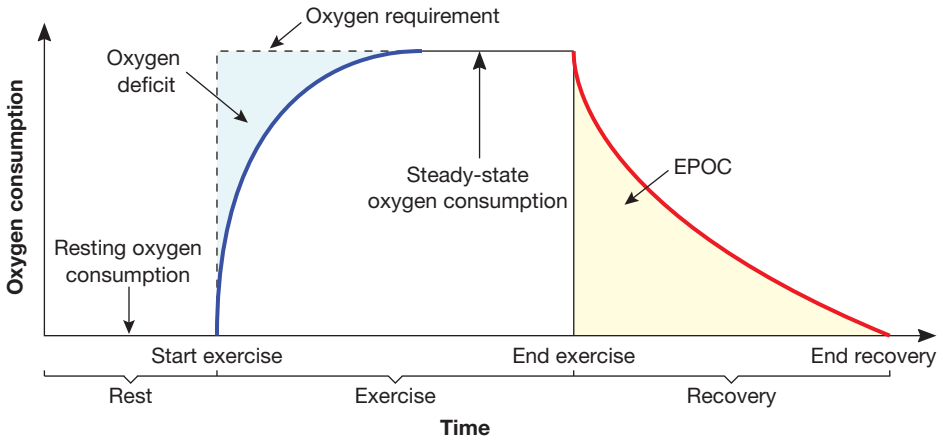
- Due to its rapid rate of ATP resynthesis, the ATP–CP system has the capacity to meet the high energy demand of very high-intensity exercise.
- As the anaerobic glycolysis and aerobic system produce ATP at slower rates, their contribution during maximal-intensity exercise of very short durations is minimal, provided the muscle has available stores of CP.
- Events where ATP–CP would be the primary supplier of ATP include the 100-metre sprint in athletics.
- In longer maximal efforts, such as a 400-metre sprint, CP stores will near depletion and the anaerobic glycolysis system will become the primary supplier of energy for muscular contractions.
- This results in a lowering of intensity as the anaerobic glycolysis system resynthesises ATP at a slower rate than the ATP–CP system.
- In the final stages of the 400-metre sprint, the aerobic system will have increased its contribution to ATP resynthesis. This also contributes to a reduction of intensity as this system produces energy at the slowest rate.
- If the exercise was to continue beyond 400 metre, approximately 60 seconds and beyond, the intensity would be further reduced to a submaximal level, with the aerobic system becoming the primary supplier of ATP. This system can produce the ATP yield needed for sustained movement, but at a slower rate.

Submaximal continuous efforts

- It is important to understand that any time energy demand is increased above resting levels — whether it be starting out on a slow jog or pushing out of the blocks at the start of a 100-metre sprint — this increased energy demand immediately requires an increased oxygen supply to the working muscles. This is because the body is trying to continue to work mostly aerobically.
- However, the respiratory and circulatory systems are unable to meet this increased demand immediately, so the body must use the anaerobic energy pathways to supplement the production of ATP until the body can increase its oxygen delivery to meet the oxygen demand of the activity. Recall that when oxygen supply and demand are equal, the body is in a steady state.
- If the activity is being performed at low intensity, then this increase in oxygen supply will not take long to achieve, and the aerobic system will quickly resume the role of primary energy supplier.
- However, with progressively higher exercise intensities, the relative energy contributions of the anaerobic systems become greater and greater due to the larger **oxygen deficit** that is created (figure 6.27).

oxygen deficit the state in which there is a discrepancy (shortfall) between oxygen supply and the oxygen needed to meet the energy requirements of the activity. The anaerobic pathways must supplement the energy demands of the activity.

FIGURE 6.27 Oxygen deficit, steady state and EPOC



Source: Reprinted by permission from NSCA, *Oxygen Uptake and the Aerobic and Anaerobic Contributions to Exercise,* Champaign, IL: Human Kinetics, 2017.

6.8.3 Intermittent exercise

Many team sports have interspersed periods of work and rest and require the players to not only run at maximal speeds for a short duration, but also maintain their speed and endurance throughout a variety of periods of play, typically ranging from 15–40 minutes. There may be short periods of rest within the game to replenish CP and glycogen stores by consuming carbohydrates. For any intermittent activity, it is more accurate to consider the energy system contribution and interplay at various stages of performance by considering the key factors of intensity, duration, recovery periods and availability of fuels throughout the whole event. For example, an Australian Rules footballer playing in the full-forward position will rely on the ATP–CP system for maximal-intensity, short-duration sprints to mark the ball. Repeated high-intensity efforts, such as multiple sprints for the ball, can occur in quick succession and will deplete CP stores. As such, the anaerobic glycolysis system would be the primary supplier of energy for any further maximal efforts. It is also worth considering that players rarely have time to fully replenish all of their CP stores unless there is a long break in play, such as quarter time. This means CP depletion can occur much earlier than at 10 seconds of maximal effort. During low-intensity periods, such as breaks in play after a team scores or when the ball goes out of bounds, the aerobic system becomes the primary supplier of ATP and the player may have sufficient time to replenish some or all of their CP stores and reduce the quantity of H^+ in their working muscles. This period of recovery can help the athlete to perform at maximal intensity in the next passage of play if necessary.

EXAM TIP

Most energy system interplay scenarios are based on intermittent activity so make sure you spend time practicing these types of questions.

on Resources

Interactivities Understanding energy terms (int-6789)
Characteristics of the three energy systems (int-6792)

Weblink Energy Systems Webinar

EXAM TIP

Some questions on energy system interplay can be worth as much as 6–8 marks. High-quality responses will:

- recognise that each energy system contributes simultaneously to enable movement
- identify the energy system with the primary or major contribution to ATP production, including reference to rate and yield. Do not use the word dominant or predominant to describe this.
- include supporting qualitative and quantitative data
- identify the contribution of the other two energy systems with reference to rate and yield.
- identify periods of low intensity where recovery processes such as CP replenishment can occur.

EXAM TIP

The table below lists the key vocabulary to use when responding to exam questions on the interplay of energy systems.

ATP–CP	Anaerobic glycolysis	Aerobic
Maximal effort	Extended maximal efforts	Submaximal efforts
Explosive	Repeat high-intensity efforts	Rest and recovery periods (opportunity for CP replenishment)
Short duration	Accelerations above steady state	
Most rapid rate	Fast rate	Slowest rate
Lowest yield	Larger yield than the ATP–CP system	Largest yield

doc-41547

PRACTICAL ACTIVITY Energy system interplay

Goal

To complete an 800-metre run and evaluate the interplay of the three energy systems in your performance.

Instructions

In pairs, take turns to complete an 800-metre run, with the non-runner using a stopwatch to record the runner's time.

Primary data/Reflection

TABLE 1 Results of the 800-metre run

	Time
Person 1	
Person 2	

- Describe the sensations and feelings you experienced during different stages of the run.
- Did you notice any changes in your breathing pattern or perceived exertion level throughout the run?
- What insights did you gain about your own physiological responses and energy system use from this run?

Question

1. Use your knowledge of energy system interplay to suggest reasons why there was a difference in performance between you and your partner, referencing the time taken to complete the 800-metre run.
2. Outline in your own words how the three energy systems would have contributed to your performance. Ensure that you use your race data when discussing the interplay of the energy systems.

on Resources

Video eLesson Interplay (eles-6599)

6.8 Activity

6.8 Quick quiz on | **6.8 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3	1, 4	2, 5

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TEST your understanding

1. At the onset of exercise, why is creatine phosphate the preferred energy source over carbohydrates and fat?
2. During aerobic exercise the body may use both carbohydrates and fats to provide energy. Their relative contribution depends on the intensity of the exercise. Explain the relationship between intensity of aerobic exercise and relative use of carbohydrates and fats as fuel.
3. Netball is a physically demanding sport that requires many skills. The energy demand on the players depends on the skills they are performing and the position they are playing. Identify the major energy system required to perform the following in netball:
   a. The goal keeper jumping up to grab a rebound
   b. The centre running to cover much of the court throughout the match
   c. The goal defence breaking away from an opponent and receiving a pass from the goal keeper

d. The goal attack sprinting 10 metres to receive the ball from the goal keeper, passing to the centre player, sprinting into the goal third to receive a pass from the centre player and then shooting a quick bounce pass to the goal shooter in the goal circle

e. The umpire walking and jogging up and down the sidelines throughout the match

4. Complete the table below outlining the characteristics of the three energy systems.

Characteristic	ATP—CP	Anaerobic glycolysis	Aerobic
Fuels used (chemical and food)			
Intensity and duration of peak energy production			
Examples of activities in which the system is the major source of energy			
Rate of energy supply			
By-products			
Type of recovery			
Advantages of the energy system			
Disadvantages of the energy system			

APPLY your understanding

5. Select a team sport of your choice. Participate in and observe a 2-minute period of play from this game.

   Explain the interplay of energy systems that would occur during performance of this activity. Make sure you indicate the typical duration and intensity of each activity or skill.

6.8 Exam question

Question 1 (6 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.7*; © VCAA

Squash is a sport played on a small indoor court, in which a player hits a ball against a wall and attempts to make the ball bounce twice before their opponent can return it.

Michael played a squash match of three games with a two-minute break between games. The match lasted 45 minutes in total. During the match, he used a variety of skills during repeated, short, high-intensity rallies. These skills included short sprints, lunges, powerful drives and smash shots.

The table below shows the frequency of rally lengths during Michael's squash match. On average, there was a seven-second rest period between rallies.

Percentage of total points played per length of rally in Michael's match

Rally length (seconds)	Frequency per game (% of total points)
0–5.9 s	20.5%
6–11.9 s	19.7%
12–17.9 s	20.2%
18–23.9 s	13.4%
24–29.9 s	7.3%
≥ 30 s	18.9%

Data: Adapted from O Girard et al., 'Game analysis and energy requirements of elite squash', *Journal of Strength and Conditioning Research*, vol. 21, no. 3, 2007, p. 912

Using specific examples from the information above, **explain** the interplay of energy systems that provides the energy required for Michael to complete his squash match.

Question 2 (6 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.7.a;* © VCAA

Rebecca, a state-level basketball player, played 30 minutes of a 40-minute game. The match had four 10-minute quarters with a 5-minute half-time break and a 2-minute break at quarter and three-quarter time.

Rebecca had several repeated high-intensity efforts on the defensive end that saw her shuffling, lunging and rebounding for periods of time ranging between 22–36 seconds. She was involved in multiple short sprints as well as explosive jumps for her eight rebounds, one steal and one blocked shot. Rebecca finished the game with 28 points, helping to lead her team to victory.

Using specific examples from the information provided above, **explain** the energy system interplay of Rebecca in her basketball game.

Question 3 (6 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.1*; © VCAA

During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200 m and 400 m freestyle swimming events.

The 200 m freestyle swimming event was swum at an average pace of 56.75 seconds per 100 metres, whereas the 400 m freestyle swimming event was swum at an average pace of 59.17 seconds per 100 metres.

With reference to the data above and to the interplay of the energy systems, **discuss** why the 400 m freestyle swimming event was completed at a slower pace than the 200 m freestyle swimming event.

Question 4 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.5*; © VCAA

In hockey, when a finals match ends in a draw, the game is decided by a shootout. Each team will select five attackers, who will each have seven seconds to attempt to score a goal. Each team alternates attempts to score until the shootout is complete.

During a shootout, the goalkeeper can be seen to:

- sprint out from the goal to the top of the circle to meet each attacker
- move from side to side to anticipate which way each attacker will go
- make explosive leaps and dives to save the ball
- have a short rest period prior to the next attacker's attempt.

Discuss the contributions from the two anaerobic pathways to the goalkeeper's performance during a shootout.

Question 5 (6 marks)

Source: Adapted from *VCE 2014, Physical Education Exam, Section B, Q.14.a;* © VCAA

Volleyball is a team sport, with a match taking approximately 40 minutes. During a game, the players are involved in high-intensity, short-duration movements, such as serving, digging, setting, spiking, jumping and blocking. The average rally time is 7 seconds; however, points can continue for more than 20 seconds. The game is explosive in nature with an average 10-second rest period between points.

Using the data provided, **describe** the interplay of the energy systems in the sport of Volleyball.

More exam questions are available in your learnON title.

6.9 Key skills

Key skills

- 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 three energy systems

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

6.9.1 Tell me

To address the key skills for this topic, it is important to remember:

- the role that ATP plays in the production of energy for muscular contractions
- the role of the fuels (chemical and food) that are used to provide the energy required for ADP to be resynthesised to ATP
- that ATP can be resynthesised via three energy pathways: the ATP–CP, anaerobic glycolysis and aerobic energy systems
- the relationship between intensity of exercise, rate of ATP and energy system contribution
- the relationship between duration of exercise, yield of ATP and energy system contribution
- the characteristics of the three energy systems, including their fuel sources, rate, yield and most effective type of recovery
- the recovery strategies used to return the body to pre-exercise conditions
- the interplay of the three energy systems and the factors that determine their contribution (intensity and duration)
- for which types of events each energy system is the major contributor to ATP resynthesis
- in which situations each energy system has a minimal contribution to ATP resynthesis, and why.

6.9.2 Show me

Practice question (6 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

The table below shows the average speed data from two cross-country alpine skiing events.

Skiing event	Distance	Average speed
Short (sprint)	1.5 km	34 km/hr
Long (endurance)	10 km	28 km/hr



Explain how the skier can generate a higher average speed in the *short (sprint)* event **compared** to the *long (endurance)* event. **Use the data** from the table above and your knowledge of energy system interplay in your response.

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Explain — provide a justification for why the skier can reach higher speeds
  Compare — comment on the energy system interplay differences between the short and long event
  Use the data — include supporting quantitative data
- **Key terminology**
  short (sprint) — a fast race over a short distance
  long (endurance) — a long race over a greater distance
- **Key concept** — energy system interplay
- **Marking scheme** — 6 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

All three energy systems will contribute at all times in the short and long skiing event. However, their relative contributions will vary based on the intensity and duration of the activity. In the 1.5-kilometre event, there would be a greater relative contribution from the anaerobic systems of ATP–CP and anaerobic glycolysis. These systems resynthesise ATP at a much faster rate. The 10-kilometre event needs a higher yield of ATP and so uses a greater aerobic contribution, which has a slower rate of ATP resynthesis. This explains why the *10-kilometre event has a lower average speed of 28 km/hr* compared to the *average speed for the short event of 34 km/hr.*

Award 1 mark for recognising that all three systems contribute to ATP resynthesis at all times in the skiing events.

Award 1 mark for the anaerobic systems would contribute more significantly to the short event.

Award 1 mark for the aerobic system would contribute more significantly to the long event.

Award 1 mark for anaerobic systems have a higher rate of ATP resynthesis, allowing a faster release of energy.

Award 1 mark for aerobic system has a slower rate of ATP resynthesis, causing a slower release of energy.

Award 1 mark for supporting data – lower average speed of 28 km/hr for the long event compared to 34 km/hr for the short event.

6.9.3 Let me do it

Question 1 (6 marks)

Kobe Bryant, an NBA basketball player with the LA Lakers, retired in 2016. In his final NBA game, Bryant scored 60 points in 42 minutes of play. His actions during the last 3 minutes and 5 seconds are presented in the game log below. Overall, in that period, the two teams were together responsible for two timeouts, two substitutions and three sets of free throws.

Score	Actions performed by Kobe Bryant	Time remaining
HOME 86 - 94 AWAY	Reverse lay-up	03 : 05 : 00 HRS MINS SECS
HOME 88 - 96 AWAY	Two free throws	02 : 16 : 00 HRS MINS SECS
HOME 90 - 96 AWAY	Fast-driving lay-up	01 : 45 : 00 HRS MINS SECS
HOME 92 - 96 AWAY	Pull-up jump shot from approximately 5 metres	01 : 27 : 00 HRS MINS SECS
HOME 95 - 96 AWAY	3-points pull-up jump shot	00 : 59 : 70 HRS MINS SECS
HOME 87 - 96 AWAY	Pull-up jump shot from approximately 6 metres	00 : 31 : 60 HRS MINS SECS
HOME 99 - 96 AWAY	Two free throws	00 : 14 : 80 HRS MINS SECS
HOME 101 - 96 AWAY	Substituted from match	00 : 04 : 10 HRS MINS SECS

Source: Adapted based on data from National Basketball Association, Official Scorer's Report, Final Box, 13 April 2016; © 2016 NBA Properties, INC.

Prior to the 3 minutes and 5 seconds mentioned above, Bryant had already played 39 minutes of the game. Using the data provided above, **discuss** Bryant's energy requirements for the last 3 minutes of play.

6.10 Review

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6.10.1 Summary

Adenosine triphosphate (ATP)

- The energy for physical activity is released by the catabolism (breaking down) of adenosine triphosphate (ATP). This energy source is stored in only very limited quantities within muscles and must be constantly replenished or resynthesised in order for muscular contractions to continue.
- ATP breaks down to ADP and Pi. ATP can be resynthesised from ADP and Pi, but energy is required to do this.
- The energy required to resynthesise ATP from ADP and Pi is produced via three energy pathways: the ATP–CP (or phosphate) energy system, the anaerobic glycolysis system and the aerobic system.

Fuels — chemical and food

- The fuels or substrates that are used by the body's three energy systems include CP, carbohydrates, fats and protein. The energy systems break down these fuels to provide the energy to resynthesise ATP.
- Chemical fuels are fuels such as CP and glycogen that are produced by the body and which we cannot eat.
- Food fuels are carbohydrates (including glucose), fats and protein, which we ingest as part of our diet.
- CP is a chemical compound which, like ATP, is stored in limited quantities within muscle cells.
- CP is a high-energy substance capable of storing and releasing energy via the high-energy bond that binds the creatine and phosphate parts of it together. When this bond is broken, energy is released that enables ATP to be resynthesised from ADP and Pi.
- Carbohydrate is broken down into glucose and is typically the body's preferred fuel source during exercise. Glucose is stored as glycogen in the muscles and liver. Any excess is stored as fat in adipose tissue around the body.
- Fats provide more energy per gram than the other fuels, but the body prefers carbohydrate as an energy source during exercise because it is easier to break down and produces energy at a faster rate.
- Protein is used as an energy source only when carbohydrate and fats are depleted; for example, in extreme conditions, such as in ultra-endurance events.

Energy systems characteristics

- The two key factors that determine the ATP demand of an activity are exercise intensity and duration.
- Exercise intensity determines the rate of ATP use and, consequently, the speed of resynthesis needed during the activity.
- Exercise duration determines the total amount or yield of ATP that needs to be resynthesised over the course of the activity.
- The two anaerobic systems (ATP–CP and anaerobic glycolysis) can supply energy for ATP resynthesis quickly but only for a short time as they have a low yield.
- The aerobic system supplies energy at a much slower rate than the anaerobic systems, but it has a much larger yield of energy for ATP resynthesis.

The ATP–CP system and recovery

- The ATP–CP system uses CP to create new ATP supplies without using oxygen.
- The ATP–CP energy system has the least complicated chain of chemical reactions and as a result can create ATP at the most rapid rate.

- Due to the limited amount of CP that can be stored in muscle, the ATP–CP system has the lowest yield of all three energy systems.
- The ATP–CP system is the major energy contributor to maximal-intensity, short-duration activities of approximately 10 seconds if stores were fully replenished before the exercise began. At this point CP stores can deplete to as little as 1–2 per cent.
- During continuous endurance exercise, CP stores may last longer. This is because, during periods of oxygen deficit, the athlete is not working maximally and will not deplete stores as quickly as during an all-out maximal effort.
- The by-products of this system are inorganic phosphate and ADP.
- A passive recovery replenishes ATP and CP stores at the fastest rate and is recommended when the ATP–CP system is a major contributor to ATP resynthesis.

The anaerobic glycolysis system and recovery

- The anaerobic glycolysis system involves the metabolism of glycogen stores within the muscle without oxygen needing to be present.
- The anaerobic glycolysis system takes longer to create ATP than the ATP–CP system. However, it still has a fast rate of resynthesis when compared to the aerobic system.
- Anaerobic glycolysis has a larger yield than the ATP–CP system but a smaller yield than the aerobic system.
- The anaerobic glycolysis system is the major contributor to high-intensity exertions and during periods of repeat high-intensity efforts, when CP stores deplete.
- The by-products of this system are lactate and hydrogen ions (H^+).
- An active recovery will oxidise H^+ ions at the fastest rate, replenish oxygen levels and assist with thermoregulation. Therefore, this recovery type is recommended when the anaerobic glycolysis system is a major contributor to ATP resynthesis.

The aerobic system and recovery

- The aerobic energy system can use glycogen and fats (and protein under extreme conditions) to provide energy for ATP resynthesis, but oxygen must be present for the chemical reactions involved in aerobic metabolism to take place.
- The aerobic energy system has a slow rate of ATP resynthesis compared to the anaerobic systems, but it has a much greater yield of ATP.
- The aerobic system is the major contributor to energy production during rest and submaximal-intensity efforts, such as endurance events.
- Aerobic metabolism occurs primarily within specialised cell structures called mitochondria.
- This system creates heat, water and carbon dioxide as by-products.
- Post-aerobic exercise, the most effective recovery type is typically active recovery because efforts above steady state will result in an accumulation of metabolic by-products such as H^+.
- Depending on other factors, such as environmental conditions (heat) and fuel depletion, recovery after aerobic exercise could also require rehydration, a nutritional approach and/or a cooling strategy.

Energy systems interplay

- Interplay refers to the simultaneous contribution of the three energy systems to ATP resynthesis.
- When exercising, the relative contribution of each system will be determined by the intensity and duration of the physical activity.
- There is a gradual transition from one system being the major supplier to another system assuming the primary contribution to ATP resynthesis.
- Energy system interplay requires an assessment of key factors such as intensity and duration to accurately determine the ATP contribution of each system overall, and at specific moments within sport and exercise.
- In submaximal efforts (70–85 per cent of MHR), oxygen demand and supply will be equal and the aerobic system will be the major contributor. In this instance, the contribution of the anaerobic systems will be minimal.

- In maximal efforts of short duration (60 seconds or less), the major contributor to ATP resynthesis will be the anaerobic systems, which produce energy at a faster rate than the aerobic system. In this instance, the contribution of the aerobic system will be minimal.
- Energy system interplay during intermittent exercise is complex. It is more accurate to consider the energy system contribution and interplay at various stages of performance by considering the key factors of intensity, duration, recovery periods and availability of fuels.
- Tables 6.3 and 6.4 summarise the main information that has been presented in this topic.

TABLE 6.3 Summary: the conversion of food to energy

Characteristics	Carbohydrates	Fats	Proteins
Conversion and storage	• Transported in the blood as glucose • Stored in muscle cells as muscle glycogen • Stored in liver as glycogen • Excess carbohydrates stored as fat in adipose tissue	• Free fatty acids in blood • Stored as triglycerides in muscle • Stored as fat in adipose tissue	• Broken down through digestion into amino acids • Excess amino acids stored as fat in adipose tissue
Major role and function	• The most readily available source of energy to fuel working muscles during exercise performance (submaximal to high-intensity exercise)	• The most concentrated form of energy, but a secondary source of energy during submaximal to high-intensity exercise • Primarily used as a source of energy during rest and low-intensity exercise	• Help the formation, growth and repair of body tissue • Help in the production of red blood cells, hormones and enzymes • Provide an emergency fuel source for energy during prolonged exercise, when carbohydrate and fat stores are depleted
Use	• At rest and during low-intensity exercise provide about one-third of the energy required • During submaximal and high-intensity exercise are used as the primary energy source • Carbohydrates can be the primary fuel for up to 90–120 minutes of continuous exercise	• At rest provide approximately two-thirds of the energy needs of the body • As exercise intensity increases, the percentage of fats being used as an energy source decreases • Fats as an energy source become increasingly important when stores of carbohydrates become depleted during endurance exercise (usually after 90–120 minutes of continuous activity)	• Generally only used in extreme situations, such as starvation or in ultra-endurance events such as an ultra-marathon

Percentage of total daily intake	• Average person: 55–65 per cent • Athletes in training: 60 per cent or greater, or 7–10 grams of carbohydrate per kilogram of body mass	• Average person: 20–25 per cent • Endurance athletes in training: 20–30 per cent	• Average person: 15 per cent • Athletes in training: strength athletes may require slightly more protein in their diets
Common food sources	**Complex carbohydrates:** • Those carbohydrate-rich foods that take longer to digest and release glucose at a slower but more sustained rate • Includes bread, cereals, pasta, lentils and baked beans **Simple carbohydrates:** • Those carbohydrate-rich foods that are digested rapidly and release glucose at a fast rate • Includes sugar, honey, bananas, potatoes, jelly beans, soft drinks and sports drinks	**Saturated fats:** • Found in animal foods such as milk, cheese and meat products • This type of fat contains cholesterol (implicated in cardiovascular disease) **Unsaturated fats:** • Two groups of unsaturated fats: polyunsaturated and monounsaturated. • Polyunsaturated fats are found in most vegetable oils (e.g. sunflower oil) and oily fish (e.g. tuna) • Monounsaturated fats are found in olive oil, avocados and nuts • Both types of unsaturated fats help lower total cholesterol levels	• Animal foods such as meat, poultry, fish, eggs and dairy products are rich in protein and contain all the essential amino acids • Plant foods such as cereals, grains, lentils, beans and peas are also good sources of protein, although they do not contain all of the essential amino acids

TABLE 6.4 Summary: characteristics of the three energy systems

Characteristics	ATP–CP system	Anaerobic glycolysis system	Aerobic system
Aerobic or anaerobic	• Anaerobic	• Anaerobic	• Aerobic
Fuel or fuels used	• **Creatine phosphate** (also known as phosphocreatine) — stored in small quantities within muscle cells	• **Carbohydrates** — stored as **glycogen** within muscle cells and the liver	• **Carbohydrates** — preferred fuel during exercise • **Fats** — stored as triglycerides in muscle cells and the liver. Used predominantly when at rest, and during lower-intensity exercise (up to about 50–65 per cent of maximum oxygen uptake) • **Proteins** — only used in extreme circumstances, such as starvation or during ultra-endurance events

(continued)

TABLE 6.4 Summary: characteristics of the three energy systems *(continued)*

Characteristics	ATP–CP system	Anaerobic glycolysis system	Aerobic system
Maximal rate of energy production	• **Fastest** rate of energy release for resynthesis of ATP from ADP and Pi • This is because this system is the least complicated of the three energy systems (fewer chemical steps), and because CP is found within the muscle cells themselves	• Provides energy for ATP resynthesis **rapidly**, but not as quickly as the ATP–CP system • The slower rate is due to a more complex series of chemical reactions, which result in glycogen breaking down to glucose, then to pyruvic acid and then eventually to lactic acid	• **Slowest** system to provide energy for ATP resynthesis due to the complex nature of its chemical reactions, and the fact that sufficient oxygen has to be made available to the muscle cells
Maximum ATP production (yield) per mole of fuel source	• Small amounts of ATP produced	• Approximately twice as much ATP produced as the ATP–CP system	• Vastly greater amounts of ATP produced compared with the two anaerobic systems
Duration and intensity of energy production	• Major energy supplier for maximal high-intensity exercise, but its capacity is depleted after approximately 10 seconds of maximal-intensity exercise	• Major energy contributor for ATP resynthesis during continuous maximal efforts once CP stores deplete • May also become the major producer of energy for ATP resynthesis during repeated short-duration maximal-intensity efforts that have insufficient recovery time to allow for full replenishment of CP stores	• Major supplier of energy for ATP resynthesis when at rest and during submaximal activity • As event duration increases and intensity decreases, the contribution of the aerobic system to energy production increases, while that of the anaerobic systems decreases
Specific examples	• Athletics field events (e.g. high jump, shot put) • Short sprints (50—100 metres) • Tennis serve • Gymnastics vault • Golf drive	• 400-metre athletic event • 50-metre swim • High-intensity tennis rally of 15–30 seconds' duration • Repeat sprints with minimal recovery in a team sport	• 10 000-metre athletic event • Marathon • 2000-metre rowing event • Mid-field players in many team sports (e.g. Australian Rules, soccer)
Type of recovery	• Passive	• Active	• Active
Metabolic by-products	• Inorganic phosphates (Pi) • ADP	• Lactate and hydrogen ions (H^+) • ADP	• Carbon dioxide (CO_2) • Water (H_2O) • Heat • ADP

Links to fitness components	• Muscular strength • Muscular power • Anaerobic capacity • Speed and agility • Reaction time	• Anaerobic capacity • Muscular endurance • Speed and agility • Muscular power	• Relevant to all fitness components because it provides the basis for recovery in anaerobic-type tasks as well as the majority of energy production for submaximal activities

6.10.2 Key terms

anaerobic glycolysis energy system provides energy for the resynthesis of ATP through the breakdown of glycogen through a series of chemical steps that do not require oxygen
active recovery low-intensity (50–60 per cent of MHR) activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling
adenosine diphosphate (ADP) a by-product that results when ATP breaks down and loses one of its phosphate groups, which are located at the end of the molecule
adenosine triphosphate (ATP) a high-energy molecule stored in muscle cells and other parts of the body. It is the energy currency for biological work.
aerobic energy system provides energy from the breakdown of carbohydrates and/or fats in the presence of oxygen
aerobic metabolism when ATP resynthesis occurs via energy pathways that require the presence of oxygen
aerobic system provides energy for the resynthesis of ATP through the breakdown of various energy fuels (mainly glycogen and triglycerides) through a series of chemical steps that require oxygen
amino acids the building blocks of protein. Protein is broken down through the process of digestion into amino acids.
anaerobic metabolism when ATP resynthesis occurs via energy pathways that do not require the presence of oxygen
ATP demand refers to how much ATP is required during an activity and the rate at which it is expended and, therefore, needs to be resynthesised
ATP–CP energy system provides energy for the resynthesis of ATP through the breakdown of creatine phosphate (CP) without oxygen being involved
carbohydrates naturally occurring compounds that consist of carbon, hydrogen and oxygen
creatine an organic substance that occurs naturally in humans and helps to supply energy to muscle
creatine phosphate (CP) a chemical compound found in muscle cells that is capable of storing and releasing energy that can be used to resynthesise ATP from ADP and Pi
excess post-exercise oxygen consumption (EPOC) the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest
fatigue an exercise-induced reduction in the ability of muscle to produce force or power
fats (lipids) an essential component of a balanced diet; should comprise about 20–25 per cent of daily food intake
free fatty acids a broken-down, transportable form of fats
glucose the simplest form of carbohydrate and the basic ingredient for anaerobic and aerobic glycolysis
glycogen the storage form of glucose; a chemical fuel found in the muscles and in larger quantities in the liver
interplay of energy systems the energy systems simultaneously working together, but at different rates, to supply the ATP required for an activity
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.

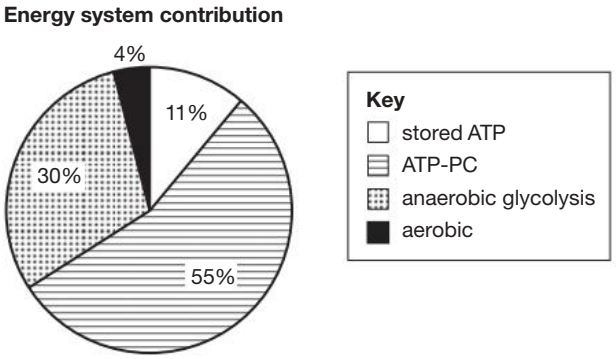
metabolic by-product (or metabolite) a substance produced as a result of chemical reactions within the body associated with the production of energy for ATP resynthesis
mitochondria cell structures (organelles) that serve as the power generators of the cell, converting nutrients into ATP in the presence of oxygen (aerobically)
oxygen deficit the state in which there is a discrepancy (shortfall) between oxygen supply and the oxygen needed to meet the energy requirements of the activity. The anaerobic pathways must supplement the energy demands of the activity.
passive recovery complete rest by standing, sitting or lying down to replenish CP at a faster rate
protein an essential component of a balanced diet. Protein allows for muscle growth and repair, fights disease, assists in chemical reactions and transports materials
pyruvic acid (pyruvate) an intermediate product in the metabolism of carbohydrates, formed by the anaerobic metabolism of glucose
rate refers to how quickly ATP is resynthesised
recovery the overcoming or reversal of the fatigue experienced as the result of participation in a training session or exercise bout, where body systems repair damaged tissue and replenish energy stores
triglycerides the stored form of fats found in adipose tissue and skeletal muscle
venous pooling an accumulation of blood in the veins in inactive muscles following activity
VO_2 max the maximum amount of oxygen per minute that can be taken in, transported and used by the body for aerobic energy production
yield the total amount of ATP that is resynthesised during an exercise bout or from a specific fuel within the bout

6.10 Exam questions

6.10 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.8;* © VCAA



Which event most effectively represents the contribution of energy systems demonstrated in the graph above?

A. 100 m sprint
B. 400 m sprint
C. 1500 m run
D. 3000 m run

Question 2 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.13*; © VCAA

The graph shows the percentage of energy contributed by carbohydrates and fats as exercise intensity changes.

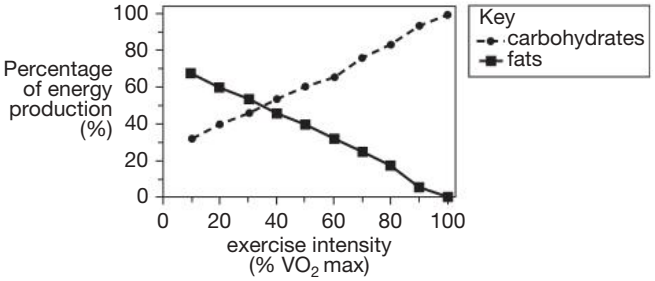
Which one of the following statements is correct?

A. As the exercise intensity increases, the contribution of fats to energy production increases.

B. As the exercise intensity increases, the contribution of carbohydrates to energy production increases.

C. At 60% VO_2 max, there is a higher contribution from fats than from carbohydrates to energy production.

D. At 50% VO_2 max, there is an even contribution between fats and carbohydrates to energy production.

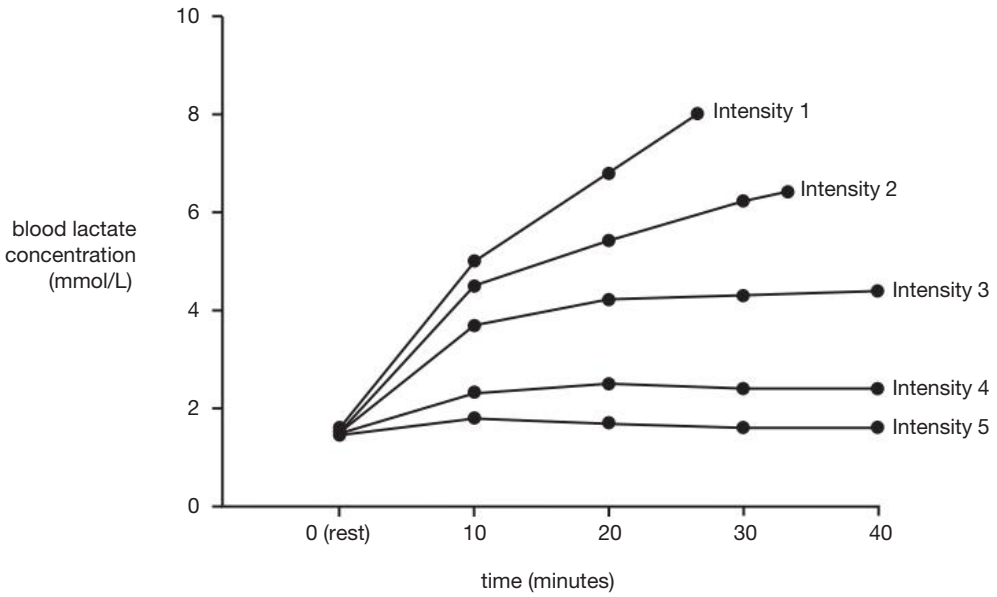


Source: Adapted from SK Powers & ET Howley, *Exercise physiology*: *theory and application to fitness and performance*, McGraw-Hill, New York, 2009, p. 61

Question 3 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.14*; © VCAA

The graph below shows the blood lactate concentration for one individual in response to this individual exercising on five different occasions at five different intensities, labelled as Intensity 1 to Intensity 5.



Source: Adapted from O Faude et al., 'Lactate threshold concepts: How valid are they?', *Sports Medicine*, vol. 39, no. 6, 2009, p. 474

The energy system that has made the greatest contribution to Intensity 1 in the graph above is

A. anaerobic glycolysis.

B. lactic acid.

C. ATP-CP.

D. aerobic.

Question 4 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.10;* © VCAA

The energy system with the highest yield of ATP but slowest rate is the

A. ATP-CP system.
B. aerobic system.
C. anaerobic system.
D. anaerobic glycolysis system.

Question 5 (1 mark)

In which energy system or systems are hydrogen ions a metabolic by-product of the chemical process?

A. Anaerobic glycolysis
B. ATP–CP
C. Aerobic glycolysis
D. Aerobic lipolysis

Question 6 (1 mark)

State an advantage of using creatine phosphate as a fuel.

A. Readily available in the liver
B. Breaks down slowly with oxygen
C. Provides a large yield of ATP at a rapid rate
D. Breaks down rapidly without oxygen

Question 7 (1 mark)

Which fuel produces the most amount of energy per mole?

A. PC
B. Triglycerides
C. Blood glucose
D. ATP

Question 8 (1 mark)

Which of the following statements is correct?

A. As exercise intensity increases, the contribution of carbohydrates to ATP production increases.
B. At rest, the contribution of carbohydrates increases.
C. As exercise intensity increases, the contribution of fats to ATP production increases.
D. As exercise intensity decreases, the contribution of creatine phosphate to ATP production increases.

Question 9 (1 mark)

A swimmer completes 50 metres of freestyle at maximal intensity finishing in 26.11 seconds. The energy system with the greatest contribution to ATP resynthesis in this activity would be:

A. the ATP–CP system.
B. the anaerobic glycolysis system.
C. the aerobic system.
D. an equal contribution between the anaerobic glycolysis and aerobic systems.

Question 10 (1 mark)

A shot putter and midfielder in soccer should typically complete which of the following recovery activities?

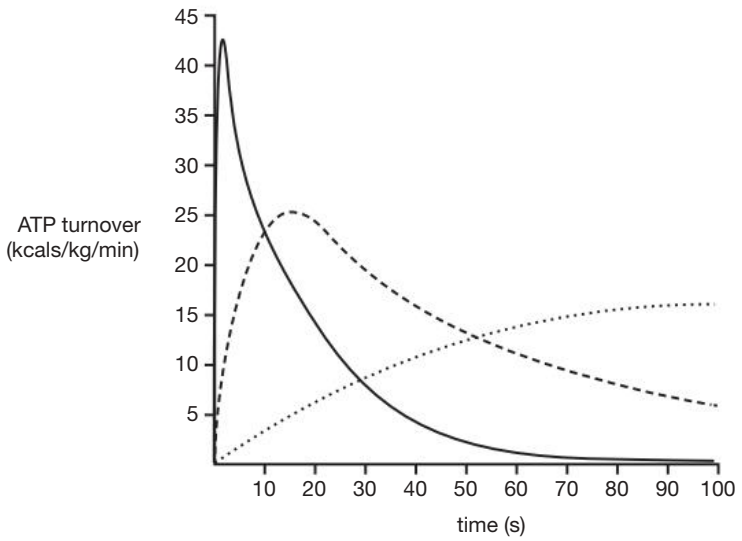
A. Sitting down (shot putter) and standing still (midfielder)
B. Jogging (shot putter) and walking (midfielder)
C. Lying down (shot putter) and jogging (midfielder)
D. Jogging (both athletes)

6.10 Section B – Short answer questions

Question 1 (6 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.4;* © VCAA

Energy system interaction and the differences in rates of ATP turnover during short-term intense exercise to fatigue



Source: JS Baker, MC McCormick & RA Robergs, 'Interaction among skeletal muscle metabolic energy systems during intense exercise', *Journal of Nutrition and Metabolism*, vol. 2010, p. 8, <https://doi.org/10.1155/2010/905612>; © 2010 Julien S Baker, et al.

Examples of track and field events in athletics

Track	Field
100 m	shot put
400 m	long jump
5000 m	pole vault

Using the graph and the examples of track and field events in the table, **compare** the characteristics of the aerobic energy system and the ATP—CP energy system by **discussing** fuel sources, rate of ATP production and recovery.

Question 2 (3 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.5.b;* © VCAA

The image below shows an athlete undergoing the 30-second Wingate cycling test. The test begins with an athlete pedalling as fast as possible on a cycle ergometer without any resistance. Within three seconds, a fixed resistance is applied to the wheel of the cycle ergometer and the athlete continues to sprint for 30 seconds.



The table below shows the relative contribution of each of the three energy systems to the total work done in three different cycle ergometer exercise tests.

	ATP—CP	Anaerobic glycolysis	Aerobic
10-second test	52%	46%	2%
30-second test	25%	45%	30%
90-second test	12%	42%	46%

Using the data provided in the table, **discuss** the reasons for the differences between the 10-second, 30-second and 90-second tests.

Question 3 (5 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.10.a;* © VCAA

In a game of netball there are similarities and differences between the energy requirements of different positions. All players on a netball court engage in short, sharp, high-intensity movements throughout the game.

The centre player is allowed to move over the whole court, except the goal circles, As well as maintaining high-intensity efforts throughout the game, the centre player is constantly on the move and has significantly shorter periods of walking or standing still than the goal shooter.

The goal shooter is only allowed within goal third and must have good spatial awareness, Compared to the centre player, the goal shooter completes similar high-intensity movement but spends a significantly greater amount of time walking or standing still.

Using the information given above, **discuss** the similarities and differences between the energy requirements of a centre player and goal shooter.

Question 4 (4 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.9;* © VCAA

The sport of skateboarding will be featured for the first time at the Tokyo Olympic Games. One of the two disciplines on the skateboarding program at the Tokyo Olympic Games will be the street skateboarding competition.

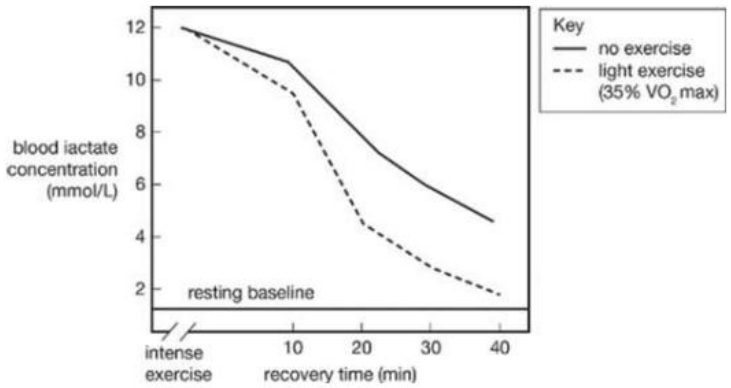
This competition will be held on a street-like course featuring stairs, handrails, kerbs, benches, walls and slopes. A variety of tricks will be performed, such as sliding the skateboard along the kerbs or handrails. Competitors will complete two 45-second runs on the same course with approximately one hour between runs. Their five best tricks will be scored.

Explain the contribution of the anaerobic energy systems to the energy requirements of competitors in the street skateboarding competition.

Question 5 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.7*; © VCAA

The graph below shows blood lactate concentration over time, comparing different recovery methods following intense exercise.



Source: Adapted from SK Powers & ET Howley, *Exercise physiology*: *theory and application to fitness and performance*, McGraw-Hill, New York, 2009, p. 54

With reference to the graph above, **explain** whether passive recovery or active recovery is more beneficial following intense exercise.

Continue to build your exam skills

Access the Unit 3 Area of Study 2 Review at the end of Topic 7. This includes:

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- Practice examination
- Practice school-assessed coursework.

7 Muscular fatigue and nutritional and hydration strategies

7.1 Overview

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LEARNING SEQUENCE

7.1 Overview
7.2 Introduction to fatigue
7.3 Fuel depletion
7.4 Accumulation of metabolic by-products
7.5 Blood lactate and performance
7.6 Thermoregulatory fatigue
7.7 Carbohydrate ingestion and protein
7.8 Nutritional strategies
7.9 Hydration needs of athletes
7.10 Key skills
7.11 Review

7.1.1 Introduction

Achieving optimal performance is an intricate balance between energy production and consumption. This has consequences for all athletes, from the elite to those pursuing general fitness. Fatigue represents a critical aspect of the physiological response to physical exertion. It is the point at which the body's ability to sustain a given level of intensity is reduced, ultimately resulting in the working muscles producing less force and less rapid muscular contractions, leading to a decline in performance.

Understanding the physiological mechanisms that result in exercise-induced fatigue is essential for optimising the design and implementation of training programs, enhancing competition performance, preventing injury and promoting wellbeing.

Further, knowledge of nutrition and hydration — key influences on the body's ability to sustain performance — can help coaches and athletes to select strategies to enhance performance, delay fatigue and accelerate recovery.

FIGURE 7.1 What fatiguing factors would triathletes experience? What nutritional and hydration strategies would they likely use pre, during and post a race?

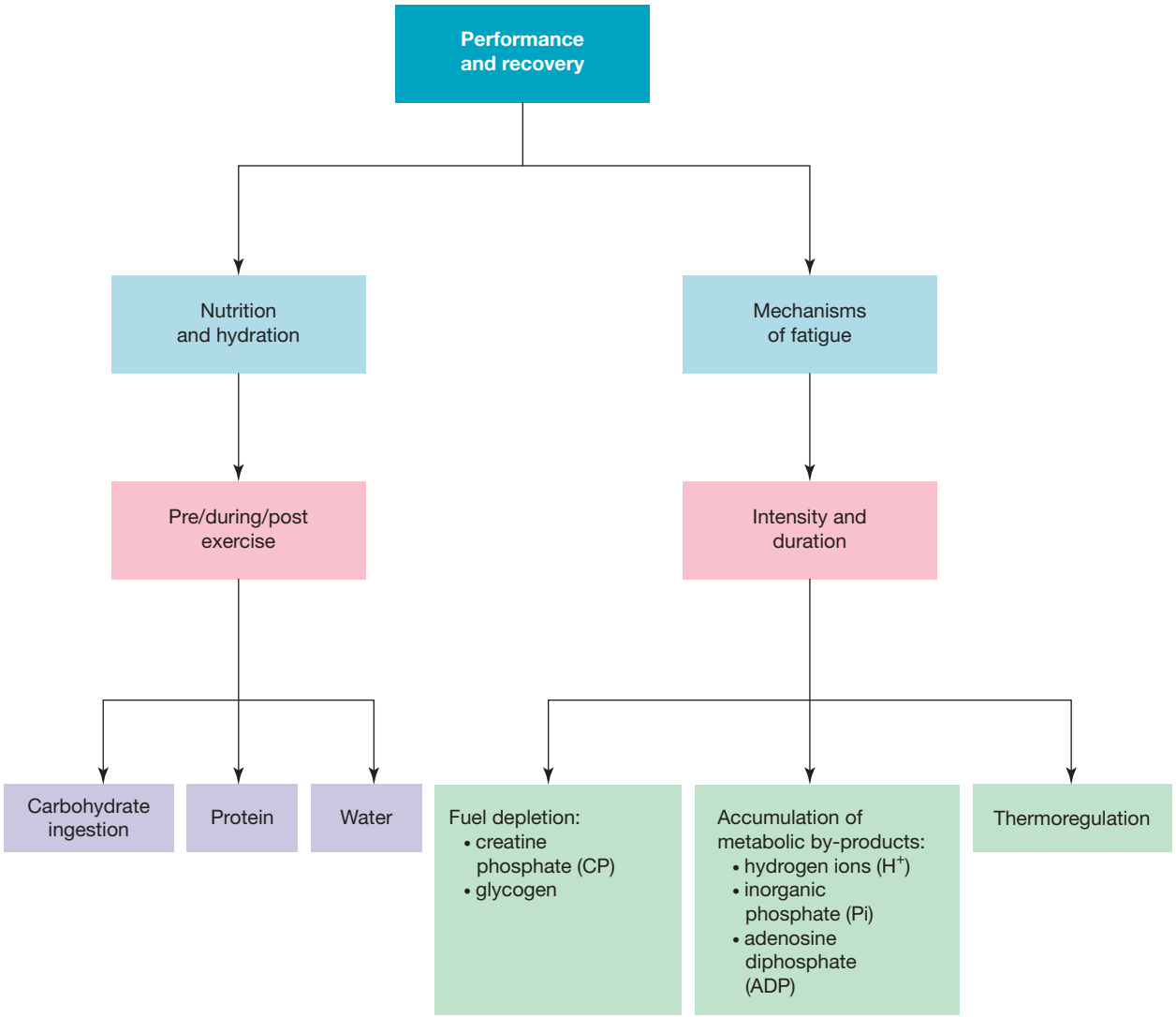


7.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations	**7.2** **7.3** **7.4** **7.5** **7.6**
• nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery including carbohydrate ingestion, protein and water	• describe nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery	**7.7** **7.8** **7.9**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.1.3 Topic preview



7.2 Introduction to fatigue

Key knowledge	Key skill
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.2.1 Fatigue

Fatigue is a gradual and **multifactorial** process, which means multiple types of fatigue are always present and occurring simultaneously (i.e. fuel depletion, accumulation of **metabolic by-products** and elevated body temperature). However, at any one point in an effort, one fatigue mechanism will be contributing most to the reduced intensity. For example, in anaerobic efforts (e.g. the pole vault) the most influential fatigue mechanism is creatine phosphate (CP) depletion (see figure 7.2a). By contrast, a marathon runner who takes over three hours to complete a 42-kilometre marathon (a prolonged aerobic event) will likely be experiencing more fatigue from glycogen depletion than from any other factor (see figure 7.2b).

fatigue an exercise-induced reduction in the ability of muscles to produce force or power

multifactorial involves or is dependent on several factors or causes

metabolic by-product a substance produced because of chemical reactions within the body associated with the production of energy for ATP resynthesis

FIGURE 7.2 The fatigue mechanisms experienced in **(a)** an anaerobic event like pole vault are different to those experienced in **(b)** an aerobic endurance event such as a marathon.



Which fatiguing mechanisms has the most influence on performance is dependent on both individual factors and the conditions in which the exercise takes place. These factors are summarised in table 7.1.

TABLE 7.1 Factors affecting fatigue mechanisms

Individual factors	Exercise conditions
• age • genetics • fitness and training status • pre-exercise nutritional state • pre-exercise hydrational state • psychological readiness	• exercise duration • exercise intensity • type of exercise (intermittent or continuous) • type of contraction (dynamic or isometric) • environmental conditions (e.g. temperature, humidity, altitude)

EXAM TIP

When determining which fatiguing factor is influencing performance the most, the two most important factors to consider are the intensity and duration of the exercise being performed.

EXAM TIP

The three key sources of FATigue that you need to know about can be recalled using the first three letters of the word. This makes them much easier to remember.

- **F**uel depletion
- **A**ccumulation of metabolic by-products
- **T**hermoregulatory fatigue.

7.2 Activity

7.2 Quick quiz on | **7.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	2, 4	3

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TEST your understanding

1. What does the term *fatigue* refer to?
2. **Predict** the major fatiguing factor that would be experienced by a sprinter or weightlifter during a competition.
3. Fatigue is multifactorial. **Explain** the meaning of this statement.

APPLY your understanding

4. The Paris to Roubaix is a 256-kilometre, one-day professional bicycle road race. Competitors typically finish in 5 to 6 hours. **Suggest** the mechanisms of fatigue a cyclist would likely experience when participating in this race. **Identify** which mechanism is likely to have the most impact on performance.

7.2 Exam question

Question 1 (3 marks)

Source: *VCE 2011, Physical Education Exam, Section A, Q.2.a;* © VCAA

The causes of fatigue during exercise are multifactorial. Fuel depletion is one cause of muscles experiencing a decrease in contractile force and speed. **List** three factors that affect the rate of fuel depletion during exercise.

More exam questions are available in your learnON title.

7.3 Fuel depletion

Key knowledge	Key skill
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Fuel depletion refers to the depletion of the body's energy fuels, which, through their breakdown, allow ATP resynthesis to occur. ATP is the body's energy currency; it powers all of the muscle cells' metabolic activity, including the ability to contract at a specific force and speed. The types of fuel depletion experienced within the muscle cells include CP depletion and glycogen depletion.

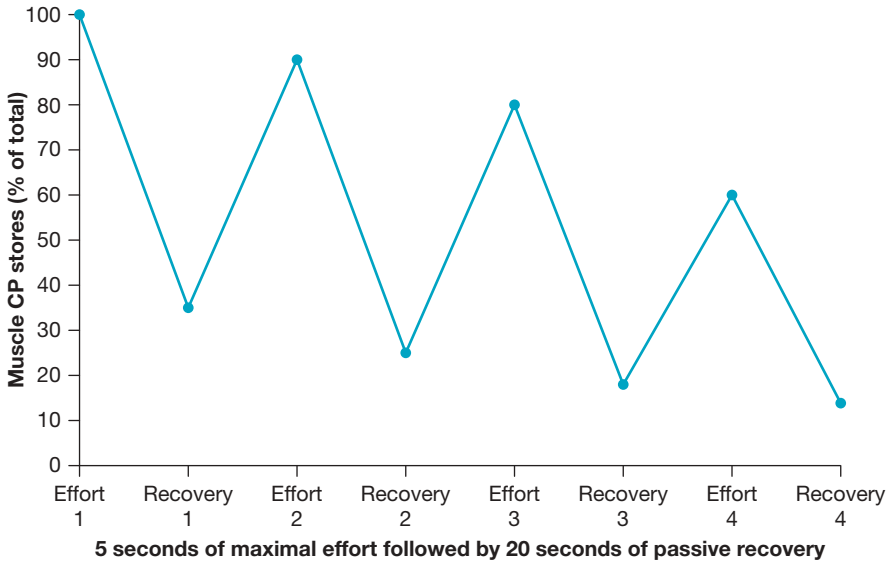
7.3.1 Creatine phosphate depletion

During maximal intensity efforts of short duration, the existing stores of intramuscular ATP are used up within the first few seconds. This activates the energy systems to maintain the required rates of ATP within the working muscles. As the muscle demand for ATP is high during maximal efforts, the muscles will use the ATP–CP system — specifically, CP as a fuel — to rapidly replenish ATP from ADP and Pi. However, CP stores are limited within the muscle and will deplete to as little as 1–2 per cent after approximately 10 seconds of all-out effort.

- CP depletion occurs in:
  - single maximal efforts of short duration.
  - repeat **intermittent** maximal efforts where there is inadequate recovery time to fully replenish CP stores (see figure 7.3). Recall, that approximately 98 per cent of CP stores are replenished after three minutes of passive recovery. This length of recovery is rarely afforded to performers in team sports.
  - long duration, continuous exercise in which submaximal effort is interspersed with periods of high or maximal intensity.

intermittent short periods of work followed by a period of rest

FIGURE 7.3 ATP–CP stores are depleted and CP stores are partially replenished during repeated intermittent maximal efforts.



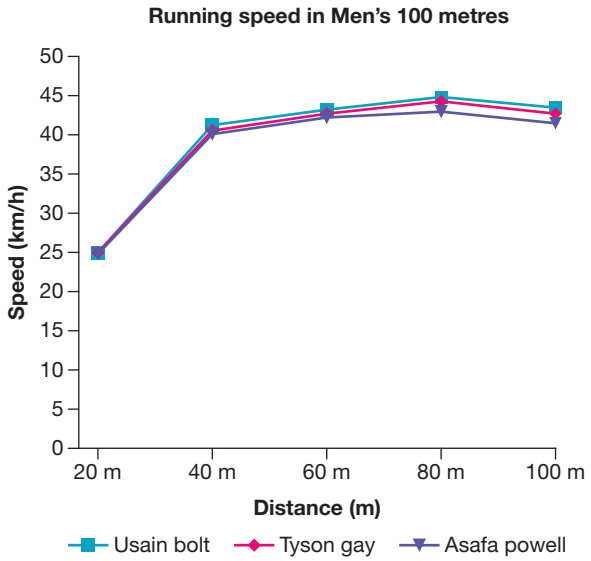
How does creatine phosphate depletion cause fatigue?

- CP resynthesises ATP within the muscle more rapidly than any other fuel source.
- When CP depletes to as low as 1–2 per cent within the muscle, the ability to replenish ATP is significantly reduced.
- The depletion of CP results in anaerobic glycolysis becoming the primary supplier of ATP for maximal efforts.
- The anaerobic glycolysis system produces ATP at a slower rate than the ATP–CP system.
- The slowing of metabolic processes caused by CP depletion plays out over distances as short as the 100-metre sprint. As seen in table 7.2 and figure 7.2, each of the top three placegetters in Usain Bolt's world record run in the 2009 Men's World Championship experienced a decline in speed (km/h) in the final 20 metres of the race. This reduction in speed was primarily due to CP depletion.

TABLE 7.2 Running speed (km/h) in Men's 100 metres, at 20-metre intervals

	20 m	40 m	60 m	80 m	100 m	Speed decline in the last 20 m
Usain Bolt	24.91	41.14	43.11	44.72	43.37	3.02%
Tyson Gay	24.91	40.44	42.60	44.17	42.60	3.55%
Asafa Powell	24.74	40.00	42.11	42.86	41.38	3.45%

FIGURE 7.4 Over short distances, such as during the 100-metre sprint, CP depletion is the main factor causing fatigue.



EXAM TIP

Remember that when CP stores deplete, the body can no longer resynthesis ATP at the most rapid rate, resulting in a reduced intensity.

7.3.2 Glycogen depletion

Carbohydrates are the body's preferred fuel source. They are used by the aerobic system during exercise of submaximal intensity, resynthesising ATP at a faster rate than fats. Carbohydrates are stored as glycogen in both the liver and the muscle, and an additional smaller amount circulates in the bloodstream as glucose. Storage of carbohydrates is higher in aerobically trained athletes and further enhanced by the nutritional strategy of **carbohydrate loading**, which enables the performer to delay the onset of glycogen depletion.

During endurance exercise, muscle glycogen stores deplete. This can occur within as little as 40 minutes during prolonged continuous exercise, during which time blood glucose levels are maintained by the breakdown of glycogen in the liver.

- However, this replenishment of blood glucose levels leads to a point at which the glycogen stores in the liver fall too low and the performer experiences **hypoglycaemia**.
- Typically, glycogen stores can be the primary fuel source for continuous, submaximal exercise for periods of 90–120 minutes.
- At exercise intensities between 65 per cent and 85 per cent of maximal oxygen uptake (**VO_2 max**), muscular fatigue is highly correlated with depletion of muscle glycogen stores. This corresponds to efforts of between 79 per cent and 92 per cent of the maximum heart rate (MHR).

carbohydrate loading a nutritional strategy in which muscle glycogen stores are maximised prior to endurance events

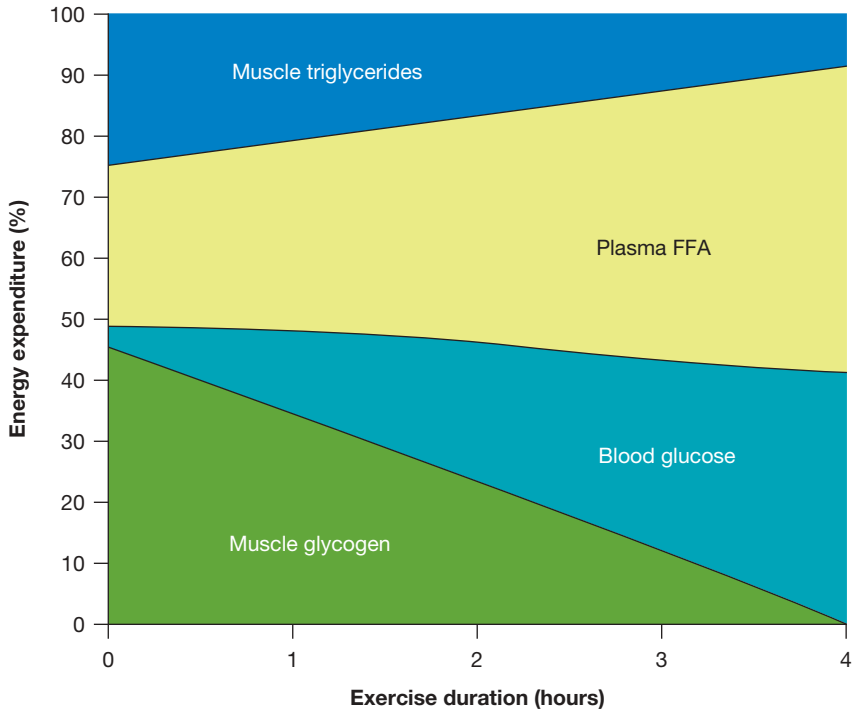
hypoglycaemia when blood sugar levels have dropped too low due to prolonged strenuous activity and depleted glycogen stores

VO_2 max the maximum amount of oxygen per minute that can be taken in, transported and used by the body for energy production

How does glycogen depletion cause fatigue?

- As glycogen stores deplete during prolonged endurance exercise, there is an increased reliance on fat (plasma free fatty acids and muscle triglycerides) metabolism (see figure 7.5).
- This increased reliance on fat metabolism slows down ATP resynthesis, decreasing exercise intensity.
- Glycogen depletion typically results in exercise intensity having to decrease to a level that can be supported primarily by fat metabolism: around 50 per cent VO_2 max, or 70 per cent MHR.

FIGURE 7.5 Contribution of primary food fuels during submaximal intensities and various durations



- An increased reliance on fat metabolism reduces an individual's exercise intensity because fats:
  - are a more complex molecule that takes longer to break down
  - require more oxygen to break down
  - produce ATP aerobically at a slower rate than glycogen.
- Thus, glycogen depletion is associated with an inability to maintain the same intensity in prolonged aerobic exercise.
- In marathon running, the point in the race at which glycogen depletion occurs (typically around 28–35 kilometres) is referred to as **'hitting the wall'** (see figure 7.6).
- Studies on perceived exertion (how difficult an effort seems to be) also indicate that participants typically do not report exercise as being highly stressful or fatiguing until such time as muscle glycogen stores are near depletion (see figure 7.7). Thus, the sensation of fatigue during prolonged exercise seems to coincide with a decreased concentration of muscle glycogen.

hitting the wall a term used in endurance sports to describe the sudden feeling of extreme fatigue associated with the depletion of glycogen stores in the muscle and liver

FIGURE 7.6 'Hitting the wall' (glycogen depletion)

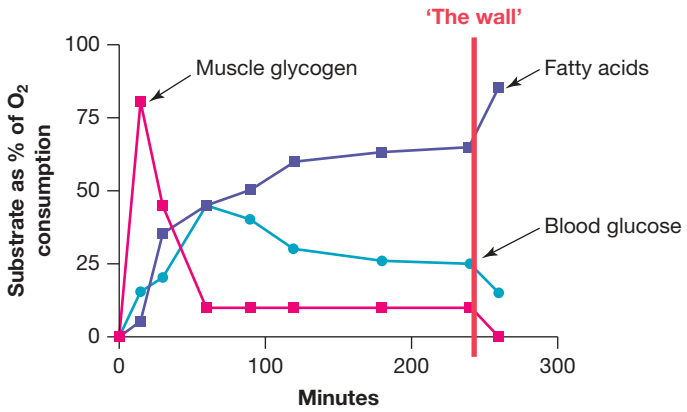
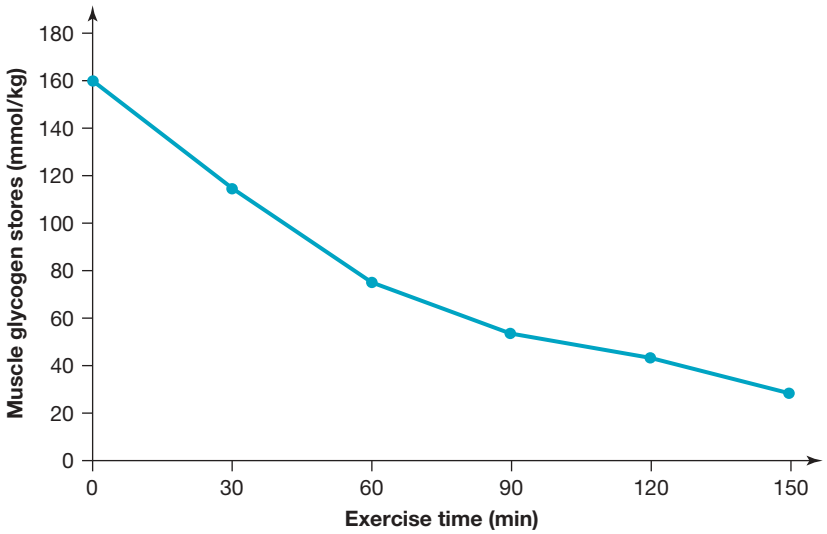
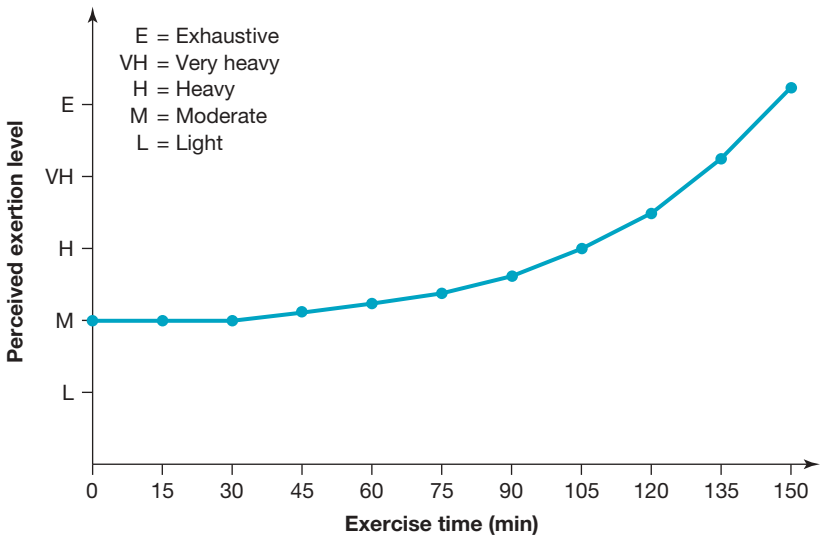


FIGURE 7.7 Glycogen depletion and perceived exertion levels





EXAM TIP

When glycogen stores deplete, fats will become the primary fuel source for energy production. This slows the rate of ATP resynthesis and exercise intensity.

7.3 Activity

7.3 Quick quiz on | **7.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	6	4, 5

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TEST your understanding

1. **Describe** a scenario in which CP depletion is likely to be the major fatiguing factor on performance.
2. In maximal efforts, **identify** which energy system will be the primary supplier of ATP if CP depletion occurs.
3. **Outline** the exercise conditions (type, intensity and duration) in which glycogen depletion typically occurs.
4. As glycogen depletion occurs, fats will become the primary fuel source. **Explain** the three disadvantages of using fats as the primary fuel source during endurance events.

APPLY your understanding

5. In the final stages of a 100-metre sprint, CP store will reach close to full depletion. **Explain** why this fatigue mechanism results in a reduced running speed.
6. A marathon covers a distance of 42 kilometres, with runners often experiencing a decline in speed 30–35 kilometres into the race. **Identify** the most likely cause of fatigue at this point of the event and **discuss** how it results in a decline in performance.

7.3 Exam questions

Question 1 (4 marks)

Source: Adapted from *VCAA 2017, Physical Education Exam, Section B, Q.13;* © VCAA

The Australian Football League (AFL) carries out a series of fitness tests at its annual draft camp to help clubs determine who is the best young talent. The Brisbane Lions selected Jarrod Berry after he performed very well at the draft camp. His results were as follows:

- 4th overall in the 6 × 30 m sprint test — 24.99 seconds total
- 1st overall in the 20 m shuttle run — level 15.1
- 1st overall in the 3 km time trial — 9.46 min

a. What is the likely initial cause of fatigue in the 6 × 30 m sprint test? **(1 mark)**

b. **Explain** how this fatigue mechanism would impact performance in this test. **(2 marks)**

c. What type of recovery would be most beneficial between each of the sprints in the 6 × 30 m sprint test? **(1 mark)**

Question 2 (4 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.8;* © VCAA

The Ironman Triathlon consists of a 3.86 km swim, a 180.25 km bicycle ride and a 42.20 km marathon, raced in that order. Races generally last eight hours for world-class performers.

With reference to the likely cause of fatigue, **discuss** fuel usage throughout the event and how this may have an impact on performance.

More exam questions are available in your learnON title.

7.4 Accumulation of metabolic by-products

Key knowledge	Key skill
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.4.1 Hydrogen ions (H^+)

In the anaerobic glycolysis system, muscular stores of glycogen are converted into glucose and then, with the aid of enzymes, this glucose is broken down into a substance called pyruvic acid (or pyruvate). If oxygen is not available in sufficient quantities at this stage in the metabolic pathway, pyruvic acid then further dissociates into lactate and H^+.

H^+ accumulates in the muscles in two key scenarios:

- when anaerobic glycolysis is the major supplier of energy for ATP resynthesis
- when working at intensities above the athlete's **lactate inflection point** (LIP).

Research indicates that the accumulation of hydrogen ions (H^+) in the muscle cells increases the acidity within the muscle (otherwise known as muscle acidosis). During this process, muscle **pH** decreases from the normal (neutral to slightly basic) value of around 7.1 at rest to an acidic value of 6.4 at exhaustion (see figure 7.8). This level of acidity appears to be incompatible with normal muscle cell function. Such a decrease in muscle PH inhibits glycolytic enzymes, slowing the rate of glycolysis and thus ATP production.

lactate inflection point the last point where lactate entry into and removal from the blood are balanced

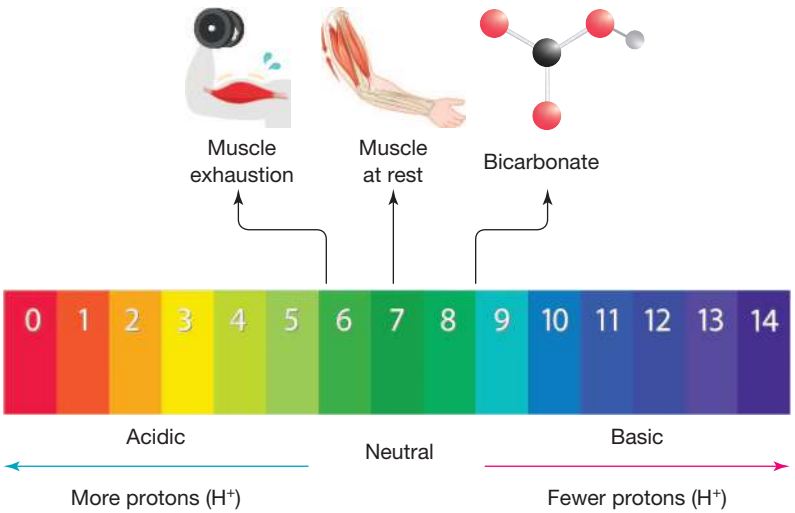
pH a measure of the acidity or alkalinity of a substance

This decrease in muscle pH due to the accumulation of H^+ causes loss of muscle power output, or fatigue.

Lactate itself is no longer recognised as a fatigue mechanism, with recent research indicating that lactate has little to no effect on muscle contractions. However:

- Lactate acts as an important intermediary in numerous metabolic processes; in particular, it can provide fuel for ATP production in the skeletal muscles and the brain.
- Lactate plays a key role in reducing the accumulation of H^+ and minimising the decrease in muscle pH.

FIGURE 7.8 The pH of the muscle cell changes as a result of anaerobic glycolysis.



There is still a lot to learn about this type of fatigue. Even the role of decreased pH as a significant cause of fatigue has been challenged by some studies in recent years. Watch this space!

How does the accumulation of hydrogen ions cause fatigue?

- The increase in acidity in the muscle inhibits glycolytic enzymes, slowing the rate of glycolysis.
- This slows the rate of ATP production and the force and velocity of muscular contractions, ultimately reducing the exercise intensity of the performer.
- The rate of H^+ accumulation will determine how rapidly the performer experiences the onset of fatigue.
- Once H^+ accumulation has occurred, the performer will need to either slow down to actively recover or they will experience exhaustion and must cease exercising.

7.4.2 Inorganic phosphate and adenosine diphosphate

One of the consequences of rapid CP use during high-intensity exercise of short duration is the accumulation of inorganic phosphate (Pi) and adenosine diphosphate (ADP), which in some studies have been shown to inhibit muscle contraction.

You will recall that when ATP is used to provide the energy for muscular contraction, it breaks down to ADP + Pi + energy. At the same time, CP breaks down to creatine + Pi + energy. These processes result in an increase in Pi within the muscle. Similarly, periods of rapid ATP use result in rising levels of ADP.

How does the accumulation of inorganic phosphate and adenosine diphosphate cause fatigue?

The exact mechanisms by which the rising levels of Pi and ADP contribute to muscular fatigue (see figure 7.9) are still not fully known and require further investigation, but it appears these by-products cause:

- interference with the role of calcium (Ca^{2+}) in the contractile process and/or interference with the cross bridge coupling cycle, inhibiting myosin's ability to generate force and motion.
- competition with ATP for the ATP binding sites on myosin, deteriorating ATP binding and weakening muscle contractions.

FIGURE 7.9 Exhausted runners after the 400-metre men's final at the 2017 World Championships in London. Due to the duration of the maximal-intensity effort required in this event, athletes experience a significant accumulation of metabolic by-products.



EXAM TIP

Knowing that inorganic phosphates inhibit muscular contractions is sufficient knowledge for the exam. You do not need to memorise the impact Pi has on calcium or myosin.

EXAM TIP

Remember that a build-up of metabolic by-products leads to decreased muscle contraction force and speed.

7.4 Activity

7.4 Quick quiz on | **7.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	7	5, 6

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TEST your understanding

1. **Identify** which energy system produces hydrogen ions (H^+) as a by-product.
2. **Identify** what causes the accumulation of blood lactate during exercise.
3. **Identify** a sport or event in which H^+ accumulation is likely to be the major fatiguing factor affecting performance.
4. **Outline** the exercise conditions (intensity and duration) under which Pi and ADP accumulate.

APPLY your understanding

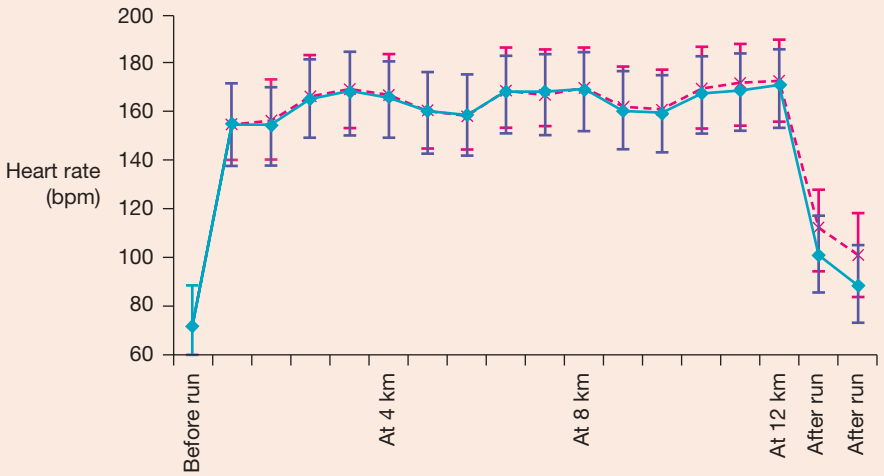
5. In a 400-metre sprint, an athlete's speed declines throughout the race, primarily due to H^+ accumulation. **Explain** the impact this by-product has on performance.
6. **Outline** what happens to the pH of a muscle in response to a 400-metre sprint. Justify your response.
7. At the start of a soccer game, a midfielder performs three repeat high-intensity sprints in quick succession. Use your understanding of energy system interplay to **discuss** why this sequence of play results in the accumulation of metabolic by-products.

7.4 Exam questions

Question 1 (2 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.11;* © VCAA

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.



Source: Adapted from R Lopez et al., 'Examining the influence of hydration status on physiological responses and running speed during trail running in the heat with controlled exercise intensity', *Journal of Strength & Conditioning Research*, vol. 25, no. 11, 2011, p. 2946

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.

Question 2 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.6;* © VCAA

The size of a playing area for soccer can be manipulated using the constraints-based approach to skill coaching and instruction.

The following table presents selected physiological data collected from players in a study of soccer that compared activity levels during five-a-side soccer games. Players completed two games of four minutes' duration, with one game on each of two different field sizes. There was three minutes of activity recovery between games.

	Player averages	
	Small field size (20 m × 28 m)	**Large field size (30 m × 42 m)**
Heart rate (% of maximum)	86	87
Blood lactate concentration (mmol/L)	3.9	4.6
Rating of perceived exertion (RPE) (/10)	5.9	6.2

Source: Data and methods based on E Rampinini, FM Impellizzeri, C Castagna, G Abt et al., 'Factors influencing physiological responses to small-sided games', *Journal of Sports Sciences*, April 2007, p. 662

Using the data provided, **compare** the factors that cause fatigue associated with playing small-field and large-field soccer.

Question 3 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.8;* © VCAA

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 and 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.

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
0–1.5	16.22
7.5–13.5	15.13
13.5–15	17.75

Explain why, physiologically, when participating in the 15 km free cross-country event, Taufatofua's average speed declined over the first 13.5 km of the race.

More exam questions are available in your learnON title.

7.5 Blood lactate and performance

Key knowledge	Key skill
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.5.1 Lactate

Lactate is formed in the muscle cell's cytoplasm when, without the presence of oxygen, a pyruvate molecule is not transferred into the mitochondria. In this scenario, an enzyme converts pyruvate into lactic acid, which quickly dissociates (splits) into lactate and hydrogen ions (H^+).

For many years, lactic acid and lactate were considered to be the same thing, and the prevailing knowledge was that the accumulation of lactic acid (lactate) that resulted from anaerobic glycolysis use during high-intensity exercise was the cause of local muscular fatigue. We now know this to be false; lactate itself is not a fatigue mechanism.

In fact, due to its role as a mobile fuel source for aerobic metabolism in the muscle and brain, lactate actually supports ATP production and reduces fatigue. Further reinforcing the concept of energy system interplay, lactate is produced from the anaerobic metabolism of glycogen, even in a rested state under fully aerobic conditions.

7.5.2 The fate of lactate: the lactate shuttle

Lactate can be moved around both intracellularly and extracellularly. The processes that move lactate are referred to as lactate shuttles.

The intracellular lactate shuttle involves the movement of lactate between the muscle cell's cytoplasm, where it is produced, and the mitochondria, where it is oxidised to pyruvate. This pyruvate then passes through the various stages of aerobic metabolism. In this way, lactate acts as an important intermediary fuel source for energy production during aerobic metabolism. To enable this process, lactate moves out of active fast-twitch glycolytic fibres and into active oxidative **type 1 slow-twitch oxidative fibres**.

type 1 slow-twitch oxidative fibres contain large and numerous mitochondria, high levels of myoglobin and a high capillary density. They are very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolism

The extracellular lactate shuttles act to move lactate from one muscle fibre to a nearby adjacent muscle fibre, and between the muscle and the bloodstream where it can then be transported to other tissues and organs, most notably the heart, respiratory muscles, brain and liver. All of these tissues use lactate as an important fuel source. In fact, studies have shown that during high-intensity exercise, these tissues use blood-borne lactate as their fuel source in preference to other fuels such as glucose. In the heart, for example, the uptake of lactate increases many-fold as the intensity of exercise increases, while the uptake of glucose remains unchanged. Thus, the rapid uptake of lactate satisfies these tissues' energy needs.

When lactate diffuses into the bloodstream from active muscles, it takes with it some of the hydrogen ions (H^+) that are also produced because of anaerobic metabolism. In this way, lactate helps to reduce H^+ accumulation within the muscle, and thus delays the onset of muscle acidosis, which, you will recall, has been implicated as a key cause of muscular fatigue.

EXAM TIP

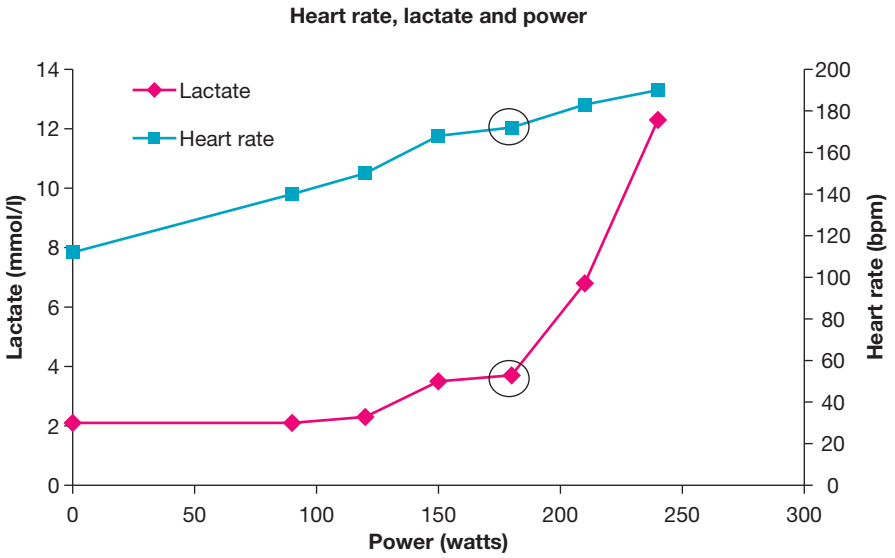
Lactic acid and lactate are not the same substance. Lactic acid is a by-product of the anaerobic breakdown of glycogen. This further breaks down into lactate and H^+. It is the H^+ that is the cause of fatigue.

7.5.3 Lactate inflection point

Changes in the lactate concentration of the blood can be determined by graphing the results of blood testing during incremental exercise (exercise that progressively increases in intensity). Figure 7.10 identifies the lactate inflection point (LIP) as the last point where lactate production and removal is balanced. It marks the last point on the graph (180 watts at 171 bpm) before there is a sharp, exponential increase in the lactate concentration in the blood (3.7 mmol/l).

It also identifies the final exercise intensity (shown as watts in Figure 7.10) or oxygen uptake value at which the blood lactate remains relatively stable. At this point, blood lactate is in a steady state.

FIGURE 7.10 Heart rate and blood lactate levels during a VO_2 max test on a cycle ergometer



7.5.4 Lactate inflection point and performance

- The LIP establishes the highest intensity of aerobic exercise an athlete can sustain without the rapid onset of fatigue occurring from the accumulation of metabolic by–products, including but not limited to H^+.
- This is because the rise in blood lactate concentration is related to rising levels of hydrogen ions within the muscle (remember, lactic acid dissociates into hydrogen ions and lactate). As a result, blood lactate can be considered a strong indirect marker for measuring muscle acidosis, which in turn leads to muscular fatigue. Measuring blood lactate is a less invasive and more practical process than attempting to measure hydrogen ions levels within the muscle.
- For coaches and athletes alike, a common goal of maximal aerobic fitness tests is to identify the intensity at which lactate production exceeds lactate removal. This provides guidance as to the aerobic training intensity required to improve endurance performance and predict the speed or power output an athlete can sustain for a prolonged period, permitting adequate storage of glycogen is available.
- At exercise intensities beyond an individual's LIP, blood lactate concentration increases exponentially in direct proportion to increases in work rate.
- Exercise intensities beyond an athlete's LIP require an increased contribution from anaerobic energy pathways to meet the ATP demands of exercise. This results in a more rapid onset of fatigue due to the accumulation of the by-products of anaerobic metabolism, but not lactate itself.
- The higher the exercise intensity performed above the inflection point, the more rapid the predicted onset of fatigue.
- During submaximal exercise that is fuelled primarily by the aerobic system, blood lactate concentrations will remain relatively stable. This is because the body is able to remove it at a similar rate to its appearance in the blood. This is known as steady state.

- Research indicates that LIP is frequently a better predictor of performance than VO_2 max in events of extended duration as it reflects the highest intensity of aerobic exercise an athlete can sustain.
- An individual's LIP varies depending on their training status. The LIP in untrained individuals typically occurs between 55 per cent and 70 per cent of VO_2 max, while in well-trained individuals, the LIP typically occurs between 75 per cent and 90 per cent of VO_2 max.

EXAM TIP

LIP is an indicator of aerobic performance and is the maximum intensity that can be sustained by the working muscles. Working at intensities above the LIP, rather than at the LIP, will result in the rapid onset of fatigue.

7.5 Activity

7.5 Quick quiz on

7.5 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	3, 5	2, 4

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TEST your understanding

1. **Identify** where in the body lactate is produced.
2. **Explain**, using your own words, the term *lactate inflection point*.
3. **Discuss** why the LIP is important to performance in endurance sports.

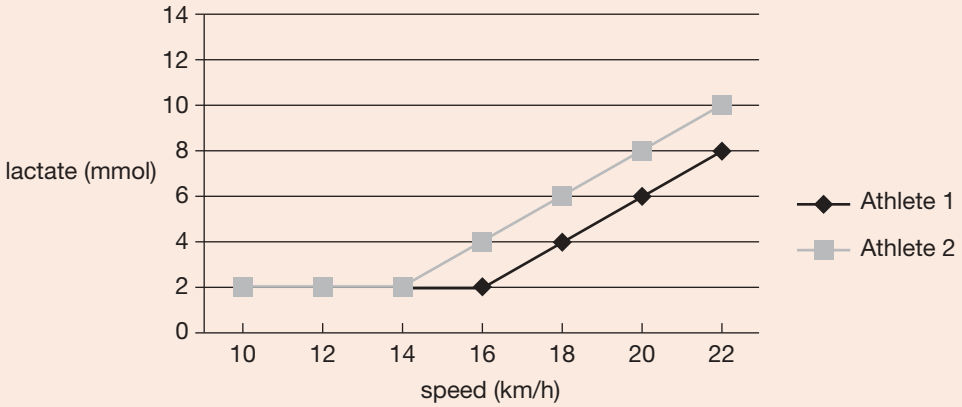
APPLY your understanding

4. **Compile** a list of sports/events where an athlete's lactate inflection point would be a key indicator of performance. **Propose** what is common with each of these activities.
5. Complete a 5-minute jog around your school or local oval. **Discuss** the impact this exercise has on blood lactate concentrations. **Justify** your response.

7.5 Exam questions

Question 1 (1 mark)

Two elite distance runners have the same maximal oxygen uptake of 83 mL/kg/min, but different lactate inflection points, as shown in the graph below.



From the graph, **identify** the running speed at which LIP occurs for Athlete 1.

Question 2 (3 marks)

Source: *VCE 2014, Physical Education Exam, Section B, Q.11;* © VCAA

The men's track cycling team pursuit event is competed over a distance of 4 km by a team of four riders. Riders in a team follow each other closely and, periodically, the lead rider (who works the hardest) moves up the bank of the track and rejoins the team at the rear. Since the winning team is decided by the third rider across the line, it is common for one rider to take a 'death pull', where he rides so hard that he cannot maintain the group pace afterwards. This allows his teammates to briefly recover behind him before they make a final three-man acceleration towards the finish line. The world record for this event is 3:53.31 minutes.

a. **Identify** the most likely cause of fatigue for the rider who makes the death pull.
b. **Explain** why a rider would be working above their LIP when riding at the front of the team.

Question 3 (2 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.14;* © VCAA

Kobe Bryant, an NBA basketball player with the LA Lakers, retired in 2016.

In his final NBA game, Bryant scored 60 points in 42 minutes of play. His actions during the last three minutes and five seconds are presented in the game log below. Overall, in that period, the two teams were together responsible for two timeouts, two substitutions and three sets of free throws.

Score	Actions performed by Kobe Bryant	Time remaining
HOME AWAY 86 - 94	Reverse lay-up	03 : 05 : 00 HRS MINS SECS
HOME AWAY 88 - 96	Two free throws	02 : 16 : 00 HRS MINS SECS
HOME AWAY 90 - 96	Fast-driving lay-up	01 : 45 : 00 HRS MINS SECS
HOME AWAY 92 - 96	Pull-up jump shot from approximately 5 meter	01 : 27 : 00 HRS MINS SECS
HOME AWAY 95 - 96	3-points pull-up jump shot	00 : 59 : 70 HRS MINS SECS
HOME AWAY 87 - 96	Pull-up jump shot from approximately 6 meter	00 : 31 : 60 HRS MINS SECS
HOME AWAY 99 - 96	Two free throws	00 : 14 : 80 HRS MINS SECS
HOME AWAY 101 - 96	Substituted from match	00 : 04 : 10 HRS MINS SECS

Source: Adapted based on data from National Basketball Association, Official Scorer's Report, Final Box, 13 April 2016; © 2016 NBA Properties, INC.

Explain a fatigue mechanism that could have had an impact on Bryant's performance towards the end of the game.

More exam questions are available in your learnON title.

7.6 Thermoregulatory fatigue

Key knowledge	Key skill
• muscular fatigue mechanisms, including fuel depletion, accumulation of metabolic by-products and thermoregulatory fatigue linked to varied sport and exercise intensities and durations	• explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.6.1 Thermoregulation

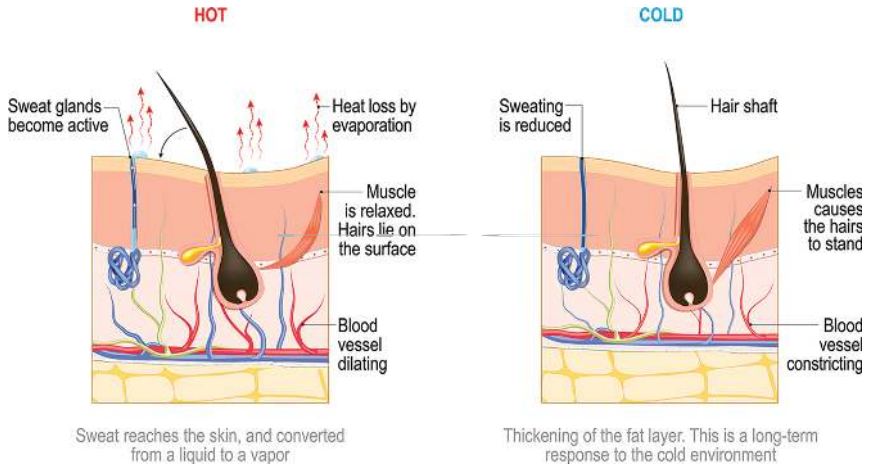
Thermoregulation is the body's system for regulating temperature. It is a cornerstone of an athlete's ability to function optimally (see figure 7.11). Thermoregulation mechanisms help return your body to **homeostasis**. The body's core temperature is usually maintained within narrow limits. Normal body temperature in adults is between 36.5 °C and 37.5 °C. This is despite wide variations in environmental conditions and elevations in heat production from exercise. It is this heat, which is generated as a by-product of energy metabolism to support muscular contractions, that is the primary concern in sport and exercise. Studies have shown that up to 80 per cent of the energy generated from our working muscles ends up as heat, making heat the main metabolic by-product of endurance activities. In colder climates, generating heat allows us to stay warm, but during exercise the body needs to expel this heat. This challenge to homeostasis is further compounded when exercising in hot climatic conditions. Ultimately, if heat production exceeds heat loss, the athlete is susceptible to **hyperthermia** (overheating).

thermoregulation the processes the body uses to maintain its core internal temperature

homeostasis the ability of the body to maintain a stable internal environment

hyperthermia high body temperature caused by a failure of the heat-regulating mechanisms of the body

FIGURE 7.11 Thermoregulation is the body's way of ensuring that its core temperature is maintained.



During high-intensity endurance events (i.e. cycling time trials and marathons), team sports and racquet sports played during the summer months, the extended period of energy metabolism results in the production of excess heat within the body. Research has shown that even in temperatures as low as 20.5 °C, athletes taking part in a 10-kilometre run experience a decline in performance of an average of 41 seconds due to the thermal conditions of the environment.

Other sports played in hot and/or humid indoor environments for extended periods of time include badminton and squash. In motor racing, too, the driver can be exposed to temperatures greater than 45 °C while performing in a restricted space, wearing layers of protective clothing and equipment. In all of these cases, higher temperatures are associated with a decrease in performance.

In contrast, a rise in body temperature acutely improves performance in single effort, explosive, short-duration activities, such as sprinting. This improvement is attributed to an increase in skeletal muscle temperature.

How do thermoregulation processes cause fatigue?

Heat, generated as a by-product of aerobic metabolism, increases core body temperature. In response, the body redistributes blood to the skin via **vasodilation** (see figure 7.12) in an attempt to increase the rate of body cooling through radiation and the evaporation of sweat from the skin surface. Evaporation is the main mechanism for heat loss.

vasodilation the process whereby blood vessels increase their internal diameter to increase blood flow

vasoconstriction the process whereby blood vessels narrow their internal diameter to reduce blood flow

FIGURE 7.12 The changes in the blood vessel due to vasodilation



What occurs from here is an interrelated series of responses:

- The increase in blood flow to the surface of the skin through vasodilation reduces the amount of blood going to the working muscles, via **vasoconstriction**, relative to the amount that would normally be directed to the muscles when exercising under cooler conditions.
- A decrease in blood flow to the working muscles reduces the oxygen available for aerobic ATP production, slowing the rate of resynthesis.
  - This also increases the body's reliance on the anaerobic pathways for the supply of energy at lower intensities, resulting in an increase in the accumulation of anaerobic by-products (such as H^+), which are associated with the rapid onset of fatigue.
- Increased sweating aims to reduce body temperature, but over extended periods also results in reduced blood plasma, blood volume and electrolyte content in the body's cells.
- The reduction in blood plasma increases blood viscosity, restricting blood circulation. At this point, the athlete becomes susceptible to dehydration. Fewer wastes are removed from muscles and sweat rates decrease, reducing the body's ability to cool itself, leading to hyperthermia.

FIGURE 7.13 Peres Jepchirchir won the Tokyo 2021 Women's Olympic Marathon for Kenya in Sapporo in hot and humid conditions.Temperatures rose above 30 °C in the final stages of the race, with 82 per cent humidity. Fifteen of the eighty eight athletes competing did not finish the race.



- The reduction in blood plasma also reduces stroke volume, meaning an athlete would have a higher heart rate for the same or similar cardiac output. This explains why athlete's can have an elevated heart rate in hot conditions.
- Glycogen is also used at a faster rate when the body is under heat stress, further increasing the contribution from the anaerobic pathways and the production of fatiguing metabolic by-products.

EXAM TIP

Remember that when exercising in hot and humid conditions, there will be a decrease in available oxygen to the muscles. This slows the rate of aerobic ATP production, causing the athlete to reduce their exercise intensity.

on Resources

Weblink How do Olympic athletes learn to handle the heat?

7.6 Activity

7.6 Quick quiz on | **7.6 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 5, 6, 8	4, 10	1, 3, 7, 9

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TEST your understanding

1. **Explain**, using your own words, the meaning of the term *thermoregulation*.
2. **Describe** the two processes the body uses to redistribute blood during exercise in hot conditions.
3. **Explain** how thermoregulation processes reduce blood plasma.
4. **Discuss** the impact thermoregulation has on oxygen delivery to the working muscles.
5. **Outline** the exercise conditions (intensity, duration and environment) under which thermoregulatory fatigue is most likely to impact performance.

APPLY your understanding

The following information refers to questions 6–10.

Use the weblink **How do Olympic athletes learn to handle the heat?**, located in the Resources panel, to answer the following questions.

6. **List** the three common causes of hyperthermia in athletes.
7. **Explain** how hyperthermia changes the way our bodies generate energy.
8. **Outline** how hyperthermia reduces venous return.
9. **Explain** how acclimatisation exercises have improved an athlete's ability to reduce their core temperature.
10. Recent research indicates that milk may play an important role in hydration. **Discuss** this concept.

7.6 Exam questions

Question 1 (2 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.10;* © VCAA



A road cycling race began at midday and took an average of four hours and 50 minutes to complete. It was completed in 29 °C.

Explain one way in which the body regulates its temperature and the effect this has on performance.

Question 2 (3 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.11.a;* © VCAA

Thermoregulation is particularly important in warm climates as core body temperature increases.

Fatigue is more likely to occur when core body temperature reaches 40 °C.

Explain what occurs physiologically when a person's core body temperature increases.

Question 3 (6 marks)

Source: *ACHPER* 2020, *Trial Exam Units 3 & 4, Section B, Q.11;* © ACHPER

An international track and field competition was held in the Middle East in summer. Daytime temperatures during this competition often reached over 35 degrees Celsius and all events were held at night. The women's marathon event was held at midnight, the average temperature throughout the event was 30 degrees. The gold medallist in the marathon finished the event in 2 hours 32 minutes, 15 minutes slower than her personal best. Thirty of the seventy athletes who started the marathon event failed to finish.

The Women's 400 m hurdles final was at held at 10 pm and the temperature was 32 degrees Celcius. The gold medallist broke the world record in this event running a time of 52.16 seconds. All eight competitors who started the event finished.

With reference to the information provided and showing clear links to the primary energy system in each event, **analyse** the different causes of fatigue for these two events and **explain** why performances in the marathon were negatively impacted but the performances in the 400 m hurdles were not.

More exam questions are available in your learnON title.

7.7 Carbohydrate ingestion and protein

Key knowledge	Key skill
• nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery including carbohydrate ingestion, protein and water	• describe nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.7.1 Nutritional requirements of athletes

It is crucial for all athletes to consume a balance of nutrients to supply their body with the energy needed for physical activity when training, competing and to aid in recovery. Nutrition plays a key role in optimising the benefits for sports performance. Appropriate nutrition is vital for everyone and includes the types of foods we eat, the quantity we consume and the timing of when we consume it. It is essential that all athletes consume appropriate quantities of carbohydrates, fats, proteins, vitamins, minerals, water and fibre.

Athletes should have appropriate nutrition and hydration plans for before (pre), during and after (post) training and competition. Each of these timings has its own requirements and purpose, which will be explored in subtopics 7.8 and 7.9 of this topic.

7.7.2 Carbohydrates

Optimal ingestion of carbohydrates is essential to performance. As you will recall, this nutrient is the most preferred and readily available source of energy to fuel working muscles.

Carbohydrates serve many functions in the human body. They:
- are the major energy fuel source for most physical activities
- regulate the metabolism of fat and protein
- provide the energy for nervous system functioning.

Carbohydrates are broken down into glucose via digestion and absorbed into the bloodstream. The blood transports glucose to the liver and muscles, where it is stored as glycogen.

Carbohydrate ingestion

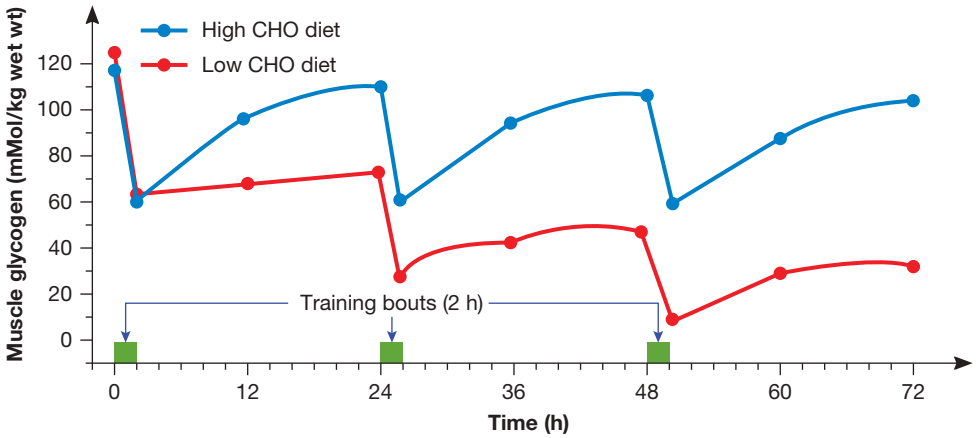
The amount of carbohydrate that an athlete consumes has a direct impact on the amount of muscle and liver glycogen available for training and competition. However, a delicate balance must be struck, because excess carbohydrate, beyond what the muscles and liver can store, is converted to fat, which can be detrimental to performance.

Figure 7.14 shows that athletes who consumed a high carbohydrate diet (70 per cent of their daily intake) were able to recover their muscle glycogen storage to nearly optimum levels prior to their next two-hour training bout. However, when the same athletes consumed a low carbohydrate diet (40 per cent of their daily intake), they experienced a cumulative decrease in muscle glycogen storage with each training bout.

The most important factor in relation to carbohydrate consumption is the number of grams ingested. For an athlete, the general guideline for daily refuelling is 7–10 grams of carbohydrates per kilogram of body mass.

Because of the importance of carbohydrate as the preferred fuel for providing energy, and the body's limited capacity to store carbohydrates as glycogen, an athlete's consumption of carbohydrates pre, during and post their performance has a major influence on their capacity to perform optimally, delay fatigue and improve recovery (see table 7.3).

FIGURE 7.14 The influence of different carbohydrate (CHO) diets on muscle glycogen stores during repeated days of training. (Adapted from Coston & Miller, 1980)



Carbohydrates can be divided into two groups:

- simple carbohydrates or sugars — metabolised by the digestive system quickly, providing an immediate release of energy (e.g. watermelon, jelly beans, sports/energy drinks, carbohydrate gels).
- complex carbohydrates or starches — metabolised by the digestive system slowly, providing a more gradual, sustained release of energy (e.g. pasta, wholegrain rice, yoghurt, porridge).

TABLE 7.3 A guide to carbohydrate intake for athletes

Timing	Purpose	Quantity
Pre-training/competition	• Optimise muscle and liver glycogen stores through consumption of primarily complex carbohydrates. • This is of particular importance for endurance events of 90 minutes or longer when glycogen depletion can be the main fatiguing factor. These athletes should use carbohydrate loading.	• A daily intake of 7–10 grams per kilogram of body mass for most athletes. • An increased ingestion of up to 10–12 grams for ultra-endurance events of 6 hours or longer.
During training/competition	• Consume simple carbohydrates that are digested and absorbed quickly to top up and maintain blood glucose levels as an immediate energy source. • Some evidence suggests that top-up fuelling is beneficial for events as short as 30 minutes, as the body preferentially uses glucose from the blood as it is a more accessible fuel source.	• Ingestion of 30–60 grams per hour in events of 1 hour or longer. • Practice during training to ensure palatability and gastric comfort.
Post-training/competition	• Replenish energy stores to optimise recovery in preparation for next session. • This should occur within the first 30–60 minutes post exercise, when the body is most receptive to converting glucose to glycogen.	• Ingestion of 1–1.5 grams per kilogram of body mass.

EXAM TIP

The quantities listed in table 7.3 are not required information for the exam. The focus of your study should be learning how nutritional and hydration strategies can enhance performance, delay fatigue and improve recovery.

Some research indicates that there is a potential disadvantage in consuming carbohydrates before exercise. Rebound hypoglycaemia is when a rise in blood insulin levels suppresses the use of fat as an energy supply and makes the muscles rely more on carbohydrate for fuel. If this happens, the result is that there will also be a drop in blood glucose levels in the initial stages of exercise. Based on this theory, there is some evidence to suggest that the pre-event meal should consist of complex carbohydrates, as they will prolong the use of glycogen stores and reduce the likelihood of rebound hypoglycaemia occurring.

It is important that athletes and coaches understand the different types of carbohydrates and how the body metabolises them.

Sports gels

Sports gels (see figure 7.15) are a highly concentrated source of carbohydrates with a honey- or syrup-like consistency. Due to their portable size and light weight, they are a practical way to 'top up' and maintain blood glucose levels during endurance exercise when glycogen stores deplete (see figure 7.16). Sports gels are also commonly used in prolonged intermittent sports such as tennis, where players will consume the gels with fluid as an immediate energy source. Sports gels can be used for post-exercise refuelling as well; however, food provides a more nutrient-dense option for recovery needs.

FIGURE 7.15 Sports gels are a convenient way for athletes to maintain adequate carbohydrate levels during an event.



FIGURE 7.16 Due to the prolonged, continuous nature of a 20 kilometer walk, athletes must consume carbohydrates to refuel during a race.



EXAM TIP

The first 30–60 minutes post exercise is vital for refuelling. This is when the body can most quickly replenish muscle and liver glycogen stores.

7.7.3 Protein

Protein gains more attention from athletes than any other nutrient, mostly because of the vital role it plays in muscle growth and repair (see figure 7.17). Both endurance and muscle-strengthening exercises stimulate **muscle protein synthesis**, making protein important for athletes who participate in these exercises.

muscle protein synthesis the process of producing new muscle protein to maintain and build muscle

Proteins can be classified as either structural or regulatory proteins, and they have several important functions in the body (see figure 7.18).

FIGURE 7.17 Foods such as meat, poultry, fish, eggs and dairy are rich in protein and contain all the essential amino acids. Plant foods such as breads, breakfast cereals, grains, lentils, beans and peas are good protein sources, but they miss at least one essential amino acid, so they should be eaten with other plant or animal protein sources. Protein is also available in formulated supplement drinks, bars and powders.

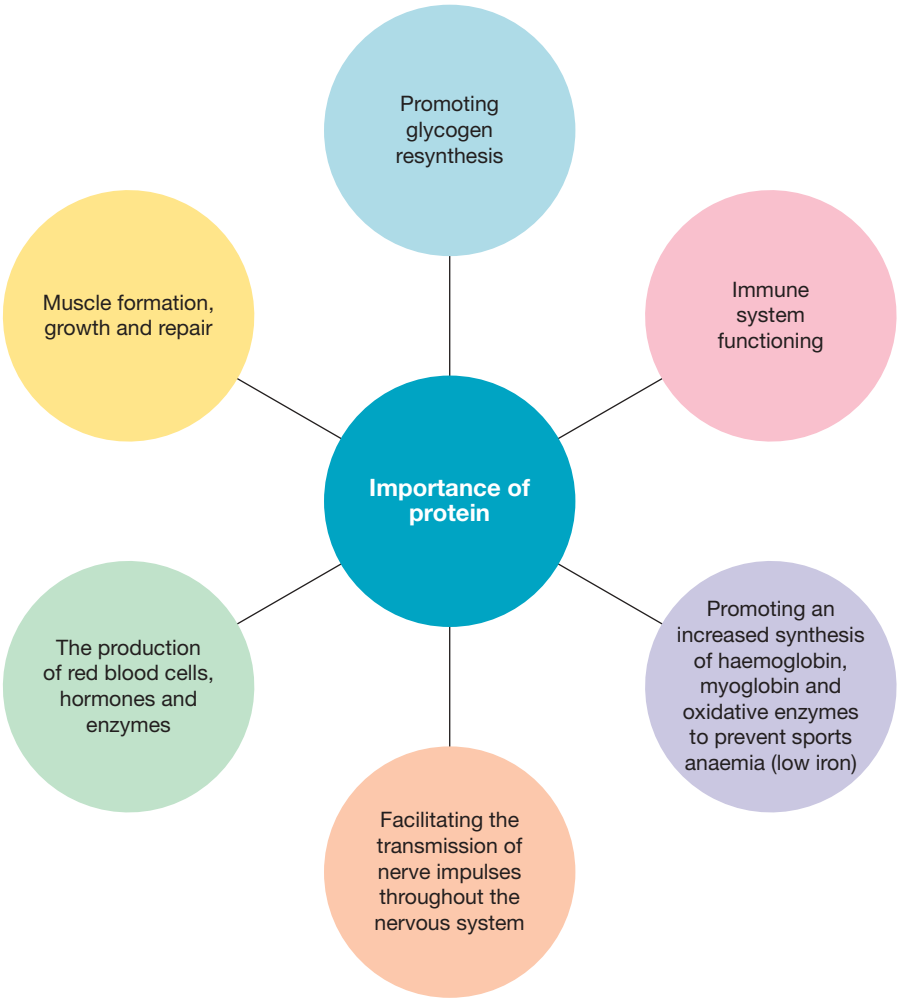


Protein ingestion

Nutritionists recommend that protein contributes up to 15 per cent of total daily food intake; however, strength and endurance athletes may require additional protein for the growth of muscle tissue because of their training. Most athletes can meet their daily protein requirement adequately through consuming a balanced diet. It has been found that additional amounts of protein are naturally ingested when the athlete increases their food intake in response to an increased training load. This is because many high-carbohydrate foods are also rich in protein; for example, bread, rice, pasta and baked beans. However, those who follow vegetarian or vegan diets or who do not consume dairy foods may have difficulty meeting protein requirements if meals are not well planned. A guideline of 1–2 grams of protein per kilogram of body mass is recommended, depending on the type of activity the athlete is participating in.

Research conducted at the Australian Institute of Sport (AIS) suggests that increasing protein intake does not necessarily lead to gains in lean-muscle tissue. Rather, it is the timing of the protein intake that matters for the athlete. Spreading consumption across the day creates multiple spikes in muscle protein synthesis, establishing a constant balance between protein breakdown and protein rebuilding in the muscles.

FIGURE 7.18 Protein has several important functions in the body.



It is also important that athletes consume foods that contain protein (amino acids) as part of their post-training or post-competition recovery process. This is because, following intense exercise, muscle protein is broken down because of micro-traumas from the demands of the exercise, creating a negative protein balance

Consumption of protein after exercise is essential for reversing this negative protein balance. Research suggests that there may be an anabolic window such that consuming protein within an hour post exercise has the greatest influence on skeletal muscle hypertrophy. That is, consuming protein during this window may enhance muscle uptake and retention of amino acids, helping to promote muscle gain and minimise muscle breakdown.

7.7.4 Protein and carbohydrates — accelerating the recovery process

Protein and carbohydrates make excellent partners for post-exercise nutrition. When consumed together, they stimulate a greater release of insulin. Specifically, the addition of protein amplifies the insulin response, promoting absorption and accelerating the recovery of muscle glycogen levels. This is an important consideration for endurance athletes who, in training and competition, regularly use a significant amount of their glycogen stores for ATP production.

Therefore, the consumption of protein with carbohydrates is essential on two fronts:

- to increase the absorption of carbohydrates, accelerating the replenishment of muscle glycogen stores
- to achieve faster muscle growth and repair.

Examples of healthy snacks that include both protein and carbohydrates:

- yoghurt
- milk drinks
- fruit smoothies
- lean meat or cheese sandwiches.

FIGURE 7.19 Foods that provide both protein and carbohydrates are ideal choices for post-exercise nutrition.



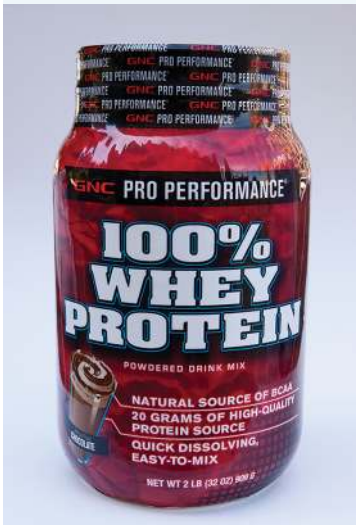
7.7.5 Protein supplementation

Protein and amino acids are popular nutritional supplements among athletes. From the previous section, we know that ingestion of protein with carbohydrates immediately post exercise enhances the synthesis of glycogen and stimulates muscle protein synthesis, which is important in terms of post-exercise recovery from catabolic microtrauma, and aids in muscle growth as part of the adaptive process.

Whether protein supplementation is required for an athlete is dependent on several factors relevant to the individual, including their training load and goals, sport and position, diet and budget. Athletes may require a supplement when consumption of food is difficult post exercise, such as when travelling on professional tours (i.e. tennis). In such cases, products such as protein powders (see figure 7.20), shakes and bars offer convenience and a practical solution to ensuring adequate protein consumption.

While supplements containing amino acids are popular among strength and endurance athletes, claims of their benefits remain unproven. It is important to note that excess proteins cannot be stored and are broken down and excreted. Further, large quantities may place a significant strain on the kidneys.

FIGURE 7.20 Whey protein is one popular nutritional supplement used by athletes.



on Resources

Weblinks Eat like an athlete
Protein intake for optimal muscle maintenance
Protein supplementation

EXAM TIP

Consuming protein and carbohydrates together aids absorption, which leads to faster replenishment of muscle glycogen, faster muscle repair and consequentially a faster recovery.

7.7 Activity

7.7 Quick quiz on | **7.7 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3	5	1, 4

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TEST your understanding

1. **Explain** why simple carbohydrates are more appropriate for use during competition.
2. **Identify** the optimal time for an athlete to consume protein post exercise. **Explain** why.
3. **Provide** an example of a snack that includes a balance of both protein and carbohydrates.

APPLY your understanding

4. Using the **Eat like an athlete** weblink in your Resources panel, listen to Michael Williams' ABC radio interview with Professor Louise Burke (Head of Sport Nutrition — AIS).
   a. **Explain** what Professor Burke means when she says that it is a team approach to the athlete's success.
   b. **Explain** what is meant by the theory of fat adaptation. What are the consequences for athletes in adopting this type of diet?
   c. **Outline** two important aspects about carbohydrates that Professor Burke discusses.
   d. **Describe** what she means by carbohydrates being 'more economical'.
   e. **Explain** why Professor Burke states that carbohydrates are important for high-intensity exercise.
   f. **Outline** why 'one size fits all' is a very simplistic approach to nutrition.
   g. **Explain** why it is important to take into account the training goals of an athlete and provide some specific examples as to different approaches to particular athlete diets.
   h. **Outline** how Professor Burke nutritionally prepares race walkers for their competition.
   i. **Discuss** Professor Burke's underlying principles for good nutrition.
5. **Create** a table summarising the nutritional needs of athletes (based on section 7.7). Include the following information:
   - transported as nutrient
   - stored as
   - common food sources.

7.7 Exam questions

Question 1 (3 marks)

Source: *VCE 2009, Physical Education Exam, Section B, Q.13.b;* © VCAA

Professional road cycling races, such as the Tour de France, last 21 days (approximately 1000 hours of competition) during which the cyclists must cover over 3500 kilometres. In some phases of the race, exercise intensity is high, as the cyclists must complete prolonged periods of exercise (e.g. time trials, high mountain ascents) at a high percentage of maximal oxygen uptake. Carbohydrates are required at each part of the race; the lead up to the race, cycling each day and during recovery. **Outline** the different roles that carbohydrates play at each part of the race.

Question 2 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.8;* © VCAA

The Ironman Triathlon consists of a 3.86 km swim, a 180.25 km bicycle ride and a 42.20 km marathon, raced in that order. Races generally last eight hours for world-class performers.

Explain, physiologically, why carbohydrates are beneficial for the athletes within the first 30 minutes of finishing the Ironman Triathlon.

Question 3 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.8;* © VCAA

The Ironman Triathlon consists of a 3.86 km swim, a 180.25 km bicycle ride and a 42.20 km marathon, raced in that order. Races generally last eight hours for world-class performers.

Suggest why an athlete would ingest protein in combination with carbohydrates after a race to aid recovery.

More exam questions are available in your learnON title.

7.8 Nutritional strategies

Key knowledge	Key skill
• nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery including carbohydrate ingestion, protein and water	• describe nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.8.1 Nutritional requirements of athletes

Each sport and athlete will have different nutritional requirements so no set dietary regime will cater for all athletes' individual needs. Athletes must develop their own individual eating plans to achieve maximum results from their training programs. Athletes require an appropriate nutrition plan for pre, during and post training or competition, as well as the specific nutritional requirements of the sport, which depend on:

- the frequency, duration and intensity of the training or competition (which can change daily)
- the athlete's individual energy expenditure, metabolism and current fitness status.

This will help to minimise fatigue, which is largely caused by an imbalance of energy, carbohydrate, protein and fat. More specifically, the following factors can cause nutrition-related fatigue in an athlete:

- depletion of glycogen stores
- hypoglycaemia (low blood glucose levels)
- dehydration
- low blood sodium levels
- iron deficiency
- gastrointestinal upset.

Athletes should follow a nutritional strategy specific to their training or competition needs and consume tried and tested foods and fluids that are tolerated well. Their strategy must include recovery meals as well as rehydration procedures.

7.8.2 Preparation

If athletes are adequately fuelled and hydrated prior to and during their event, then the recovery process is much faster. The ability of an athlete to recover quickly, so as to perform optimally during their next training session or competition, relies on them implementing effective nutritional and hydration recovery practices.

7.8.3 Short duration events

As fatigue is not usually caused by glycogen depletion during high-intensity sports that are shorter than 60 minutes, there is little need to fuel during the event (see figure 7.21); however, there is evidence to suggest that fuelling during events of 30 minute or more can be beneficial because it provides the brain with food — this feed-forward mechanism increases the rate of neural firing and thus aids in maintaining intensity and preventing fatigue. The athlete should ensure that glycogen stores are replenished post exercise so that the full storage of carbohydrate is available for the next training bout or performance.

Fluid replacement is another main concern and should match fluid loss. Water is adequate for hydration during short-duration activities; however, recent studies suggest that sports drinks, which contain carbohydrates and electrolytes such as sodium, may promote more effective rehydration by driving the thirst mechanism, while also increasing absorption and fluid retention. Electrolytes are essential minerals for body processes such as muscle contraction, hydration and regulating pH levels.

FIGURE 7.21 Athletes compete in the women's 200 metre final during the Tokyo 2020 Olympic Games. When competing in short-duration, high-intensity sports, athletes do not require increased carbohydrate consumption due to the low ATP yield needed in these events.



7.8.4 Submaximal endurance events

To maximise glycogen stores, endurance athletes competing in events lasting longer than 90 minutes — for example, marathons, road cycling, triathlons and cross-country skiing — need to consume additional carbohydrate before the event.

This process is known as carbohydrate loading and refers to an athlete increasing their carbohydrate intake and reducing (tapering) their training volume to maximise stores of muscle and liver glycogen. This delays glycogen depletion and enhances performance, as glycogen can resynthesie ATP at a faster rate than fats. Research indicates that the loading should take place in the 2–3 days prior to competition, where as much as 80 per cent of the diet should be carbohydrate. This can be achieved by consuming a mix of both simple and complex carbohydrates, depending on the athlete's preference. Carbohydrate loading attempts to prolong carbohydrates as the main fuel source and delay the body's reliance on fats as the primary fuel source, which slow the rate of ATP resynthesis and decrease the body's power output.

Well-trained endurance athletes are already at an advantage due to aerobic muscular adaptations that enable their muscles to store greater amounts of glycogen and to use it sparingly during aerobic exercise while maintaining the required exercise intensity. This training adaption, known as glycogen sparing, will be explored in topic 14.

on Resources

Weblink Carb loading for success: what you need to know

7.8.5 Intermittent sports

Intermittent or team sports can typically be fuelled by existing glycogen stores in most well-trained athletes without the need to implement carbohydrate loading. In contrast to continuous sports, team sports offer opportunities for athletes to rest, recover and refuel during break times when demand for ATP is low. Furthermore, as you will have discovered, different positions in team sports have different energy system requirements and players have different body compositions (see figure 7.22). Therefore, each player has varying nutritional needs. It is generally recommended to eat a main meal 3–4 hours before the start of a game. This meal should contain carbohydrate and protein, and be low in fat and fibre to minimise possible stomach discomfort.

FIGURE 7.22 Intermittent sports like Australian Rules football have different energy system requirements depending on the position the athlete plays. As a result, each player has varying nutritional needs before, during and after a game.



7.8.6 Refuelling during exercise

Sports lasting less than 90 minutes can be adequately fuelled by stored carbohydrate and fat without the need to replenish these fuels during the actual event. However, some level of fatigue may occur, and refuelling via drinks containing carbohydrate, such as sports drinks, is recommended.

Players of sports that last longer than 90 minutes will benefit from the consumption of carbohydrate (i.e. simple carbohydrate) during the activity. Carbohydrate consumption keeps blood glucose levels within 'normal' range, providing an immediate fuel source and delaying fatigue.

Sports Dietitians Australia recommends that athletes start refuelling early in the event and consume 30–60 grams of carbohydrates per hour to adequately refuel. Some examples of suitable foods that provide approximately 60 grams of carbohydrates for moderate or immediate release of energy include:

- two sports drinks (600 millilitres each)
- one jam or honey sandwich
- two bananas
- two carbohydrate gels
- 95 grams of jellybeans.

Combining refuelling of carbohydrate with fluid replacement is also sound practice for athletes. **Carbohydration**, as the practice is known, meets the refuelling requirements outlined above, and at the same time replaces any fluids lost through sweat. Commercially available sports drinks, such as Gatorade and Powerade, promote both rehydration and the replenishment of fuels. Athletes should strive to replace approximately 250 millilitres (1 cup) of fluid every 15 minutes, although individual variations and environmental conditions must also be catered for (see table 7.4).

carbohydration combining hydration and refuelling at the same time

TABLE 7.4 Suggested refuelling during exercise

Type of exercise	Refuelling suggestions
Intermittent sports	• Recent studies have found that athletes in intermittent team sports may benefit from consuming carbohydrates during the game. This decreases the perception of fatigue, prevents low blood glucose levels and promotes glycogen sparing. • Hydration must also be addressed throughout the game.
Endurance events > 90 minutes	• As there is a limited supply of glycogen within the muscles or liver, carbohydrate refuelling is advised at a rate of approximately 30–60 grams per hour. • Sports drinks, bananas, carbohydrate gels, sports bars or sugar confectionery such as jellybeans are recommended for consumption during endurance events to refuel. • Athletes can choose which foods are most comfortable to ingest while competing. They just need to be quickly digested and absorbed so as to top up and maintain blood glucose levels as an immediate energy source. • Hydration must also be addressed throughout the event.
Ultra-endurance events > 4 hours	• Typically, ultra-endurance athletes compete at a lower intensity than those in team sports or shorter-distance events. • This allows more effective digestion to take place while competing, so the athlete can consume small amounts of solid foods (see figure 7.22). • High-carbohydrate foods, in conjunction with small amounts of protein and fat, are recommended for ultra-endurance athletes. • Muesli bars, sports or breakfast bars and jam sandwiches are a good choice for ingestion during performance. • Hydration must also be addressed throughout the event.

Note: Some evidence suggests that top-up fuelling is beneficial for events as short as 30 minutes, as the body preferentially uses glucose from the blood due to it being a more accessible fuel source.

FIGURE 7.23 Mark Cavendish at the start line for the 160.6-kilometre stage 6 of the Tour de France, 2021. Riders consume a variety of carbohydrate snacks during the event to maintain their blood glucose levels as an immediate energy source.



7.8.7 Nutritional recovery from exercise

The importance of carbohydrate and protein consumption post-exercise has been discussed earlier in this topic. The post-exercise period is considered the most critical part of nutrient timing. The main points for consideration for post-exercise nutrition include:

- Muscle and liver glycogen stores need to be replenished as quickly as possible
- Ingestion of carbohydrates should occur within the first 30–60 minutes post exercise when the body is most receptive to converting glucose to glycogen.
- Most athletes should ingest 1–1.5 grams of carbohydrate per kilogram of body mass. This can be as a main meal or a snack.
- Consuming the recommended amount of nutrients post exercise enhances recovery from catabolic muscle microtrauma and restores energy reserves.
- During the first couple of hours following exercise, the muscle is more receptive to restoring greater amounts of carbohydrate.
- Initially consuming simple carbohydrates will allow for the faster absorption and resynthesis of glycogen in the muscle and liver.
- A high carbohydrate diet should be maintained in the 4–6 hours following exercise to further enhance glycogen resynthesis.
- The consumption of both carbohydrate and protein post-exercise will enhance the nutritional recovery process due to the increased presence of insulin, which stimulates muscle growth and the uptake of glycogen into the muscle cells.
- Appropriate post-exercise nutrition supports the immune system.

Combining carbohydrates and protein for enhanced recovery

- Carbohydrates provide a source of glucose in the blood for the recovery of fuel stores, whereas protein provides a source of amino acids for the repair of catabolic microtrauma within the muscle cells.
- These two macronutrients work together to make the recovery process faster.
- Glucose and amino acids together stimulate the production of insulin, which in turn acts as a very powerful anabolic hormone to increase the uptake of amino acids and enhance muscle recovery and growth.
- The combination of a quick-absorbing carbohydrate and a fast-digesting protein (whey protein) is the best recovery combination.
- A protein–carbohydrate snack after exercise allows for faster muscle repair and anabolic adaptation to training, as well as the restoration of muscle glycogen levels.

7.8.8 Recovery nutrition to support the immune system

Intensive training causes the suppression of the immune system, and this continues in the hours following the training or exercise bout. During this time, athletes have a greater susceptibility to illness. Therefore, it is important to consume adequate levels of micronutrients, including vitamin C and E, glutamine, zinc and probiotics. Further, carbohydrates reduce the stress hormone response and supply fuel to the immune system white cells. This is another reason it is essential to consume adequate carbohydrates before, during and after prolonged or high-intensity intermittent exercise.

doc-41959

PRACTICAL ACTIVITY Interview

Goal

To interview a professional or semi-professional athlete to learn:

- if they follow a specific dietary plan for training, competition and/or recovery
- how it is designed to reduce fatigue and enhance their level of performance and recovery.

Instructions

1. Contact a professional or semi-professional athlete that you would like to interview. If this isn't possible, you can interview an aspiring junior athlete from a local club or school. When arranging the interview, tell them the reason for the interview, how it will be conducted (video recording, voice recording, note taking) and how long you will need.
2. Prepare for the interview by designing a set of questions to ask the athlete. You can use the questions below to help you. Send the questions to the interviee before the interview, so they can prepare.
3. Interview the athlete and collect the information.

Primary data/Reflection

- How did you feel the interview went?
- Were there any questions that you would like to have asked to gain a better understanding of the athlete's dietary plan?
- Were you surprised by any of the responses the athlete provided? Explain why.
- What challenges do you think the athlete might have adhering to their dietary plan?

Questions

1. Describe a typical daily menu or meal plan from the athlete's dietary plan.
2. Assess their current dietary plan. Determine whether this dietary plan is satisfactory for optimum performance in their sport and for their recovery from training and competition.
3. What hydration requirements does this athlete have?
4. What modifications or suggestions would you make to improve their dietary plan?
5. How does the athlete monitor their dietary progress and adjust their dietary plan accordingly?

on Resources

Weblinks Sports drinks — Sports Dietitians Australia (SDA)
Sports diet

7.8 Activity

7.8 Quick quiz on | **7.8 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 5	2, 4, 6	3, 7

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TEST your understanding

1. **List** three factors that can cause nutrition-related fatigue in an athlete.
2. **Discuss** why carbohydrate stores should be replenished post exercise.
3. **Explain** why sports drinks may promote more effective hydration.
4. **Discuss** how carbohydrate loading can improve performance in endurance sports.
5. **Outline** the role of carbohydrates in supporting the immune system during recovery.

APPLY your understanding

6. The modern pentathlon is an Olympic sport that consists of five different events: fencing, 200 metres freestyle swimming, show jumping, pistol shooting and a 3200-metre cross-country run. All events are completed in one day. **Consider** the specific recovery nutritional strategies Chloe Esposito may have used to perform at her optimum and win gold at the Rio 2016 Olympic Games.

FIGURE 7.24 Chloe Esposito won gold for Australia in the modern pentathlon at the Rio Olympic Games in 2016.



7. Select two different sports from the range of fact sheets listed on the **Sports diet** weblink in your Resources panel, providing information on nutritional recommendations.
   Research the nutritional needs of both of the sports selected by investigating the following:
   - energy system requirements of the sport
   - fuel needs
   - fluid needs
   - pre-event requirements
   - during the event requirements
   - recovery needs
   - other hydration or nutrition tips.

   Present your findings to the class in the form of two case studies.

7.8 Exam questions

Question 1 (11 marks)

Lucy is training as a part of the women's eight rowing crew. Her training day typically consists of the following:

- Morning, water session — 90 min/17–20 km long steady-state rowing
- Afternoon, dry land — rowing ergometer 4 × 25 min or 3 × 7 km, medium to high intensity
- Once a week, she performs a test ergometer — 30 min max or 5 km max
- 3 × week, she also undertakes resistance training.

Lucy's meal plan is listed in the table below.

Meal	Sample menu
Pre-workout (5:30 am)	1 apple + 2 tbsp peanut butter
Post-workout (9:00 am)	1 cup muesli + 1 banana + 1 tbsp honey + 1 plain greek yogurt + 1 small cup peanut butter + 1 tbsp sliced almonds
Pre-workout (1:00 pm)	2 whole eggs + 57 g smoked salmon + 1 whole wheat english muffin + 1 orange
Lunch (3:00 pm)	1 smoothie + ¾ cup cooked rice + 2 cups cooked broccoli + 1 small avocado + 4 oz chicken
Dinner (7:00 pm)	1 large green salad w/ 2 tbsp balsamic vinegar + 2 tbsp olive oil + 5 oz salmon + 1 cup acorn squash + 2 dark chocolate squares + 1 small plain greek yogurt + ½ cup raspberries

a. **Identify** one food source rich in carbohydrate. **(1 mark)**
b. **Identify** one food source rich in protein. **(1 mark)**
c. **Outline** the role of protein in recovery. **(2 marks)**
d. Research suggests that combining carbohydrate and protein post-exercise will enhance the recovery process. **Identify** the recommended ratio and **discuss** how combining the two macronutrients assists in the recovery process. **(4 marks)**
e. An athlete undertaking an intense training program may be more susceptible to illness. **Explain** why this may be the case and **outline** how carbohydrates may help to reduce the risk. **(3 marks)**

More exam questions are available in your learnON title.

7.9 Hydration needs of athletes

Key knowledge	Key skill
• nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery including carbohydrate ingestion, protein and water	• describe nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.9.1 Dehydration

Our bodies are made up of approximately 60 per cent water, and water has many important functions within our bodies, including:

- transportation of energy, waste, hormones and antibodies
- dilution of waste products
- lubrication of surfaces and membranes
- helping to regulate body temperature
- involvement in all of the chemical reactions in the body.

dehydration the loss of too much fluid from the body

During exercise, to help us regulate our body temperature, we produce sweat and lose water through evaporation on our skin. (The water we lose through sweat comes from blood plasma.) If this water is not replaced, we can become dehydrated. **Dehydration** is the result of thermoregulatory fatigue and results in a reduced blood volume, making delivery of oxygen to working muscles more challenging. This can result in the rapid onset of fatigue and in some cases can lead to life-threatening problems such as kidney failure.

Quantitatively, dehydration is defined as a body fluid deficit of more than 2 per cent of body mass. Hydration needs are highly individual, with factors such as genetics, body weight, weather conditions and exercise intensity influencing sweat rates. It is important for athletes to develop individual fluid intake practices before, during and after training or competition to ensure their fluid intake compensates for sweat lost during exercise. These practices should be well rehearsed to ensure they accommodate for **gastrointestinal tolerance**.

gastrointestinal tolerance the ability to digest or fully metabolise a food/drink

7.9.2 How much fluid is needed?

Sports dietitians suggest that athletes adhere to the following guidelines:

Timing	Hydration guidelines
Pre-training/competition	• Consume approximately 200–600 millilitres of fluid, preferably water. • Begin exercise hydrated to lower the risk of becoming dehydrated during exercise. • Begin drinking early in exercise and consume small volumes (250 millilitres or 1 cup) every 15 minutes.
During training/competition	• Replace approximately 250 millilitres (1 cup) of fluid every 15 minutes. This can be challenging in sports that offer few opportunities to replace fluid. • Water intake can enhance performance by maintaining a stable body temperature, enabling the body to perform the processes involved in producing energy. It can also help to reduce the impact of thermoregulatory fatigue (see figure 7.25).
Post-training/competition	• The amount of fluid needed post-exercise to fully rehydrate is approximately 150 per cent of your body fluid loss. For example, a 1 kilogram loss in body weight roughly equals a 1 litre loss of fluid, so you would need to consume 1.5 litres of fluid to rehydrate adequately. • The priority is to return the body to pre-exercise fluid levels.

FIGURE 7.25 Triathletes passing through a water station in the final leg of the event.



7.9.3 Estimating sweat rate and fluid loss

In endurance exercise completed in hot and/or humid conditions, as much as 6 litres, or the equivalent of 3–4 kilograms of body weight, can be lost through sweat and other mechanisms. It is a good idea for an athlete to gain an understanding of their sweat rates by weighing themselves pre and post-exercise (see figure 7.26) so that the most appropriate hydration strategies can be followed to achieve optimum performance. The amount of fluid needed post-exercise to fully rehydrate is approximately 150% of your body fluid loss. For example, a 1 kilogram loss in body weight roughly equals a 1 litre loss of fluid, so you would need to consume 1.5 litres of fluid to rehydrate adequately. While it is very challenging in some events/sports to drink enough to prevent loss of body weight, the amount of weight loss should be limited to less than 2 per cent of body weight so as not to decrease performance.

FIGURE 7.26 One of the reasons F1 drivers weigh themselves before and after a race is to determine how much weight they have lost from sweat because of the high temperatures in the car.



7.9.4 The role of electrolytes and sports drinks

While water itself is a suitable fluid replacement and is a good choice for sports lasting less than 60 minutes, it is not always the most efficient means of rehydration, especially if fluid losses have been high. In these instances, athletes should consider the use of electrolytes and sports drinks in their rehydration plan.

During sweating, the body loses both water and some electrolytes, such as sodium (Na^+). Electrolytes are used by muscle, nerve and cardiac cells to maintain voltages across their membranes and to allow electrical messages to flow across them. Electrolytes reduce urine output, enable fluid to empty quickly from the stomach, promote absorption from the intestine and encourage fluid retention. Consumption of electrolytes also helps to avoid the risk of hyponatremia, a potentially fatal condition that can be caused by drinking too much ordinary water.

Electrolyte supplements can be used during and post exercise to assist retention of fluid, accelerating the rehydration process (see figure 7.27). If an electrolyte supplement is not available, consuming salty foods that contain carbohydrate (glucose), such as cereal and bread, alongside ordinary water can be an effective alternative.

FIGURE 7.27 Sports drinks rehydrate, replace electrolytes and refuel carbohydrates.



Sports drinks can be used during and post exercise where both fuelling (carbohydrates) and hydration are required (see figure 7.28). Studies have shown that fluid intake increases when drinks are cool, flavoured and contain sodium. However, the higher the carbohydrate levels in drinks, the slower the rate of stomach emptying, so ensuring the product contains adequate water is important. The body may take between 4 and 24 hours to completely rehydrate, depending on the exercise that was undertaken.

It has also been found that when consumed with food, 'water, sports drinks and milk-based products are equally effective at replacing lost fluid. Without food, milk-based products typically restore fluid faster than sports drinks' (Sports Dietitians Australia).

FIGURE 7.28 Gatorade and Lucozade are two of the sports drinks on the market.



Sports Dietitians Australia outlines the following practical applications for consuming sports drinks.

Before exercise

Consuming sports drinks prior to physical activity can help optimise hydration and energy (carbohydrate) levels. The carbohydrates present in these drinks can enhance the availability of energy sources, and the sodium can help diminish urinary output before exercise.

During exercise

Sports drinks are ideally formulated for consumption during physical activities that extend beyond 90 minutes, ensuring ideal hydration and energy supply. These drinks can enhance an athlete's endurance and efficiency in both practice and competitive settings by supplying vital energy to active muscles and the brain.

Recovery

Sports drinks can help replenish fluids and electrolytes depleted through perspiration and restoring glycogen stores. When the interval between workout sessions or competitions is brief, opting for drinks with a greater sodium concentration can speed up the rehydration phase. It's important to combine sports drinks with a balanced intake of foods and liquids that supply sufficient carbohydrates, proteins, and other vital nutrients, in order to achieve full recovery.

Sports drinks and adolescents

For the active adolescent, the use of sports drinks in place of water on the sports field or as a general beverage is not necessary and may lead to excessive caloric consumption. For competitive adolescent athletes, consuming sports drinks during prolonged submaximal and intermittent maximal exercise, or milk during recovery, can be beneficial by providing carbohydrate, fluid, electrolytes and protein (in the case of milk). It is important to note that sports drinks are not the same as caffeinated energy drinks, and adolescent athletes should not be encouraged to consume energy drinks around sporting activities.

CASE STUDY

Are sports drinks better than water when exercising?

Sometimes, it depends on the individual situation.

Should you take a bottle of sports drink down to the gym when you do that hour's aerobics class? Will you feel ill effects without it? And what about that Saturday soccer game?

Well, whether you would benefit from consuming a sports drink depends on the events you are taking part in and your goals, says Professor Louise Burke of the Australian Institute of Sport.

Sports drinks typically contain water and electrolytes (usually sodium and potassium) for rehydration, and carbohydrates (as sugars) for energy.

They were invented in the 1960s to replenish fluid and provide extra fuel for intense sporting activity of a long duration (more than 90 minutes).

'If you're in the gym pedalling to lose weight while you read a magazine, then you don't need a sports drink, just drink water,' says Burke, who runs the nutrition program for the elite athletes at the institute.

Professor Clare Collins, a spokesperson for the Dietitians Association of Australia, agrees, saying sports drinks are for serious athletes only.

'For ordinary people who play soccer on a Saturday, there's no need for them because their fluid requirements can be met by water and generally you're not sweating enough to lose excessive amounts of electrolytes.'

Do you need the carbs?

But what if you do consider yourself a committed athlete and you're taking part in a marathon or triathlon event?

Well, Burke says the carbs in sports drinks can be helpful if you are aiming for a personal best, or taking part in a competition you really must win.

'From the physiological point of view, there's a benefit in having carbs for sustained intense exercise of over 90 minutes,' says Burke — who declares the AIS receives a sponsorship from a sports drink manufacturer.

This is because when we start exercising, our muscles initially use their stores of carbohydrate for fuel, but these stores become depleted after about 90 minutes.

Our muscles then start to become more reliant on fat burning for fuel. This isn't as efficient as burning carbohydrates, so our pace is slowed.

'The intake of worthwhile amounts of carbohydrate from a source during exercise, such as a sports drink, will provide an alternative or additional source of fuel to allow carbohydrate to continue to be 'burned' at the higher levels needed to sustain the athlete's optimal pace,' Burke explains.

The carbs can also have a motivational effect even in shorter workouts, says Burke.

'Experiments have shown that just swilling a sports drink around your mouth and then spitting it out can make athletes perform better.' The brain seems to become more motivated with just the promise of carbs.

Don't forget the sugar

But if a sports drink can help a serious athlete, why shouldn't we all use them?

Well, the problem is the carbohydrates (usually sugars) in the drink: one litre containing 60 grams of carbs equates to 960 kilojoules.

'We want people to be aware of the kilojoules they contain,' says Collins.

'If you are exercising to lose weight, then drinking a sports drink could mean you need to spend another 30 minutes or more in the gym.'

The American Academy of Pediatrics recently expressed concern about the carbohydrates in sports drinks, saying: 'Frequent or excessive intake of caloric sports drinks can substantially increase the risk for overweight or obesity in children and adolescents.'

We should also be mindful of their effects on our teeth. Both Burke and Collins warn that, like all sugary acidic beverages, sports drinks contribute to dental erosion, so it's important to consider this in your overall dental care regime.

Lastly, don't confuse sports drinks with energy drinks. These often contain more carbohydrates than sports drinks as well as stimulants like caffeine.

So, when you're deciding whether to choose water or a sports drink, here are some guidelines.

Use water:

- when exercising to lose weight
- when exercising for an hour or less.

Consider using a sports drink:

- for fuel when doing intense sustained exercise for 90 minutes or more. You need at least 30 g carbs/hour.
- when the outcome of a competition is important to you and you need to perform at your best. Using small amounts every 10–15 minutes can make you feel like working harder.

Professor Louise Burke of the Australian Institute of Sport and Professor Clare Collins of the Dietitians Association of Australia spoke to Clare Pain.

Source: www.abc.net.au

7.9.5 Is milk an effective rehydration strategy?

Milk provides the body with a source of water, carbohydrate, fat, protein and sodium. Several studies show that milk is as effective as, or better than, sports drinks or water for rehydration. The extensive variety in flavour, texture and taste of milk may also make rehydrating more enjoyable and enhance rehydration.

Key findings of studies on the effectiveness of milk as a rehydration strategy include:

- less urine is produced (i.e. there is greater fluid retention) when milk is consumed compared to water or sports drinks
- milk contributes to post-exercise glycogen resynthesis
- milk has a higher energy density than both water and sports drinks. This results in rehydration over a longer period as there is a slower emptying of fluid from the stomach.

7.9 Activity

7.9 Quick quiz on | **7.9 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4	6	3, 5, 7, 8

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TEST your understanding

1. **Identify** three functions of water in the human body.
2. **Identify** the factors that influence the sweat rate of an athlete.
3. **Explain** why fluid intake strategies should be practiced before they are used in competition.
4. As a general guideline, **state** how much fluid sports dietitians recommend an athlete consume before, during and after an exercise session.

APPLY your understanding

5. **Explain** why sports drinks are sometimes the preferred source of rehydration in comparison to water.
6. For each of the following people, **suggest** what type of hydration would be best.
   a. A mum who walks for 30 minutes with a pram around the local creek to maintain her weight and fitness.
   b. A local footballer who goes to the gym four times a week to work on his strength and power via a weights program.
   c. An elite netballer who trains five times a week, completing individual cardio sessions (i.e. running) or specified team training sessions. She also plays competitively once a week.
   d. A weightlifter who trains every day but needs to monitor their weight prior to competition.
   e. A road cyclist competing in a multi-day event consisting of approximately 100 kilometres each day.
7. Read the article 'Are sports drinks better than water when exercising?' and answer the following questions.
   a. **Explain** why sports drinks were originally invented.
   b. **Describe** the types of activities where water is the recommended hydration method.
   c. **Describe** the types of activities where sports drinks are the recommended hydration method.
   d. **Discuss** how sports drinks can have a motivational effect on an athlete's performance.
   e. **Explain** why sports drinks are not recommended for the average person.
9. Visit a supermarket or visit their online shop and look at the range of sports drinks and energy drinks available.
   a. **Record** the available sports drinks.
   b. **Analyse** these products in terms of their use during and post exercise and any claimed benefits of each drink.
   c. **Present** your findings as a written report.

7.9 Exam questions

Question 1 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.10;* © VCAA

During a soccer match, soccer referees cover significant ground to be able to best adjudicate the game. Following a soccer game in 33 °C heat, soccer referees undertake a rehydration protocol of 1.5 L of rehydration fluid per 1 kg of body weight lost.

a. With reference to blood plasma, **explain** the benefit of this rehydration protocol for soccer referees. **(2 marks)**
b. **Discuss** the benefit of including carbohydrates in the rehydration fluid for soccer referees. **(2 marks)**

Question 2 (2 marks)

Marathon runners will train daily for up to 2–3 hours of continuous exercise per session. **Describe** how effective rehydration would enhance the athlete's training performance.

More exam questions are available in your learnON title.

7.10 Key skills

Key skills

- explain the muscular fatigue mechanisms associated with the use of the 3 energy systems and the individual and environmental factors that influence fatigue under various intensities and durations
- describe nutritional and hydration strategies used to enhance performance, delay fatigue and improve recovery

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

7.10.1 Tell me

To address these key skills, it is important to remember:

- fatigue reduces the body's ability to sustain a given level of intensity, which results in the working muscles producing less rapid and forceful contractions and the athlete experiencing a decline in performance
- **fat**iguing factors include **f**uel depletion, the **a**ccumulation of metabolic by-products and **t**hermoregulatory fatigue

- the lactate inflection point plays an important role in performance; it is the last point where lactate entry into and removal from the blood are balanced
- when effectively used, nutrition and hydration strategies can enhance performance, delay fatigue and accelerate recovery
- the most suitable nutrition and hydration strategies differ for each athlete and sport, depending on a variety of factors
- carbohydrates, protein and hydration, before, during and after exercise, play a role in performance, fatigue and recovery
- certain foods and fluids are better able to enhance performance and recovery.

7.10.2 Show me

Practice question (3 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *VCE 2013 Physical Education Exam, Section B, Q.8.b;* © VCAA

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
Total	42.195 km	3:37:51



Explain why it is important for Brett to be *adequately* hydrated *prior* to running a *marathon*. (3 marks)

Decode the question

Strategies to decode the question

- **Identify the action word:**
  Explain — provide detail to show the relationship between adequately hydrating and performance in a marathon
- **Key terminology** — *marathon*, *adequately*, *prior*
- **Key concept** — hydration
- **Marking scheme** — 3 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

If Brett *commences* the run *sufficiently* hydrated, he is better able to maintain body fluid and manage sweat losses throughout the run. Therefore, he is at less risk of thermoregulatory fatigue or dehydration. Blood plasma would not be *significantly reduced* and more oxygen could be delivered to the working muscles for the production of aerobic ATP, assisting Brett to run the marathon at a higher aerobic intensity.

Award 1 mark for discussing the importance of being appropriately hydrated prior to the race.

Award 1 mark for identifying that being hydrated delays fatigue.

Award 1 mark for explaining how being hydrated links to performance in a marathon.

7.10.3 Let me do it

Question 1 (3 marks)

In the round robin stage of a Summer Olympic hockey tournament, teams play a total of five games with as little as 24 hours break between matches. **Describe** the importance of adequate post-match hydration during this tournament and **recommend** a suitable strategy to achieve this.

7.11 Review

Hey students! Now that it's time to revise this topic, go online to:

Review your results

Watch teacher-led videos

Practise exam questions

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7.11.1 Summary

Introduction to fatigue

- Fatigue can be defined as an exercise-induced reduction in the ability of muscles to produce forceful and rapid contractions.
- Fatigue is multifactorial in that it involves or is dependent on several factors or causes.
- The causal mechanisms of fatigue depend on the type, duration, intensity and environment in which the exercise is being performed, as well as other factors such as the fitness and training status of the athlete and their nutritional state.

Fuel depletion

- Fuel depletion refers to the depletion of energy fuels that, through their breakdown, allow ATP resynthesis to occur.
- The types of fuel depletion experienced within the muscle cells include CP depletion and glycogen depletion.
- The depletion of CP is most significant in maximal efforts of short duration and results in the anaerobic glycolysis system becoming the primary supplier of ATP for maximal efforts. This system produces ATP at a slower rate, reducing exercise intensity.
- Glycogen depletion occurs during prolonged endurance exercise, and results in an increased reliance on fat (plasma free fatty acid and muscle triglycerides) metabolism. This reduces an individual's exercise intensity because fats are a more complex molecule that takes longer, and requires more oxygen, to break down. It thus produces ATP aerobically at a slower rate than glycogen.

Accumulation of metabolic by-products

- Metabolic by-products are substances produced as a result of chemical reactions within the body associated with the production of energy for ATP resynthesis. These by-products include lactate, hydrogen ions (H^+), inorganic phosphate (Pi) and adenosine diphosphate (ADP).
- When exercising at high intensities, metabolic by-products will accumulate, slowing the rate of ATP production and decreasing the force and velocity of muscular contractions.

Blood lactate and performance

- Lactate is formed in the cytoplasm of muscle cells when, in the absence of oxygen, a pyruvate molecule is not transferred into the mitochondria. In this scenario, an enzyme converts pyruvate into lactic acid which quickly dissociates (splits) into lactate and hydrogen ions (H^+).
- Lactate inflection point (LIP) represents the last point at which lactate entry into and removal from the blood are balanced.
- LIP establishes the highest intensity of aerobic exercise an athlete can sustain without the rapid onset of fatigue occurring from the accumulation of metabolic by-products.

Thermoregulatory fatigue

- Heat, generated as a by-product of aerobic metabolism, increases core body temperature. In response, the body redistributes blood to the skin via vasodilation and away from the muscles via vasoconstriction, in an attempt to cool the body through radiation and the evaporation of sweat from the skin's surface.
- This redistribution of blood decreases blood flow to the working muscles, reducing the available oxygen for aerobic ATP production, causing the athlete to reduce their exercise intensity.

Carbohydrate ingestion and protein

- The essential nutrients that are required by all athletes include carbohydrates, fats, proteins, vitamins, minerals, water and fibre.
- Athletes need to consider appropriate nutrition and hydration plans for before, during and after training/competition.
- Because of the importance of carbohydrate as the preferred fuel for providing energy, and the body's limited capacity to store carbohydrates as glycogen, an athlete's consumption of carbohydrates before, during and after their performance has a major influence on their capacity to perform optimally, delay fatigue and improve recovery.
- Simple carbohydrates or sugars that are metabolised by the digestive system quickly (e.g. watermelon, jellybeans, sports/energy drinks and carbohydrate gels) provide an immediate release of energy.
- Complex carbohydrates or starches that are metabolised by the digestive system slowly (e.g. pasta, wholegrain rice, yoghurt and porridge) provide a more gradual, sustained release of energy.
- Pre-training/competition, the priority is to optimise muscle and liver glycogen stores through consumption of primarily complex carbohydrates.
- During training/competition, the priority is to consume simple carbohydrates that are digested and absorbed quickly in order to top up and maintain blood glucose levels as an immediate energy source.
- Post-training, the priority is to replenish energy stores within the first 30–60 minutes post exercise to optimise recovery in preparation for the next session.
- Protein is required to assist in the recovery or repair of damaged body tissue post exercise.
- The timing of protein consumption is an important consideration for the athlete, Within an hour post exercise has been shown to be optimal.
- The consumption of both carbohydrates and protein together results in faster replenishment of muscle glycogen stores and quicker muscle growth and repair. This makes the recovery process faster.

Nutritional strategies

- Each sport and athlete have different nutritional requirements; no set dietary regime will cater for all athletes' individual needs.
- The following factors can cause nutrition-related fatigue in an athlete: depletion of glycogen stores, hypoglycaemia (low blood glucose levels), dehydration, low blood sodium levels, iron deficiency and gastrointestinal upset.
- If athletes are adequately fuelled and hydrated prior to and during their event, then the recovery process is much faster.
- Carbohydrate loading is a strategy that involves increasing carbohydrate intake and reducing (tapering) training volume prior to endurance competitions to maximise stores of muscle and liver glycogen and delay glycogen depletion.
- Athletes should undertake a nutritional strategy specific to their training or competition needs. The following event categories may be helpful: short duration, submaximal endurance, intermittent sports.
- Players of sports that last longer than 90 minutes may benefit from the consumption of carbohydrate during the activity. Simple carbohydrates are best for this.
- The post-exercise period is considered the most critical part of nutrient timing. Carbohydrates should be ingested within the first 30–60 minutes post exercise when the body is most receptive to converting glucose to glycogen.

Hydration needs of athletes

- It is important that athletes develop individual fluid intake practices before, during and after training/competition to ensure their fluid intake compensates for sweat lost during exercise.
- Fluid loss can lead to a decline in performance. It is important to consume fluid before, during (if applicable) and after exercise.
- Most athletes should consume approximately 200–600 millilitres of fluid prior to their event, and replace approximately 250 millilitres (1 cup) every 15 minutes during the actual event. The amount of fluid needed post-exercise to fully rehydrate is approximately 150 per cent of your body fluid loss.
- Water is suitable for short-duration events lasting less than 60 minutes; sports drinks are better for longer events.
- Water intake can enhance performance by maintaining a stable body temperature, which enables the body to adequately perform the processes involved in producing energy. It can also help to reduce the impact of thermoregulatory fatigue.
- Sports drinks rehydrate, replace electrolytes and refuel carbohydrates. They can be used during and post exercise where rehydration as well as fuelling (carbohydrates) are a priority.
- Sports drinks can actually speed up the process of absorption (gastric emptying) and the retention of water in the body.
- Electrolytes reduce urine output, enable fluid to empty quickly from the stomach, promote absorption from the intestine and encourage fluid retention.
- Milk-based products are also effective for rehydration. They promote fluid retention, enable rehydration over a longer period and contribute to glycogen resynthesis.

7.11.2 Key terms

carbohydrate loading a nutritional strategy in which muscle glycogen stores are maximised prior to endurance events
carbohydration combining hydration and refuelling at the same time
dehydration the loss of too much fluid from the body
fatigue an exercise-induced reduction in the ability of muscles to produce force or power
gastrointestinal tolerance the ability to digest or fully metabolise a food/drink
hitting the wall a term used in endurance sports to describe the sudden feeling of extreme fatigue associated with the depletion of glycogen stores in the muscle and liver
homeostasis the ability of the body to maintain a stable internal environment
hyperthermia high body temperature caused by a failure of the heat-regulating mechanisms of the body
hypoglycaemia when blood sugar levels have dropped too low due to prolonged strenuous activity and depleted glycogen stores
intermittent short periods of work followed by a period of rest
lactate inflection point the last point where lactate entry into and removal from the blood are balanced
metabolic by-product a substance produced because of chemical reactions within the body associated with the production of energy for ATP resynthesis
multifactorial involves or is dependent on several factors or causes
muscle protein synthesis the process of producing new muscle protein to maintain and build muscle
pH a measure of the acidity or alkalinity of a substance
thermoregulation the processes the body uses to maintain its core internal temperature
type 1 slow-twitch oxidative fibres contain large and numerous mitochondria, high levels of myoglobin and a high capillary density. They are very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolism
vasoconstriction the process whereby blood vessels narrow their internal diameter to reduce blood flow
vasodilation the process whereby blood vessels increase their internal diameter to increase blood flow
VO_2 max the maximum amount of oxygen per minute that can be taken in, transported and used by the body for energy production

7.11 Exam questions

7.11 Section A – Multiple choice questions

Question 1 (1 mark)

Which of the following would most likely be the main cause of fatigue in an elite 400-metre swim race that takes 3 minutes and 43 seconds to complete?

A. Glycogen depletion
B. CP depletion
C. Accumulation of lactate ions in the blood
D. Accumulation of hydrogen ions in the muscle

Question 2 (1 mark)

Which of the following represents the fatiguing metabolic by-products produced by a sprinter completing the 200 metres?

A. ATP, lactate, Pi
B. ADP, Pi, H^+
C. CO_2, H_2O, ATP
D. H^+, lactate, Pi

Question 3 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.2;* © VCAA

Weightlifters consume water after their final lift in a competition.

Water is used in recovery to

A. help an athlete return to pre-exercise levels.
B. refuel an athlete with carbohydrates to return this nutrient to pre-exercise levels.
C. refuel an athlete with protein and fats to return these nutrients to pre-exercise levels.
D. refuel an athlete with protein and carbohydrates to return these nutrients to pre-exercise levels.

Question 4 (1 mark)

Source: *VCE 2023, Physical Education Exam*, *Section A, Q.12;* © VCAA

The most likely cause of fatigue for an athlete who completed the 400 m hurdles event in 50.68 seconds is

A. accumulation of metabolic by-products.
B. glycogen depletion.
C. PC depletion.
D. dehydration.

Question 5 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.10;* © VCAA

The most likely fatigue mechanism for a trained marathon runner who completes a marathon in approximately three hours is

A. CP depletion.
B. accumulation of metabolic by-products.
C. glycogen depletion.
D. exceeding lactate inflection point (LIP).

Question 6 (1 mark)

Source: *VCE 2014, Physical Education Exam, Section A, Q.2;* © VCAA

The most likely cause of fatigue for a runner in a 100 m sprint is

A. dehydration.
B. depletion of CP stores.
C. depletion of muscle glycogen.
D. accumulation of hydrogen ions (H^+).

Question 7 (1 mark)

When working at your lactate inflection point (LIP), the energy system resynthesising the most ATP is the:

A. aerobic system.
B. anaerobic glycolysis system.
C. ATP–CP system.
D. lactate glycolysis system.

Question 8 (1 mark)

The athlete who benefits most from the highest lactate inflection point is a:

A. 400-metre sprinter.
B. hockey goalkeeper.
C. netball goalshooter.
D. triathlete.

Question 9 (1 mark)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section A, Q.15*; © ACHPER

Foods which are high in protein include

A. wholegrain rice, poultry and dairy products.
B. soy products, lean meat and fish.
C. fish, vegetables and wholegrain rice.
D. soy products, fish and avocados.

Question 10 (1 mark)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section A, Q.9*; © ACHPER

Consuming water before, during and after exercise

A. provides the body with carbohydrates.
B. can enhance performance, maintain constant core temperature and assist with recovery.
C. decreases blood plasma.
D. provides no physical benefits to the body.

7.11 Section B – Extended response

Question 1 (2 marks)

Source: *VCE 2023, Physical EducationExam, Section B, Q.2;* © VCAA

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 tire stages being approximately 3500 km. Each stage varies in distance and duration, with the average stage taking around four hours to complete.



Immediately after each stage of the bicycle race, cyclists will often drink chocolate milk. The chocolate milk is a good source of both carbohydrates and protein.

Explain the benefit of consuming protein and carbohydrates together for a cyclist's recovery.

Question 2 (4 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.8;* © VCAA

The Ironman Triathlon consists of a 3.86 km swim, a 180.25 km bicycle ride and a 42.20 km marathon, raced in that order. Races generally last eight hours for world-class performers.

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.

Question 3 (4 marks)

Source: Adapted from *VCE 2013, Physical Education Exam, Section B, Q.3.c;* © VCAA

Part of a 12-week training program for an untrained individual who is competing in a 10 km fun run is shown below.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
10	rest	fartlek training 5 minutes hard/ 5 minutes easy × 3	6-kilometre run @ 75–85% MHR	rest	fartlek training 10 minutes hard/ 4 minutes easy × 4	rest	60-minute run @ 75–85% MHR
12	rest	rest	30-minute easy run @ 70% MHR	rest	20-minute easy run @ 70% MHR	rest	**10-kilometre fun run**

Explain what would occur physiologically if the individual trained too high above the exercise intensity range prescribed for the sessions on Wednesday and Sunday in Week 10.

Question 4 (3 marks)

Source: *VCE 2013, Physical Education Exam, Section B, Q.8.a;* © VCAA

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
Total	42.195 km	3:37:51

Provide a physiological explanation as to why the final 10-kilometre split was slower than the previous three split times.

Continue to build your exam skills

Access the Units 3 Area Study 2 Review at the end of Topic 7. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

AREA OF STUDY 2 How does the body produce energy?

OUTCOME 2

On completion of this unit, the student should be able to 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.

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

REVIEW CONTENT SEQUENCE

U3 AOS2 Extended response — Build your exam skills
U3 AOS2 Practice examination online only
U3 AOS2 Practice school-assessed coursework online only

U3 AOS2 Extended response — Build your exam skills

Tell me

To address these questions, it is important to remember:

- examples of acute responses that occur in the respiratory and cardiovascular systems and how they support the aerobic resynthesis of ATP
- that ATP is resynthesised via three energy systems: the ATP–CP, anaerobic glycolysis and aerobic energy systems
- the characteristics of each energy system, including their fuel sources, rate and yield
- the relationship between intensity of exercise, rate of ATP synthesis and energy system contribution
- the relationship between duration of exercise, yield of ATP and energy system contribution
- the interplay of the three energy systems and the two key factors that determine their contribution: intensity and duration
- the fatiguing factors (e.g. fuel depletion and the accumulation of metabolic by-products), when they occur and how they influence performance
- the relevance of the lactate inflection point to aerobic performance
- to make regular connection to the stimulus material in your response, including by using relevant data to support your answer.

Show me

Practice question (8 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.2;* © ACHPER

At a recent swimming championship, the winner of the women's 50-metre freestyle swimming event swam a time of 23.78 seconds. Her teammate won the women's 800-metre freestyle event in 8 minutes 20.02 seconds.



Using the data provided, **discuss** the *similarities and differences* in the following factors for the 50-metre and 800-metre freestyle events:

- energy system interplay
- fatigue factors.

Decode the question

Strategies to decode the question

- **Identify the action words**
  Use the data — include supporting quantitative data
  Discuss — presents a clear, considered and balanced argument
- **Key terminology** — *similarities and differences*
- **Key concepts** — energy system interplay, fatigue factors
- **Marking scheme** — 8 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response

In both the 50-metre and 800-metre events, there would be contributions from all three energy systems; however, they would make contributions in varying proportions to the successful completion of the events. Both events would have a major contribution from the ATP–CP system as the swimmers exploded from the blocks; however, the 50-metre event would rely heavily on this energy system for a *significant proportion* of the total event duration (23.78 seconds) and, due to its *maximal nature* would *deplete CP stores* much more rapidly than the 800-metre event.

The 50-metre event would have little contribution from the aerobic energy system due to its *short duration* and *maximal intensity*, as this system produces energy at a *slower rate*. The 800-metre event would use the aerobic energy system as the major provider of ATP (due to its long duration of 8:20.02 seconds) once steady state is reached and the demands for oxygen can be met *aerobically*.

Both events would require significant contributions from the anaerobic glycolysis system. In the 50-metre event, this system would be the *major provider of energy* in the latter half of the event when CP stores are depleted and a high rate of energy production is still required to complete the event. However, the anaerobic glycolysis system produces *ATP at a slower rate* that the ATP–CP system, as such CP depletion is the main fatiguing factor in the 50-metre event.

In the 800-metre event, the anaerobic glycolysis system is an *important contributor* to total energy production throughout the event and specifically before the swimmer reaches *steady state* at the start of the event and again as the swimmer lifts intensity, which is likely to occur over the final stages of the race.

This will result in the accumulation of metabolic by-products such as H^+, and be the main *fatiguing factor* in the 800-metre event. This *accumulation* would also occur in the 50-metre event but act on the athlete over a much shorter period of time.

Marking guide

High range response	• Ideas are well-organised and convey a clear message • Similarities and differences in energy system interplay are thoroughly discussed • Strong connection to the stimulus is made, including the use of relevant data • Link between energy system use and fatigue accurately discussed with reference to the differences that exist
Mid range response	• Ideas are grouped together in three different paragraphs • Stimulus is somewhat incorporated into the response • Similarities and differences in energy system interplay are discussed with minor connection to intensity and duration • Link between energy system use and fatigue is made for each event, but lacks full detail or accuracy • There are inaccuracies in the answer
Low range response	• Poorly structured and difficult to follow • Limited reference to the stimulus material • Subject content is poorly understood or not discussed • Discussion of only one major area (e.g. energy systems) • More of a list of some correct information rather than links

Let me do it

Extended response questions learn on

Question 1 (8 marks)

Source: Adapted from *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.13;* © ACHPER

Two track events for women included in the Olympic Games are the 100-metre hurdles and 3000-metre steeplechase.

The world record for the 100-metre hurdles is 12.12 seconds. In this race, each athlete must jump over 10 obstacles, 84 centimetres in height, which are placed equally over the 100-metre distance.

The world record for the 3000-metre steeplechase is 8:44.32 seconds. In each lap of the track, the athlete must jump explosively over four regular barriers of 76 centimetres in height and one water jump barrier. There are a total of 28 barriers for the 3000-metre event.

FIGURE Athletes competing in (a) the 100-metre hurdles and (b) the 3000-metre steeplechase



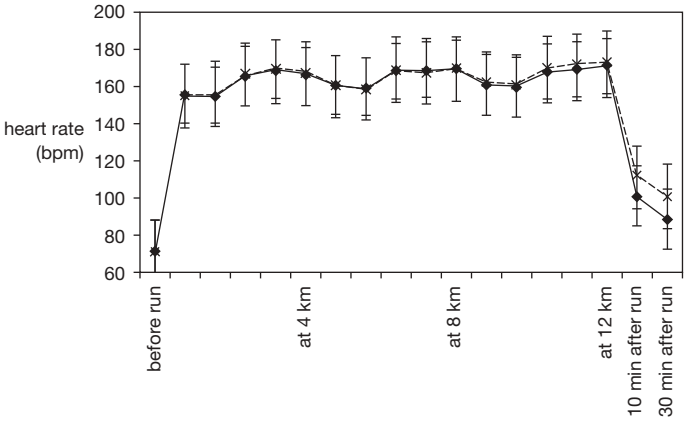
Using the information provided and your understanding of energy system interplay and fatigue, compare the 100-metre hurdles and 3000-metre steeplechase events. Your response should include reference to:

- rate of energy production
- fuel use
- causes of fatigue
- the relevance of the lactate inflection point (LIP) to both events.

Question 2 (8 marks)

Source: Adapted from *VCE 2022, Physical Education Exam, Section B, Q.11.b;* © VCAA

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.



Source: Adapted from R Lopez et al., 'Examining the influence of hydration status on physiological responses and running speed during trail running in the heat with controlled exercise intensity', *Journal of Strength & Conditioning Research*, vol. 25, no. 11, 2011, p. 2946

Use the trail runner's training data to analyse the interplay of energy systems in relation to:

- intensity
- duration.

In your response, include the role in the provision of energy to the trail runner of the acute responses of the:

- cardiovascular system
- respiratory system.

Hey students! Now that you have completed the Extended Response, access the following in learnON

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UNIT 4 AREA OF STUDY 1

What are the foundations of an effective training program?

Step 1 — Data collection from participation and activity analysis

Why?	How?

• To justify the physiological requirements of an activity:
  • energy systems
  • fitness components
  • major muscle groups
  • fatiguing factors.
• To inform an appropriate assessment of fitness.
	• Collect and analyse data using:
	  • skill frequencies
	  • movement patterns
	  • heart rates
	  • work-to-rest ratios.

Step 2 — Assessment of fitness

Why?	How?
• To identify the physiological strengths, weaknesses, and potential area of improvement for the athlete. • To provide motivation. • To assess an athlete's suitability to a sport or position. • To set benchmarks/baselines.	• Select a range of suitable (standardised and recognised) tests based upon the specific physiological requirements identified in the activity analysis. • Consider the aims, protocols, reliability, validity, and accuracy of each test. • Undertake a pre-health screening (PARQ) and attain informed consent.



UNIT 4 AREA OF STUDY 2

How is training implemented effectively to improve fitness?

Step 3 — Select and participate in appropriate training methods

Why?	How?
• To achieve the specific chronic adaptations of the cardiovascular, respiratory and muscular systems that improve fitness and enhance performance for the chosen activity.	• Select appropriate training methods from the data collection and fitness assessment analysis, such as: • continuous • circuit • interval (short, intermediate, long and HIIT) • fartlek • weight/resistance • plyometrics • flexibility.

Step 4 — Apply relevant training principles

Why?	How?
• To ensure that the relevant chronic adaptations occur for the training program to achieve its overall goal of improving the athlete's fitness and/or performance.	• Consideration and application of appropriate training principles such as: • frequency • intensity • time/duration • type • progression • specificity • individuality • diminishing returns • variety • maintenance • tapering • overtraining and detraining.

Step 5 — Design and participate in each individual training session

Why?	How?
• To plan and implement the components of each session to achieve progressive overload, incorporating the relevant training principles, appropriate training method/s, intensity, volume, and duration.	• Include the important components: • warm up • conditioning phase • cool down.

Step 6 — Monitor, record and evaluate training

Why?	How?
• To evaluate and critique the effectiveness of the program from the data obtained. • Identify and prescribe any appropriate modifications to the training program based on the evaluation. • To make informed decisions to enhance training effectiveness and work towards optimal performance levels.	• To monitor, record and analyse the physiological, psychological and sociological training data with the use of training diaries, digital tools and wearable technologies.

UNIT 4

AREA OF STUDY 1

What are the foundations of an effective training program?

OUTCOME 1

On completion of this unit, the student should be able to undertake an activity analysis to justify the physiological requirements of an activity that informs an appropriate assessment of fitness.

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TOPIC SEQUENCE

8 Fitness components 346

9 Activity analysis 382

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Extended response — Build your exam skills 481

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8 Fitness components

8.1 Overview

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LEARNING SEQUENCE

8.1 Overview
8.2 Aerobic power and anaerobic capacity
8.3 Muscular strength, muscular power and muscular endurance
8.4 Speed and agility
8.5 Flexibility, balance and coordination
8.6 Key skills
8.7 Review

8.1.1 Introduction

The term 'fitness' is used in a variety of ways. In order to describe fitness accurately, the fitness components should be referred to. Each sport or activity will rely on different fitness components. This information can be gained from activity analysis. Additionally, within certain sports and activities, different fitness components will be relied on at different times.

Understanding fitness components helps us to understand the specific physical requirements to test and then train to improve performance.

Different factors also affect each fitness component, which is important to consider when developing and reviewing training programs.

FIGURE 8.1 What does being 'fit' mean to you and what affects your fitness?

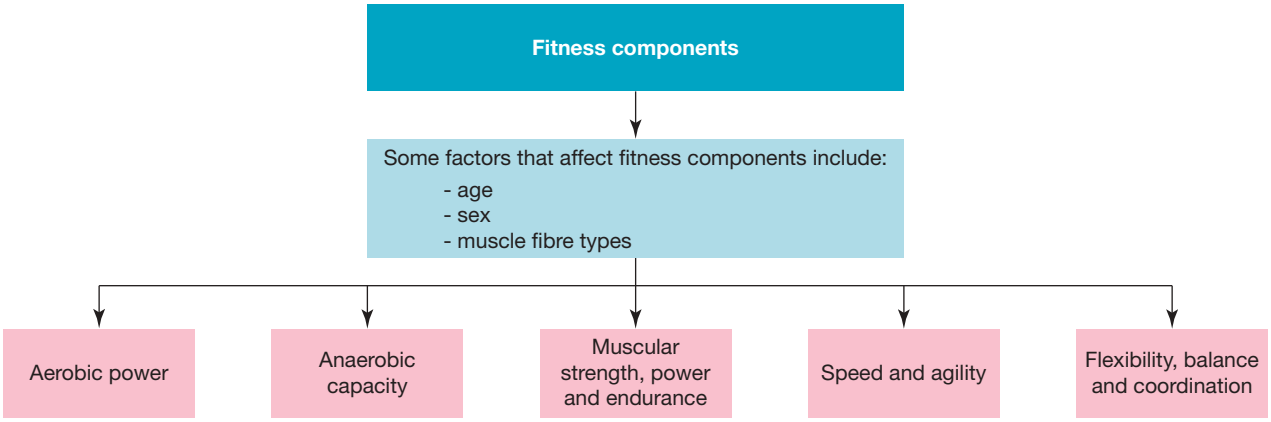


8.1.2 Key knowledge and Key skills

Key knowledge	Key skill	Subtopic
• 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)	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity	**8.2** **8.3** **8.4** **8.5**

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8.1.3 Topic preview



8.2 Aerobic power and anaerobic capacity

Key knowledge	Key skill
• 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)	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

8.2.1 Aerobic power

Aerobic power is the maximum rate of energy production from the aerobic energy system (i.e. the energy produced in the presence of oxygen). The cardiovascular and respiratory systems work together to deliver oxygen to the working muscles for any physical exertion that requires aerobic power (see figure 8.2).

aerobic power the maximum rate of energy production from the aerobic energy system (i.e. energy produced in the presence of oxygen)

If the cardiovascular and respiratory systems are highly trained, the athlete will be better able to produce ATP for the working muscles under aerobic conditions (at a higher intensity for longer), and they will have increased capacity for efficiently replenishing the anaerobic systems.

Aerobic power is of high importance in:

- extended athletic events, such as marathons, triathlons and cross-country skiing (see figure 8.3)
- team sports requiring repeated efforts over a longer period of time
- racquet sports, such as tennis and squash, due to the duration of the games
- intermittent sports, for positions that cover a lot of distance or have increased movements over a long period of time such as netball, football, hockey, soccer, volleyball, water polo, basketball, lacrosse and rugby.

FIGURE 8.2 Aerobic power relies on the cardiovascular and respiratory systems working together.

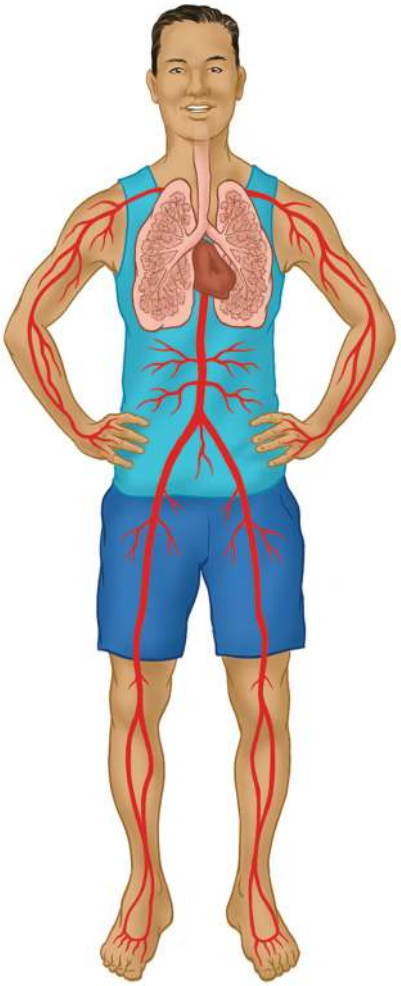


FIGURE 8.3 Long-distance cyclists require the highest levels of aerobic power in order to work at higher intensities for long periods of time, often for multiple days in a row.

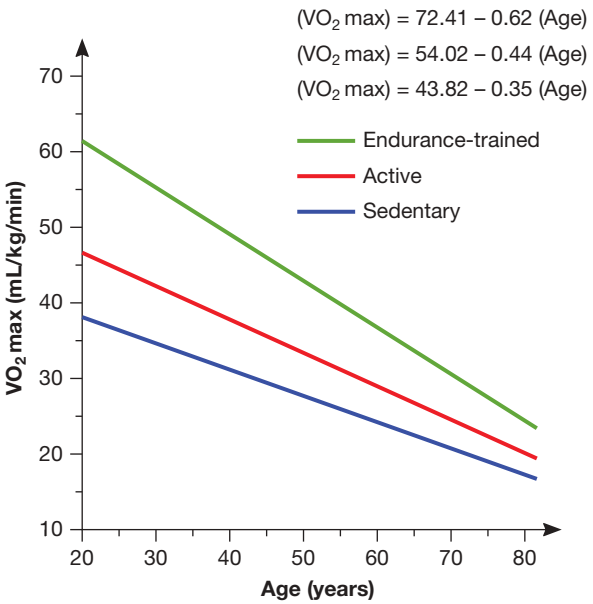


Factors affecting aerobic power

TABLE 8.1 Some factors affecting aerobic power

Factor	Effect on aerobic power
Muscle fibre type	*A greater percentage of slow-twitch fibres will increase aerobic power (VO_2 max).* Slow-twitch fibres work aerobically. Therefore, the more slow-twitch fibres a person has, the greater their ability to work aerobically.
Sex	*Males generally have a higher aerobic power (VO_2 max) than females.* This is due to males generally having larger lungs (increased oxygen uptake), higher haemoglobin levels (increased oxygen transport) and more muscle mass and therefore mitochondria (increased oxygen utilisation).
Age	*Aerobic power (VO_2 max) peaks in a person's early to mid 20s and then decreases as age increases.* This is due to the decreased elasticity of the lungs (decreased oxygen uptake), decreased haemoglobin (decreased oxygen transport) and decreased muscle mass and therefore mitochondria (decreased oxygen utilisation).

FIGURE 8.4 From a person's early to mid 20s, aerobic power, measured by VO_2 max, decreases.



Tests for aerobic power

Some common ways to test aerobic power include:

- 20-metre multi-stage test or 20-metre shuttle run test
- yo-yo intermittent recovery test
- Cooper 12-minute run test
- VO_2 max Astrand-Rhyming cycle ergometer test
- VO_2 max treadmill test.

Training methods for aerobic power

The most appropriate training methods to develop aerobic power are continuous, fartlek, long-interval, HIIT and circuit training with a W:R ratio of 1:1 or 2:1 (see topic 13 for more details).

8.2.2 Anaerobic capacity

Anaerobic capacity is the total amount of energy obtainable from the anaerobic energy systems (the combined capacity of the ATP–CP system and anaerobic glycolysis system).

anaerobic capacity the total amount of energy obtainable from the anaerobic energy systems (the combined capacity of the ATP–CP system and the anaerobic glycolysis system)

Anaerobic capacity is generally measured over a maximal effort up to one minute. As you have already learned, during a maximal effort up to one minute, the ATP–CP system initially plays a major role, and then the anaerobic glycolysis system will contribute most significantly. The longer and more efficiently these systems can contribute significantly to performance, the greater an individual's anaerobic capacity will be.

High anaerobic capacity can allow an athlete to complete longer maximal intensity efforts (e.g. an elite 400-metre sprint; see figure 8.5) and to repeat more maximal intensity efforts with limited recovery (e.g. the repeated sprints required for three runs in cricket).

FIGURE 8.5 400-metre hurdlers require very high anaerobic capacity in order to sprint 400 metres and jump 10 hurdles along the way.



Anaerobic capacity is of high importance in:

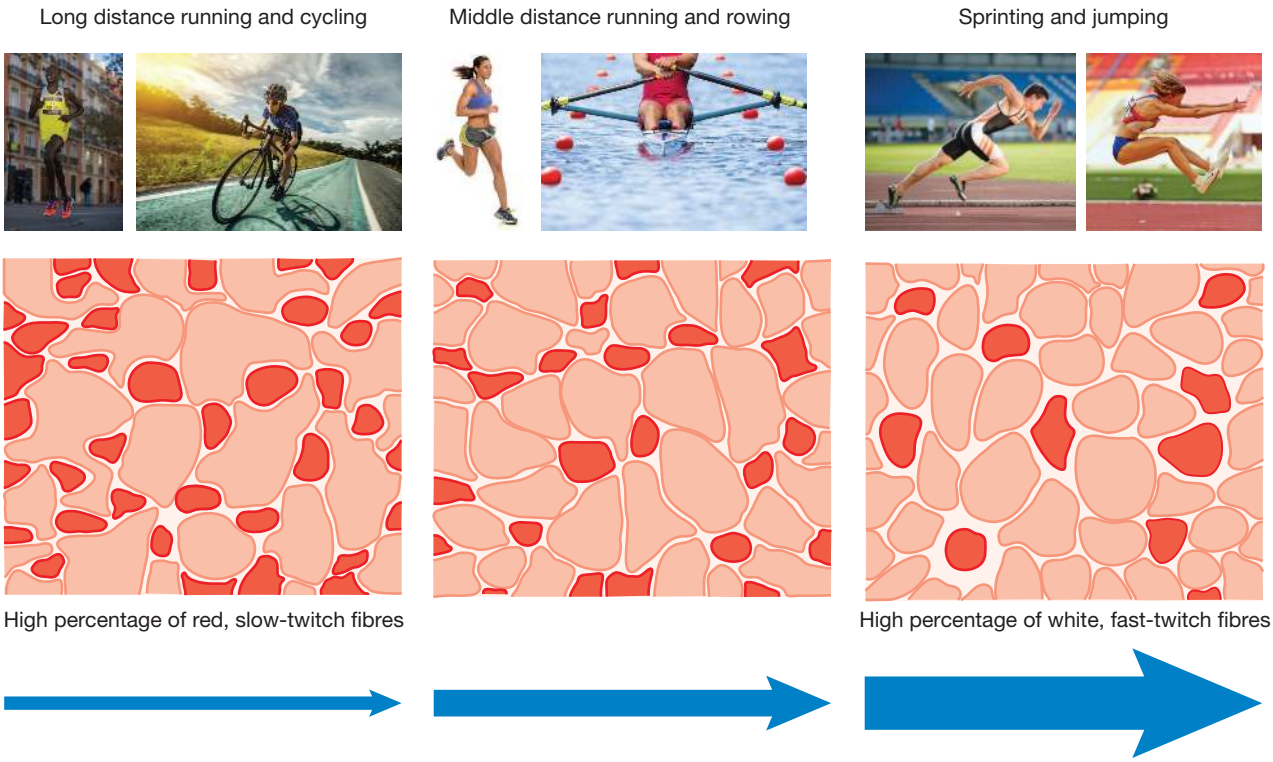
- repeated sprints in intermittent sports with insufficient recovery
- an elite level 400-metre run
- a 100-metre sprint in swimming.

Factors affecting anaerobic capacity

TABLE 8.2 Some factors affecting anaerobic capacity

Factor	Effect on anaerobic capacity
Muscle fibre type	*A greater percentage of fast-twitch fibres will increase anaerobic capacity.* Fast-twitch fibres work anaerobically. Therefore, the more fast-twitch fibres a person has, the greater their ability to work anaerobically (see figure 8.6).
Sex	*Males generally have a higher anaerobic capacity than females.* This is due to males generally having more muscle mass and therefore more places to store CP and anaerobic enzymes, increasing their ability to work anaerobically.
Age	*Anaerobic capacity peaks in a person's 20s and then decreases as age increases.* This is due to decreased muscle mass, which means fewer places to store CP and anaerobic enzymes.
Lactate tolerance	*The greater a person's lactate tolerance, the greater their anaerobic capacity.* The more metabolic by-products that can be tolerated, the more high-intensity efforts / longer high-intensity efforts can be made.

FIGURE 8.6 The percentage of slow-twitch (red) and fast-twitch (white) fibres is a significant factor affecting an individual's anaerobic capacity. The greater the percentage of fast-twitch fibres, the greater one's ability to generate anaerobic energy and, therefore, the greater the anaerobic capacity. Sprinters and jumpers require high anaerobic capacity.



Tests for anaerobic capacity

Some common ways to test anaerobic capacity are:

- phosphate recovery test
- 30-second Wingate test
- Repco peak power test. (See topic 10 for more details.)

Training methods for anaerobic capacity

The most appropriate training methods to develop anaerobic capacity are short and intermediate interval training (see topic 13 for more details).

doc-41964

PRACTICAL ACTIVITY Aerobic power

Goal

To test aerobic power.

Instructions

1. As a class, complete a warm up consisting of a 200-metre jog and 2–3 dynamic stretches, such as leg swings, walking lunges and hip circles, to prepare for the run and step test.
2. To complete the 20-metre multistage (or shuttle run) fitness test, refer to the instructions in section 10.4 in topic 10.
3. Record your maximal oxygen update (VO_2 max).
4. After a 10-minute rest, complete the Harvard step test, which is also found in section 10.4 of topic 10.
5. Calculate your fitness index and record it.

Primary data/Reflection

TABLE 1 Results from the tests

Multistage fitness test	
Harvard step test	

Data: MS Chelly et al., 'Match analysis of elite adolescent team handball players', *Journal of Strength and Conditioning Research*, vol. 25, no. 9, 2011, p. 2414

- Discuss the acute responses to the tests. What was similar? What was different?
- Justify these tests as aerobic power tests.
- Compare your experiences between the multistage fitness test and the Harvard step test. Which test did you find more challenging, and why?
- Reflect on your recovery following each test. How long did it take for your heart rate to return to normal levels? Did you notice any differences in recovery time between the two tests?

Questions

1. Explain the correlation between students' aerobic power and their main sport.
2. Outline the correlation between the different aerobic power tests.
3. What variables might affect the results? Explain how each test is specific to a sport when considering muscle groups/actions and energy system contribution.
4. Explain the role of each energy system in achieving level 12 on the multistage fitness test.
5. Explain how having good anaerobic capacity, as well as high aerobic power, may lead to success in the multistage fitness test.
6. Compare your results with those of two other students. Discuss what factors may have affected these results.

EXAM TIP

When justifying the importance of fitness components, make sure you link to the key terms in the descriptions.

For example: Aerobic power is important for a midfielder in soccer as they spend a significant amount of time running, which requires a high rate of aerobic energy production.

8.2 Activity

8.2 Quick quiz on

8.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 6, 7, 8	9, 10

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TEST your understanding

1. **Describe** *aerobic power*.
2. **List** five sports or activities that you have played that require aerobic power.
3. **Describe** *anaerobic capacity*.
4. **List** five sports or activities that you have played that require anaerobic capacity.
5. **Outline** the role of the three energy systems in producing aerobic power and anaerobic capacity.

APPLY your understanding

6. **Explain** the main differences between aerobic power and anaerobic capacity.
7. **Discuss** a time when aerobic power and anaerobic capacity are contributing most significantly during a triathlon.
8. **Discuss** when you would use aerobic power and when you would use anaerobic capacity during a team game such as basketball.

9. Use figure 8.4 to answer the following questions.
   a. **Identify** a trend.
   b. **Explain** a reason for the trend identified in part a.
10. Examine figure 8.6 and answer the following questions.
   a. Fast-twitch fibres are white and slow-twitch fibres are red. Using your understanding of the characteristics of fast- and slow-twitch fibres, **discuss** why this may be so.
   b. **Justify** the significance of fast-twitch fibres for weightlifters.

8.2 Exam questions

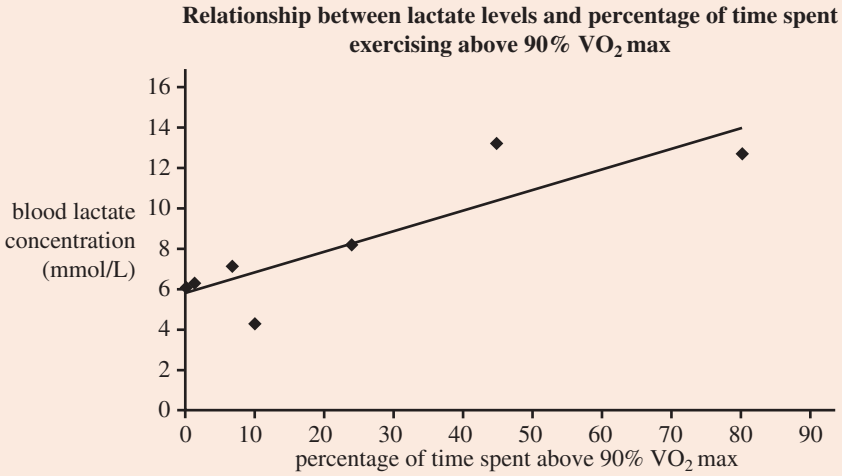
Question 1 (1 mark)

Outline the main difference between aerobic power and anaerobic capacity.

Question 2 (4 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.7;* © VCAA

Michael had his lactate measured during his squash match. The graph below shows the relationship between lactate levels and the percentage of time Michael spent exercising above 90% VO_2 max.



Source: Adapted from O Girard et al., 'Game analysis and energy requirements of elite squash', *Journal of Strength and Conditioning Research,* vol. 21, no. 3, 2007, p. 911

a. **Outline** the relationship between blood lactate concentration and the percentage of time spent exercising above 90% VO_2 max. **(1 mark)**
b. Referring to the graph above and to the fitness component of anaerobic capacity, **discuss** why the relationship outlined in part b exists. **(3 marks)**

Question 3 (3 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.3.e;* © VCAA

In a study, elite-level male sprint and distance runners' blood lactate levels were assessed under different conditions. The runners had been training for three months and were in the middle of their competitive season.

The following data was collected.

Distance		Sprint runners	Distance runners
		Blood lactate (mmol/L)	Blood lactate (mmol/L)
400 m	baseline	1.3	1.3
	post-exercise	6.6	4.1
1600 m	baseline	1.4	1.5
	post-exercise	14.5	8.8

Data: TJ Canfield & KA Gabel, 'Blood lactate, heart rate, and rating of perceived exertion in collegiate sprint, middle distance, and long distance runners after 400 and 1600 meter runs', *International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering*, vol. 7, no. 8, 2013, p. 479

Distance runners train to increase their anaerobic capacity.

Explain why increasing their anaerobic capacity would be beneficial to a distance runner's performance.

Question 4 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section B, Q.5.a; © VCAA*

The image below shows an athlete undergoing the 30-second Wingate cycling test. The test begins with an athlete pedalling as fast as possible on a cycle ergometer without any resistance. Within three seconds, a fixed resistance is applied to the wheel of the cycle ergometer and the athlete continues to sprint for 30 seconds.



Which component of fitness does the 30-second Wingate cycling test measure?

Question 5 (2 marks)

Source: *VCE 2009, Physical Education Exam, Section B, Q.13.c.ii; © VCAA*

Australia's Cadel Evans has performed extremely well in the Tour de France over the past couple of years. He has a high maximal oxygen uptake measuring over 85.

Describe how high aerobic power would assist Cadel Evans while competing in the Tour De France.

More exam questions are available in your learnON title.

8.3 Muscular strength, muscular power and muscular endurance

Key knowledge	Key skill
• 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)	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

8.3.1 Muscular strength

Muscular strength is the peak force that a muscle can develop. Apart from in weightlifting, this peak force strength movement is used infrequently in competitive or recreational sport. However, it is not difficult to imagine muscles creating near-peak force during sports participation.

muscular strength the peak force that a muscle can develop

Muscular strength is of high importance in:

- pushing with seven teammates against eight opponents in a Rugby Union scrum (see figure 8.7)
- gripping a hockey stick while making a powerful shot at goal
- attempting a static or submission hold against an opponent in wrestling
- leaning out to try to keep a boat upright while sailing.

1 RM (1 repetition maximum) the maximum amount of force that can be generated in one maximal contraction. This is commonly used to measure strength.

FIGURE 8.7 Pushing against your teammates and against the opposition in a scrum to gain possession of the ball is an example of muscular strength.



Factors affecting muscular strength

TABLE 8.3 Some factors affecting muscular strength

Factor	Effect on strength
Cross-sectional area	*The larger the muscle, the greater the strength potential* (see figure 8.8). This relates to the muscle mass, not the total body area in which the muscle is found. The diameter of the biceps, for example, may include both muscle and fat.
Fibre type	*Fast-twitch (white) fibres are capable of greater strength output than are slow-twitch (red) fibres*.
Sex	*Males generally have greater muscle mass, so they have greater absolute strength*. However, relative to the cross-sectional area of muscle, there is no difference in the strength available to any gender (see figure 8.8).
Speed of muscle contraction	*The more slowly a muscle contracts, the more force it can create* (see figure 8.9). Compare an isometric contraction with a powerful, isotonic contraction. A **1 RM** weight lift is performed much more slowly than 12 RM movements, because it requires more strength.
Age	*Strength peaks in performers aged 20–30 years, then decreases with the body's diminishing ability to process protein, which decreases muscle mass.* Regular exercise can slow this process.
Warm up	*Warmed-up muscles have a greater ability to create strength than muscles that are not warmed up*.
Joint angle around the muscle	*For each joint angle in movement, there is an optimal angle for the creation of strength* (see figure 8.10).
Muscle fibre arrangement	*Multipennate and pennate arrangements have more sarcomeres (the contractile component of a muscle cell) than fusiform muscles. Therefore, they can generate greater muscular strength.*

FIGURE 8.8 As the cross-sectional area of muscle increases, the strength potential also rises.

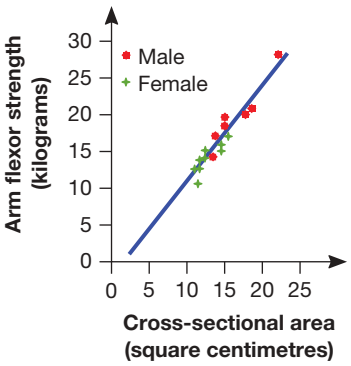


FIGURE 8.9 As speed of contraction increases, the amount of force created decreases.

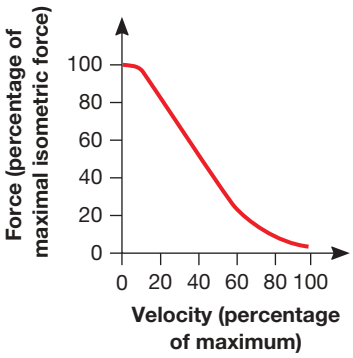
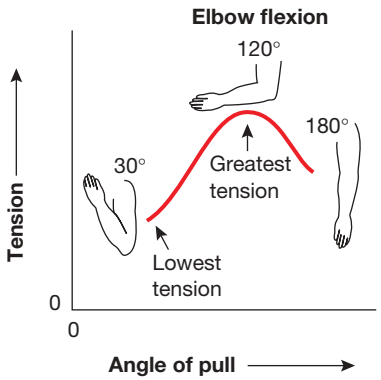


FIGURE 8.10 The strength available as a joint moves depends on the angle of the joint.



Tests for muscular strength

Some common ways to test muscular strength include:

- 1 RM (bench press, back squat, leg press)
- grip strength dynamometer
- seven-stage abdominal strength test. (See topic 10 for more details.)

muscular power the ability of a muscle or group of muscles to exert a maximum amount of force in the shortest period of time

Training methods for muscular strength

The most appropriate training method to develop muscular strength is resistance training (see topic 13 for more details).

8.3.2 Muscular power

Muscular power is the ability of a muscle or group of muscles to exert a maximum amount of force in the shortest period of time. Muscular power is a combination of strength and speed (see figure 8.11).

Muscular power is central to successful performance in most sports where distance, height or any quick generation of force is important. It is difficult to think of many sports or recreational activities for which muscular power is not needed.

Muscular power is important in:

- field events, such as shot-put, discus, javelin, high jump, long jump and hammer throw
- Rugby League or Rugby Union tackles
- arms and legs in volleyball spikes
- netball or basketball, when the player leaps to intercept the ball (see figure 8.12)
- arms in hockey, when the player performs a defensive clearance
- golf, when the golfer drives the ball
- the legs in a sprint
- the arms in a tennis serve
- the legs and arms in a gymnastics floor routine.

FIGURE 8.11 Andy Murray requires muscular power to serve a ball in a tennis match.



Factors affecting muscular power

Some factors affecting power are the same as those affecting muscular strength, as power combines strength and speed (see table 8.3).

Tests for muscular power

Some common ways to test power are:

- vertical jump
- standing long jump
- the basketball throw. (See topic 10 for more details.)

Training methods for muscular power

The most appropriate training method to develop muscular power is plyometrics training. Resistance training with fast contractions and appropriate recovery between repetitions is also commonly used to develop power (see topic 13 for more details).

FIGURE 8.12 Basketballers require muscular power for a number of actions, including in the legs to jump and defend.



8.3.3 Muscular endurance

Muscular endurance is the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time.

Muscular endurance is often controlled by the body's tolerance of the increasing levels of lactate, which is a by-product of the glycolytic energy pathways. Heavy arms or legs during any high-intensity effort of around 60 seconds are a direct result of the body's ability to tolerate building levels of lactate and are an indicator of the person's muscular endurance. Muscular endurance is also important in long distance and continuous events, which may be aerobic in nature but require repeated efforts from a muscle or muscle group.

Muscular endurance is of high importance for:

- the arms, legs and abdominals in a 200-metre swim
- the arms, legs and abdominals in a 2000-metre rowing race (see figure 8.13)
- the abdominals, hip muscles and legs in a marathon (see figure 8.14).

muscular endurance the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time

FIGURE 8.13 These under-19 Australian rowers require muscular endurance of the upper body and legs to maintain high-intensity efforts for the 2000-metre race.



FIGURE 8.14 While a fun run is predominantly aerobic in nature, it requires muscular endurance of the legs.



Factors affecting muscular endurance

TABLE 8.4 Some factors affecting muscular endurance

Factor	Effect on muscular endurance
Lactate tolerance	*The greater the lactate tolerance, the greater the muscular endurance.* The more metabolic by-products that can be tolerated, the more high-intensity efforts/longer high-intensity efforts can be made.
Sex	*Males generally have greater muscular endurance than females.* Greater aerobic power and muscular strength corresponds to better endurance.
Muscle fibre type	*A greater percentage of slow-twitch fibres will increase muscular endurance.* Slow-twitch fibres work aerobically. Therefore, the greater the number of slow-twitch fibres, the greater the muscle's ability to work aerobically and contract repeatedly over a longer period of time. Slow-twitch fibres have greater resistance to fatigue than fast-twitch fibres.

Tests for muscular endurance

Some common ways to test muscular endurance are:

- 60-second push-up test = muscular endurance of upper body muscles
- 30-second sit-up test = muscular endurance of the abdominal muscles
- flexed arm hang test. (See topic 10 for more details.)

Training methods for muscular endurance

The most appropriate training methods to develop muscular endurance where the anaerobic glycolysis energy system is contributing most significantly are resistance (with high repetitions and little recovery, W:R 1:3) and intermediate interval training.

For muscular endurance where the aerobic system is contributing most significantly, the most appropriate training methods would be the same as those used to develop aerobic power (see topic 13 for more details).

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PRACTICAL ACTIVITY Muscular endurance

Goal

To test muscle endurance by completing 60 seconds of different activities.

Instructions

1. Complete a thorough warm up and stretch
2. Undertake the following tests, allowing 3-minute rest periods between each activity.
   - 60 seconds of push-ups
   - 60 seconds of bench jumps
   - 60 seconds of sit-ups
3. Record your results in a table like the one shown below, then collate your data with the results from the rest of the class.
4. Present the class results for each test as a table and as a graph.

Primary data/Reflection

TABLE 1 Results from the different muscular endurance tests

	Number of repetitions
Push-ups	
Bench jumps	
Sit-ups	

- List the muscles involved in each of the exercises.
- What do the results indicate about your muscular endurance?
- Suggest a sport that would use each of the above tests.

Questions

1. Think about the difference between muscular endurance and muscular strength. How did these tests assess endurance specifically?
2. Analyse the varying results and explain possible reasons for at least two differences in the results.
3. Explain how increased aerobic power could positively impact muscular endurance.

doc-41966

PRACTICAL ACTIVITY Muscular power

Goal

To train muscular power through leaps, bounding and jumping a variety of distances.

Equipment

- 6 stick-like objects

Instructions

1. Use the **Fly game** weblink in the Resources panel to learn how to play the game of Fly.
2. Spread the six sticks out, 1 metre part.
3. One player takes a turn to run through the sticks, placing one foot between each stick, making sure they do not touch any of the sticks with their feet.
4. Once they reach the last stick, they take the biggest leap they can over it and stay where they land.
5. They then call out which stick they want to move to mark the place they landed (e.g. stick 2). This will increase the size of the gap between some of the sticks.
6. Repeat this process for the other players. A player is 'out' if they touch a stick with their foot or if they need to take more than one step between sticks. The winner is the player who can jump between the increasing gaps in one step and not touch the sticks.

Primary data/Reflection

- How many successful jumps did you achieve?
- Did you find the Fly game enjoyable and engaging? Why or why not?
- How did you feel during the Fly game in terms of muscular power demand compared to other physical activities or games?
- Which muscles did you feel were primarily engaged during the game?
- Discuss any feelings of fatigue experienced during or after playing the Fly game. How did muscular endurance affect your ability to sustain performance?
- Did you use any strategies to manage fatigue during gameplay?

Questions

1. How does greater muscular power increase the chance of success in the game of Fly?
2. Compare the importance of muscular power and muscular endurance in the game of Fly.
3. Discuss the energy system interplay during a game of Fly.

EXAM TIP

When differentiating between muscular strength, muscular power and muscular endurance, it is important to use the key differences to justify the fitness component as all involve force. Muscular strength is peak force, whereas muscular power will be an effort with speed, and muscular endurance will involve repeated contractions.

on Resources

Weblink Fly game

Video eLesson Muscular strength, muscular power and muscular endurance (eles-6618)

8.3 Activity

8.3 Quick quiz on | **8.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 5	7, 8	6, 9, 10

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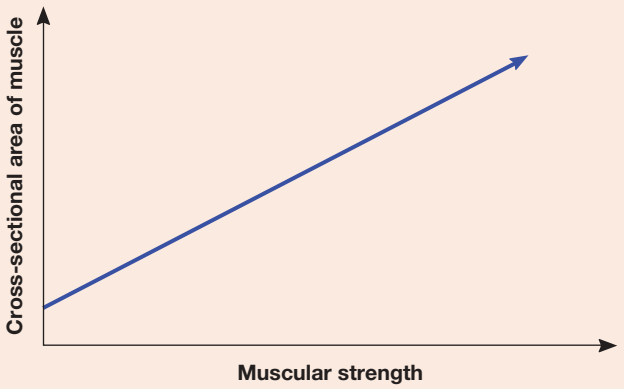
TEST your understanding

1. **Describe** *muscular strength*.
2. **Describe** *muscular power*.
3. **Describe** *muscular endurance*.
4. **List** five additional sporting actions not listed in section 8.3.2 that exemplify muscular power.
5. **Outline** the differences between muscular strength, muscular endurance and muscular power. Use sporting examples in your response.

APPLY your understanding

6. **Identify** and **justify** the following movements as muscular strength, power or endurance:
   - 1 RM leg press
   - 1 minute of step-ups
   - 3 × box jumps
7. **Discuss** the need for muscular strength, muscular power and muscular endurance in a 2000-metre row.
8. **List**, from most important to least important, muscular strength, muscular power and muscular endurance for the following sports and skill. **Discuss** your responses.
   - track cycling
   - road cycling
   - handstand
9. Choose one of the following sports and **explain** how muscular strength, power and endurance can contribute to a successful performance.
   - Australian Rules football
   - rugby
   - gymnastics

10.



a. **Describe** the trend shown by the graph.
b. **Explain** how an increase in the cross-sectional size of muscle produces increased muscular strength.

8.3 Exam questions

Question 1 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.11*; © VCAA

The image below shows a parkour movement. Parkour is an urban physical activity in which individuals run, jump, climb and vault over obstacles, often in regular community settings.



Which one of the following fitness components is the most important component in the parkour movement shown above?

A. muscular endurance
B. muscular strength
C. muscular power
D. aerobic power

Question 2 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.9;* © VCAA

Greater strength can be generated in muscles with a

A. greater percentage of fast-twitch muscle fibres.
B. greater percentage of slow-twitch muscle fibres.
C. faster speed of contraction.
D. joint angle of 180 degrees.

Question 3 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.4;* © VCAA

Sport climbing is a new addition to the 2020 Summer Olympics. It will feature three disciplines, two of which are described below:

- Speed climbing involves two climbers securing safety ropes to themselves and attempting to scale a 15 m high wall faster than their opponent. The men's world record is 5.48 seconds and the women's world record is 7.32 seconds.
- Lead climbing involves climbers attempting to climb a specific route as high as they can on a wall measuring more than 15 m in height in a maximum of six minutes, with a safety rope attached.

Event	Speed of climber
speed climbing 	2.04 m/s
lead climbing 	0.041 m/s

Muscular power and muscular endurance have been identified as important fitness components for speed climbing and lead climbing respectively.

At the 2020 Summer Olympics, each climber will compete in both disciplines.

Explain why muscular strength can aid both muscular power and muscular endurance.

Question 4 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section B, Q.3;* © VCAA

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.

Which fitness component is measured by a 1 RM bench press test?

Question 5 (4 marks)

Source: *VCE 2011, Physical Education Exam, Section B, Q.6.b;* © VCAA

List two factors and **explain** how each factor affects muscular strength.

More exam questions are available in your learnON title.

8.4 Speed and agility

Key knowledge	Key skill
• 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)	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

8.4.1 Speed

Speed is the rate of motion (distance/time). For sporting performance, speed is defined as the ability to move the body or part of the body from one point to another as quickly as possible.

speed the rate of motion (distance/time)

Speed is important in:

- undertaking any sprint event in athletics (see figure 8.15)
- accelerating to create space or evade an opponent in team games
- arm speed in releasing a javelin or discus
- racquet and club speed in striking sports (see figure 8.16).

FIGURE 8.15 Sprint cycling requires full-body speed.



FIGURE 8.16 Table tennis players require part-body speed to react and return the ball.



Factors affecting speed

TABLE 8.5 Some factors affecting speed

Factor	Effect on speed
Muscle fibre type	*A greater percentage of fast-twitch fibres will increase speed.* Fast-twitch fibres generate increased force production and power output, therefore increasing speed.
Sex	*Males generally have greater speed than females.* Males have increased levels of testosterone, and therefore greater muscle mass, which provides the capacity to generate more force, increasing speed.
Age	*As age increases, speed decreases (negative linear relationship).* A decreased ability to use protein (protein synthesis) leads to decreased muscle mass, reducing speed.

(continued)

TABLE 8.5 Some factors affecting speed *(continued)*

Factor	Effect on speed
Reaction time	*The faster the reaction time, the greater the reaction speed.* When responding to a stimulus, a faster reaction time means you're able to react with a greater speed. For example, taking off from the starting block quickly once the starter gun goes off.
Flexibility	*The greater the flexibility/stride/stroke length, the greater the speed.* Greater range of motion, due to increased flexibility, may mean an athlete can get further in each stroke/stride, making them more efficient in technique and increasing their speed.

Tests for speed

Some common ways to test speed include:

- 20-metre sprint test
- 35-metre sprint test
- 50-metre sprint test. (See topic 10 for more details.)

Training methods for speed

The most appropriate way to develop speed is by using short interval training (see topic 13 for more details).

8.4.2 Agility

Agility combines speed and dynamic balance, allowing the performer to change direction with maximal speed without losing balance.

agility a quick change in direction while maintaining balance

In sports such as gymnastics, planned agility is required. Most sports, such as team sports, require reactive agility where players are required to change direction quickly in response to a stimulus.

Agility is of high importance in:

- evading an opponent in soccer or rugby
- reacting to an opponent's baulk in hockey
- dribbling the ball around opponents in soccer or basketball (see figure 8.17)
- changing direction during a dance, gymnastics or aerobics sequence (see figure 8.18)
- moving to make a play in squash while avoiding an opponent.

FIGURE 8.17 Basketballers require agility to move around and past opponents and teammates.



FIGURE 8.18 Nina Kennedy requires a high level of agility to change direction and go up and over the bar in pole vault.



The factors affecting agility are similar to those affecting speed (see table 8.5), as agility requires speed.

Tests for agility

Some common ways to test agility are:

- Semo agility test
- 5-0-5 agility test
- Illinois agility test. (See topic 10 for more details.)

Training methods for agility

The most appropriate training method to develop agility is short interval training, ideally with changes of direction; for example, shuttle run sprints (see topic 13 for more details).

EXAM TIP

When discussing factors that affect speed and agility, remember to link the factor to the speed or rate of muscle contraction as this is more specific to speed and agility.

8.4 Activity

8.4 Quick quiz on | **8.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 6	7, 8

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TEST your understanding

1. **Describe** *speed*.
2. The following skills are recorded in a skill frequency table for a sport. Based on this data, **identify** which fitness component is most important.

Skill	Frequency
Change of direction	12
Passes	34
Sprints	10

   A. Muscular strength
   B. Muscular power
   C. Muscular endurance
   D. Speed
3. **List** five sports in which speed is important. Do not use the same sports listed in the subtopic.
4. **Describe** *agility*.
5. **Discuss** how increased muscular power could benefit speed and agility.

APPLY your understanding

6. Select a team sport and **design** an agility test that mimics the movement patterns required in the game. For example:
   - Netball: a centre player's first five seconds of movement following a centre pass
   - Australian Rules football: an on-baller's first five seconds of movement following a centre bounce
   - Hockey: the inside-right's movement as the team makes an attacking break from defence

7. For the following sports, **discuss** whether speed or agility is more desirable and **justify** your response:
   - pickleball
   - korfball
   - ultimate frisbee
   - lacrosse
   - European handball
8. Speed and agility are vital in a successful gymnastics floor routine. **Explain** the role that each of these fitness components would play, using specific examples.

8.4 Exam questions

Question 1 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.12;* © VCAA

Agility is the ability to

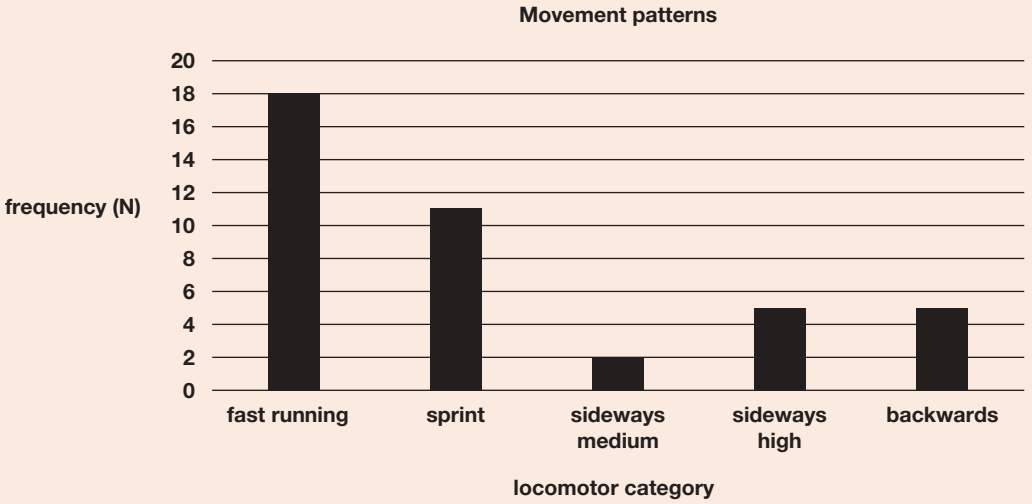
A. control equilibrium while moving.
B. change direction while maintaining balance.
C. move the body quickly from one point to another.
D. exert a maximum amount of force in the shortest period of time.

Question 2 (2 marks)

Source: Adapted from *VCE 2018, Physical Education Exam, Section B, Q.1;* © VCAA

A coach collected data on one player during a 60-minute recreational European handball match.

The data is presented in the following graph and table.



Source: Data and ideas from SCA Povos et al., 'Physical and physiological demands of recreational team handball for adult untrained men', *Biomed Research International*, 2017, p. 5

Skill frequency table

throws	20
jumps	27
changes of direction	13

a. **Justify** what information in the table above suggests agility is an important fitness component in European handball.
b. **Justify** what information in the table above suggests speed is an important fitness component in European handball.
c. **Identify** and **justify**, based on the data, which fitness component (speed or agility) is most important in European handball.

Question 3 (2 marks)

Identify and **justify** what type of muscle fibres elite athletes require to generate high speed.

Question 4 (7 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.8;* © VCAA

Michelle Payne is the first female jockey to win the Melbourne Cup. After the race she stated, '...you know what? It's not all about strength, there is so much more involved, getting the horse into a rhythm, getting the horse to try for you, it's being patient'.

Source: Isabelle Westbury, 'Michelle Payne's Melbourne Cup win should be a game-changer for women's sports', *Sydney Morning Herald*, 4 November 2015.

a. Payne says, 'It's not all about strength'.
List one other fitness component that may also be important for a jockey and **justify** your response. **(2 marks)**

b. Males have higher levels of testosterone than females, resulting in more muscle mass. This leads to greater absolute strength. **State** two other factors that affect strength. **(2 marks)**

c. Physiological data from two athletes is shown in the table below.

	Athlete 1	Athlete 2
VO_2 max	63 mL/kg/min	52 mL/kg/min
Type II muscle fibres (gastrocnemius)	24%	75%
Type I muscle fibres (gastrocnemius)	76%	25%
Leg press 1 repetition maximum (RM)	220 kg	300 kg

Based on the data, **justify** which athlete is likely to perform better in 100 m and 200 m sprint events. **(3 marks)**

Question 5 (2 marks)

Speed and agility are both important in tennis. Using specific examples, **outline** the difference between speed and agility.

More exam questions are available in your learnON title.

8.5 Flexibility, balance and coordination

Key knowledge	Key skill
• 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)	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

8.5.1 Flexibility

Flexibility is the range of movement around a joint. It is the interaction between the body's skeletal and muscular systems to allow a full and unimpeded range of joint movement to muscle actions.

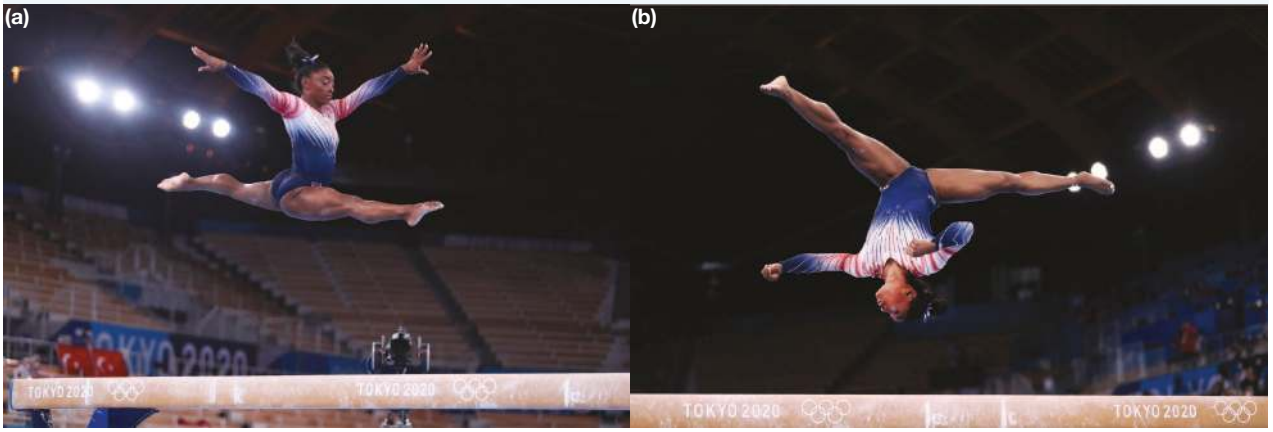
flexibility the range of movement around a joint

Flexibility is of high importance in:

- performing gymnastics routines or diving
- a goalie in hockey or soccer stretching to prevent a score
- shoulders for a swimmer, tennis player or hammer thrower
- hips and upper legs for rowers, AFL players and runners.

Flexibility is essential for all sports and recreational activities. Therefore, it must be an integral part of all fitness training programs. Some sports require more flexibility of more body parts than do others. Flexibility may be dynamic (moving) or static (stationary) (see figure 8.19). Generally, it needs to be dynamic, and it is often combined with speed to create agility.

FIGURE 8.19 Olympic champion Simone Biles of the United States demonstrates **(a)** dynamic flexibility and **(b)** static flexibility on the balance beam in the women's all-around gymnastics at the Tokyo 2020 Olympic Games.



Factors affecting flexibility

TABLE 8.6 Some factors affecting flexibility

Factor	Effect on flexibility
Type of joint	*Ball and socket joints have a greater range of movement than hinge joints.* The shoulder, a ball and socket joint, has great mobility The knee joint, a hinge joint, has less flexibility.
Warm-up	*Warm-up routines generally increase the temperature of both the muscles and the structures within the joints, increasing flexibility.*
Sex	*Hormonal differences mean that females are generally more flexible than males.* Higher levels of testosterone are associated with increased muscle mass, which can decrease flexibility. Increased levels of oestrogen are thought to improve the flexibility of connective tissue.
Age	*Increasing age past peak (generally mid-20s) decreases flexibility.* From childhood to a person's mid-20s, flexibility will be high. After that age, decreased collagen levels negatively impact flexibility.
Length of muscles at rest	*If muscles at rest are shortened, then flexibility is limited.* This may happen if the individual has too much sedentary work (which chronically shortens the hamstrings). If weight-training exercises are not performed through the full range of motion, then the muscles will shorten.

Tests for flexibility

Some common ways to test for flexibility include:

- trunk flexion (sit-and-reach) test
- trunk rotation test
- groin flexibility test
- shoulder and wrist elevation test
- trunk and neck extension test
- ankle extension/dorsiflexion test
- shoulder rotation test. (See topic 10 for more details.)

Training methods for flexibility

The most appropriate training method to develop flexibility is specialised flexibility training (stretching) (see topic 13 for more details).

FIGURE 8.20 Usain Bolt has more flexibility at the hip joint, giving him a greater stride length. Bolt takes an average of 41 steps per 100 metres, compared to 44 for other elite 100-metre sprinters.



CONCEPT CONNECTOR

To observe the effect of a warm up on flexibility, first try to touch your toes, keeping your legs straight and hinging at the hips. Note where you can reach to (e.g. your ankles). Then complete a 1-minute jog on the spot and 1 minute of walking hamstring scoops. Once done, try to touch your toes again and note your result. Were there differences in the results between males and females?

8.5.2 Balance

Balance is the ability of the body to remain in a state of equilibrium while performing a desired task.

balance the ability of the body to remain in a state of equilibrium while performing a desired task

There are two recognised types:

1. dynamic balance, which involves keeping the body's balance under control while moving
2. static balance, which involves keeping the body's balance under control while not moving.

Balance is a fitness component that is central to all physical activity and it is often the discriminating factor between excellent and average performance (see figure 8.21). For example, consider a 200-metre sprint in athletics, especially as the runners come around the bend. The sprinters run at varying distances from the inside line of their lanes, and their accompanying control of style, balance and speed ultimately contributes to their success at the finish.

FIGURE 8.21 Sailing and aerobics often require high levels of balance.





Balance is of high importance when:

- running around a bend in a 200-metre athletic race
- performing a 60-second aerobics routine
- performing a handstand in a gymnastics routine
- standing on one foot while shooting a goal in netball.

Factors affecting balance

A person's balance depends on a range of factors. Some of these are shown in table 8.7.

TABLE 8.7 Some factors affecting balance

Factor	Effect on balance
Age	As age increases past adulthood, balance can decrease.
Ears	If the inner ear is damaged, balance can be affected.
Muscle strength	The lower your muscular strength, particularly in the core muscles, the less balanced you are likely to be.

Tests for balance

The stork stand test is a common way to test balance, but many sports will have sport-specific balance tests.

Training methods for balance

Balance can be developed using resistance training of the core muscles (see topic 13 for more details).

8.5.3 Coordination

Coordination is the ability to use different parts of the body together smoothly and efficiently.

coordination the ability to use different parts of the body together smoothly and efficiently

It comes from the interaction of the neural, muscular and skeletal body systems. Coordination is a complex fitness component that requires sound levels of other fitness components such as strength, balance and agility. In sport, someone who appears well coordinated may also be described as having good timing.

Some sports require hand–eye coordination, some require foot–eye coordination and many require a combination of both (see figure 8.22).

FIGURE 8.22 Hockey requires excellent hand-eye coordination, whereas soccer mainly relies on foot-eye coordination.



Factors affecting coordination

Some of the factors affecting coordination are given in table 8.8.

TABLE 8.8 Some factors affecting coordination

Factor	Effect on coordination
Neurological conditions	Different neurological conditions can impact sensory and motor information, which will negatively affect coordination.
Muscle strength and endurance	Increased strength and endurance can make skills easier to complete, with greater coordination.
Stage of learning	As learners move from the cognitive to autonomous stage of learning, there will be an increase in coordination as they master the movements and skills.

doc-41967

PRACTICAL ACTIVITY Flexibility and balance

Goal

To improve flexibility and balance by completing a Pilates or yoga session.

Instructions

1. Before completing the session, perform a standing stork test for balance and a hamstring stretch for flexibility, recording your results from both.
2. Complete a mat Pilates or yoga session with an adequate warm up at the start.
3. After the session is over, complete the standing stork test and hamstring stretch again and record your results.

Primary data/Reflection

TABLE 1 Results before and after the session

	Before session	After session
Standing stork test		
Hamstring stretch		

- Rate the perceived difficulty of the class on a scale from 1 to 10.
- Note any specific poses or exercises that were particularly challenging or beneficial for balance and flexibility.
- Describe any challenges you encountered during the class, particularly in terms of balance or flexibility.
- Discuss how the session increased your awareness of body alignment, posture and muscle engagement.

Questions

1. Discuss the potential long-term benefits of regularly practicing yoga/Pilates for improving balance and flexibility.
2. Outline how yoga/Pilates could also help with maintaining and improving muscular strength and endurance.
3. Many AFL footballers include at least one session a week of Pilates, Body Balance or yoga in their training programs. Explain how this may improve performance in AFL.

EXAM TIP

It can be challenging to justify flexibility, balance and coordination from skill frequency tables. It is easier to justify these from images where you can see range of motion around a joint and/or maintenance of equilibrium. When given data or images, you must use evidence for your justifications from what is given, not from your own experience.

8.5 Activity

8.5 Quick quiz on | **8.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 6, 10	8, 9	2, 5, 7

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TEST your understanding

1. **Describe** the term *flexibility*.
2. The following image is of a hurdler.



   Explain the importance of flexibility for the hurdler.
3. **List** five sports or sporting actions that exemplify flexibility. Use sports and actions other than those listed in this subtopic.
4. **Describe** *static flexibility* and *dynamic flexibility*.
5. Select three different sporting or outdoor activities. **List** the skills needed for each activity and **assess** whether they require static or dynamic balance, or a combination of the two.

APPLY your understanding

6. **Outline** why flexibility is essential to every sports training session.
7. Study the factors that affect flexibility as listed in table 8.6. Select your favourite sport and **examine** how each of the factors influences the level of achievement of an elite performer in that sport.
8. Using examples of dynamic and static flexibility in sporting situations, **contrast** the two types of flexibility.
9. In groups of three or four, arrange to visit a training session of one of your school's sports teams.
   a. **List** the flexibility work done by the team during the session.
   b. **Discuss** the purpose of the flexibility work completed.
10. **Outline** how sex and age affect flexibility.

8.5 Exam questions

Question 1 (1 mark)

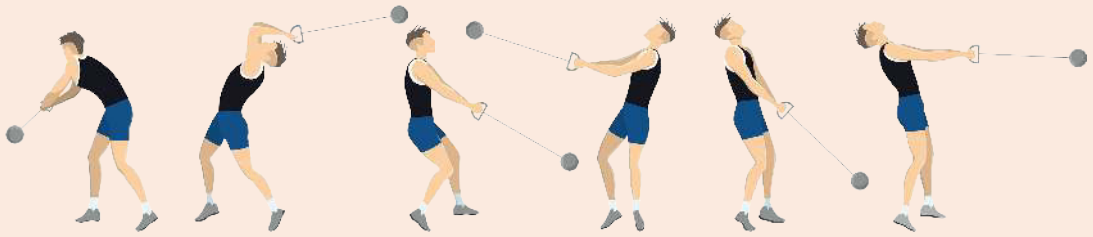
Source: *VCE 2018, Physical Education Exam, Section A, Q.11;* © VCAA

Which one of the following factors affects flexibility?

A. blood volume
B. body mass index
C. muscle fibre type
D. range of movement around the joint

Question 2 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.2;* © VCAA



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.

Question 3 (4 marks)

Source: *VCE 2015, Physical Education Exam, Section B, Q.4.a;* © VCAA

Men's gymnastics involves performance in the pommel horse event (shown below). In this static hold, the gymnast supports himself with his hands. His feet and body are not supposed to touch the pommel horse or the ground.



Using the image above, **identify** two fitness components required to perform the skill shown by the gymnast. **Justify** your selection with reference to the skill shown in the image.

Question 4 (5 marks)

Source: *VCE 2006, Physical Education Exam, Section B, Q.11.b;* © VCAA

The data in Figure 4 shows that the squash player lunged for the ball 67 times.

FIGURE 4 Number of times the player stretched/lunged for the ball in different directions

	Direction of stretch				Total number of stretches
	Forehand side	Backhand side	Lunge	Reach	
Total	75	91	67	21	254



a. **Name** the major fitness component being demonstrated in the photograph above. **(1 mark)**

b. **List four** factors affecting flexibility. **(4 marks)**

Question 5 (3 marks)

Evaluate the impact of poor flexibility on sports performance, citing specific examples from different sports.

More exam questions are available in your learnON title.

8.6 Key skills

Key skill

- justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

8.6.1 Tell me

To address this key skill, it is important to remember:

- the key terms for each fitness component (e.g. agility is changing direction quickly without losing balance)
- when discussing the effects of a factor, provide clear links to the impact
- age, sex and muscle fibre type are usually the easiest factors to explain for a number of the fitness components.

8.6.2 Show me

Practice question (4 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: *VCE 2023, Physical Education Exam, Section B, Q.2.a;* © VCAA

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.



The VO_2 maximum cycle ergometer test is a common fitness test performed by professional cyclists.

a. **State** the fitness component tested using the *VO_2 maximum cycle ergometer test*. (1 mark)

b. **Identify** and **explain** a *factor* that *affects* the fitness component identified in **part a** and how it may *impact* Jai. (3 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  State — provide a specific name without explanation
  Identify — determine the key characteristics or features
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *VO_2 maximum cycle ergometer test*, *fitness test*, *factor*, *affects*, *impact*
- **Key concepts** — fitness component
- **Marking scheme** — 4 marks — always check marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a. *Aerobic power*
Award 1 mark for stating the fitness component tested.

b. A *factor* that affects aerobic power is slow-twitch muscle fibres. Slow-twitch muscle fibres have greater blood flow, increasing the ability to use oxygen. This increases Jai's aerobic power and thus his ability to cycle for long periods of time.
Award 1 mark for identifying a factor that affects aerobic power.
Award 1 mark for explaining how the factor affects aerobic power.
Award 1 mark for identifying how the factor impacts Jai.

8.6.3 Let me do it

Question 1 (4 marks)

Source: Adapted from *VCE 2023, Physical Education Exam, Section B, Q.11;* © VCAA

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 canoes 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.



a. **State** an important fitness component in the canoe slalom. **(1 mark)**

b. Slovenian Benjamin Savšek won the gold medal in the men's event at the same competition in 98.25 seconds. Using your understanding of factors affecting fitness components, **explain** how sex may affect performance in the canoe slalom. **(3 marks)**

8.7 Review

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8.7.1 Summary

Aerobic power and anaerobic capacity

- Fitness components are those aspects of fitness that should be performed to a reasonable level in any sport or activity; these fitness components are affected by aerobic and anaerobic capacity.
- Age, sex and the percentage of fast- or slow-twitch muscle fibres significantly affect most fitness components.
- Aerobic power is a factor that affects fitness in physical activity; it is the maximum rate of energy production from the aerobic energy system.
- Anaerobic capacity is the total amount of energy obtainable from the anaerobic energy systems (the combined capacity of the ATP–CP system and the anaerobic glycolysis system). This also affects fitness.

Muscular strength, muscular power and muscular endurance

- Fitness components are those aspects of fitness that should be performed to a reasonable level in any sport or activity; these fitness components are affected by muscular strength, muscular power and muscular endurance.
- Muscular endurance refers to the capacity of a muscle, or a collection of muscles, to continuously perform contractions against a resistance over a prolonged time frame.
- Muscular power is the capability of a muscle, or a set of muscles, to produce the greatest force in the minimal amount of time possible.
- Muscular strength is the maximum level of force that a muscle can generate.

Speed and agility

- Agility is the skill to alter direction swiftly while maintaining stability. It is applicable in team ball sports like soccer.
- Speed is the capacity to move oneself or a body part rapidly from one location to another, like in sprinting.

Flexibility, balance and coordination

- Flexibility is the extent of possible movement around a joint.
- Balance is how proficient the body is in maintaining a state of steadiness during the execution of a chosen activity.
- Coordination is the ability to use different parts of the body together smoothly and efficiently.

8.7.2 Key terms

1 RM (1 repetition maximum) the maximum amount of force that can be generated in one maximal contraction. This is commonly used to measure strength.
aerobic power the maximum rate of energy production from the aerobic energy system (i.e. energy produced in the presence of oxygen)
agility a quick change in direction while maintaining balance
anaerobic capacity the total amount of energy obtainable from the anaerobic energy systems (the combined capacity of the ATP–CP system and the anaerobic glycolysis system)
balance the ability of the body to remain in a state of equilibrium while performing a desired task
coordination the ability to use different parts of the body together smoothly and efficiently

flexibility the range of movement around a joint
muscular endurance the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time
muscular power the ability of a muscle or group of muscles to exert a maximum amount of force in the shortest period of time
muscular strength the peak force that a muscle can develop
speed the rate of motion (distance/time)

8.7 Exam questions

8.7 Section A — Multiple choice questions

Question 1 (1 mark)

The rate at which one can utilise oxygen to generate energy is called:

A. anaerobic capacity.
B. muscular endurance.
C. aerobic capacity.
D. aerobic power.

Question 2 (1 mark)

Which of the following events is most likely to rely predominately on muscular power?

A. 100-metre sprint
B. Shot-put
C. Weightlifting
D. 400-metre sprint

Question 3 (1 mark)

Which of the following best describes the relationship between muscle fibre type and anaerobic capacity?

A. A 50/50 split of slow- and fast-twitch fibres will result in the greatest anaerobic capacity.
B. The greater the percentage of slow-twitch fibres, the greater the anaerobic capacity.
C. The greater the percentage of fast-twitch fibres, the lower the anaerobic capacity.
D. The greater the percentage of fast-twitch fibres, the greater the anaerobic capacity.

Question 4 (1 mark)

A one-off maximal effort against resistance requires which fitness component?

A. Muscular power
B. Speed
C. Muscular strength
D. Balance

Question 5 (1 mark)

Who is likely to generate the greatest speed?

A. An individual with 85 per cent fast-twitch muscle fibres
B. An individual with 85 per cent slow-twitch muscle fibres
C. A 50-year-old male
D. A 50-year-old female

Question 6 (1 mark)

Source: Adapted from *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.14;* © ACHPER

Consider the following table.

Skill	Frequency
lob pass	0
bounce pass	1
chest pass	23
receive pass	9
defend	22

Based on this data, which fitness component is most important for the centre player in netball?

A. Upper body power
B. Lower body power
C. Agility
D. Aerobic power

Question 7 (1 mark)

Dynamic flexibility is:

A. flexibility around all joints.
B. flexibility when moving.
C. flexibility when stationary.
D. flexibility done at the end of a training session.

Question 8 (1 mark)

Source: Adapted from *VCE 2022, Physical Education Exam, Section B, Q.6;* © VCAA

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: MS Chelly et al., 'Match analysis of elite adolescent team handball players', *Journal of Strength and Conditioning Research*, vol. 25, no. 9, 2011, p. 2414

Based on the data, what fitness component would be used to cover the greatest distance in handball?

A. Speed
B. Aerobic power
C. Anaerobic capacity
D. Agility

Question 9 (1 mark)

Which of the following best describes a factor affecting muscular strength?

A. Females are more likely to have increased levels of testosterone, which increases muscle mass and therefore muscular strength.
B. Males are more likely to have increased levels of testosterone, which increases muscle mass and therefore muscular strength.
C. As age increases, muscle mass increases, and so does muscular strength.
D. The faster the contraction speed, the greater the force of contraction.

Question 10 (1 mark)

Females tend to have a physiological advantage over males of similar age in which fitness component?

A. Flexibility
B. Aerobic power
C. Muscular power
D. Anaerobic capacity

8.7 Section B — Short answer questions

Question 1 (1 mark)

Source: *ACHPER 2022, Units 3 & 4 Trial Exam, Section B, Q.1.b;* © ACHPER

Name one recognised standardised fitness test that assesses the flexibility of the lower body.

Question 2 (4 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.6.c;* © ACHPER

The following table represents the movement patterns of a centre player in a game of interschool netball.

Locomotor movement pattern	Percentage of game time %
standing	14.3
walk forward	24.5
walk backwards	8.8
shuffle	4.0
jog	18.3
stride	20.8
sprint	9.3

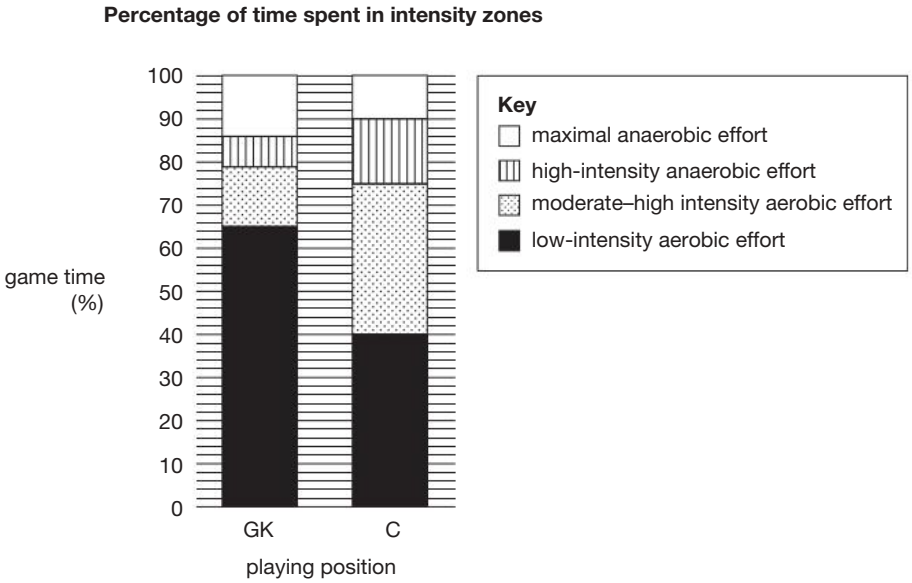
Discuss, with reference to the data above, two important fitness components for the centre player.

Question 3 (2 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.3.c;* © VCAA

Asher is an active 13-year-old boy who has started playing netball. He rotates between goalkeeper (GK) and centre (C) positions.

The graph below shows the percentage of game time Asher spent in each intensity zone.



Source: Adapted from CM Young, PB Gastin, N Sanders, L Mackey & DB Dwyer, 'Player load in elite netball: match, training and positional comparisons', *International Journal of Sports Physiology and Performance*, vol. 11, no. 8, 2016, p. 1076

Speed is an important fitness component for netballers, especially in the GK position.

Explain the importance of speed for Asher when he plays GK.

Question 4 (1 mark)

The long jump requires an athlete to run up and apply an explosive force to propel themselves into the air.

State the most important fitness component for a long jumper in the jumping phase.

Question 5 (2 marks)

During the 2020 Tokyo Olympic Games, Australian athlete Ariarne Titmus won gold medals in the 200-metre and 400-metre freestyle swimming events.

Identify and **justify** a fitness component that is important for success in the 200-metre and 400-metre freestyle swimming events.

Continue to build your exam skills

Access the Unit 4 Area of Study 1 Review at the end of Topic 10. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

9 Activity analysis

9.1 Overview

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LEARNING SEQUENCE

9.1 Overview
9.2 Data collection from activity analysis
9.3 Skill frequency analysis
9.4 Movement pattern analysis
9.5 Heart rate analysis
9.6 Work-to-rest ratio analysis
9.7 Case study — Netball
9.8 Key skills
9.9 Review

9.1.1 Introduction

In order to create an effective training program, it is important that the program is specific to the needs of the athlete. Activity analysis includes carefully analysing data collected (e.g. heart rates, skill frequencies, movement patterns and work-to-rest ratios) from elite performances to determine the most important physiological requirements of the activity or position. This allows the coach to make informed decisions for the remaining steps of creating a training program.

After this first and vital step has been completed, coaches will decide what fitness components, energy systems and muscles are important. This will then guide which fitness tests should be completed as part of the training program.

FIGURE 9.1 What might a coach conclude about the most important physiological requirements based on this data?

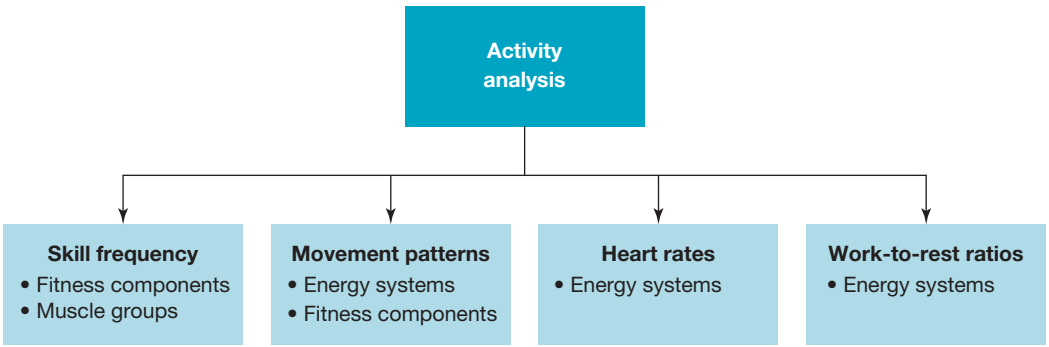


9.1.2 Key knowledge and Key skills

Key knowledge	Key skill	Subtopic
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements	**9.2** **9.3** **9.4** **9.5** **9.6**

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9.1.3 Topic preview



9.2 Data collection from activity analysis

Key knowledge	Key skill
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements

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9.2.1 What is activity analysis?

Activity analysis helps to determine the most important physical requirements of an activity, which enables coaches and performers to make the important link between training and the actual performance of an activity. It involves recording and illustrating the physical demands on the performer in the competitive setting. Elite athletes are often the ideal subjects for activity analysis because they exhibit the movements and skills that are most likely to lead to optimal performance. These physical demands can then be translated to the training situation. The key to successful activity analysis centres on the training principle of specificity (see topic 11); that is, quality activity analysis helps coaches and performers to gain specific knowledge that can be used to design tailored training programs (see figure 9.1).

activity analysis the recording and analysis of movement and skill data from a game, sport or activity

This knowledge can include the most important energy systems, fitness components and muscle groups.

Team sports and individual sports of an intermittent nature are most suited to activity analysis (see figure 9.2). For example:

- netball
- volleyball
- hockey
- squash
- water polo
- golf
- archery
- surfing.

FIGURE 9.2 Netball and surfing are intermittent sports, and activity analysis, such as skill frequency tables, can provide much insight into their physiological requirements.



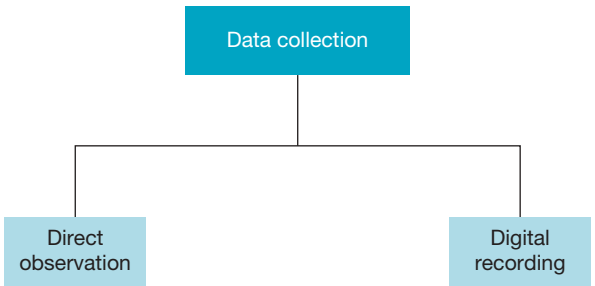
Analysis of continuous activities such as middle-distance and long-distance running, road cycling, rowing and swimming is more limited to the measurement of heart rates and intensities.

It is important that, where possible, the highest level of performance is observed; for example, elite. This allows for greater accuracy in data collection as it should provide information about how to achieve optimal performance.

9.2.2 Methods of data collection

Data collection is the process of gathering information. This is the first step of activity analysis. Once the data is collected, it can be analysed.

data collection the process of gathering information



Direct observation

The most common method for gathering data is observation. The coach or interested party views the player or team from the sideline. The gathered information is subjective and may include:

- how the athlete moves around the playing area
- where they move to
- the intensity of their sprint or playing
- the frequency of particular skill movements, such as backhand tennis shots
- the muscle groups that are being used
- the team plays that are in use.

This method is very practical and is the most common method used in schools and community sports; however, due to its subjective nature and the speed of games, it has low accuracy.

Digital recording

Digital recording can be less practical but it has higher accuracy. Statistical data can be recorded live and analysed immediately, or gathered and analysed after the event. The use of video is the preferred method to record data, because the coach and athlete can replay, slow down and freeze-frame the images. This method of activity analysis is commonly used in all top sporting teams.

Many elite teams now have access to programs that allow for immediate analysis of digital recording, reducing the burden of data collection and making the collection and analysis of data incredibly efficient and accurate.

CONCEPT CONNECTOR

Using your smart watch, explore what kinds of data can be recorded for different activities. Use the watch to record some data (e.g. short run or walk), then open up the accompanying app (if relevant) to see how the recorded information is presented. Discuss any similarities or differences between different brands of watch or apps.

EXAM TIP

Methods of activity analysis is how it is completed. It is important to carefully read the questions to ensure you know what it is asking.

on Resources

Weblinks AFL recording methods 1
AFL recording methods 2
Scotty James halfpipe

9.2 Activity

9.2 Quick quiz on | **9.2 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5	6, 7

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TEST your understanding

1. **Define** the term *activity analysis*.
2. **Identify** when an activity analysis should be completed and why.

3. **Outline** an advantage of digital recording as a method of activity analysis.
4. **Outline** the difference between data collection and activity analysis.
5. **Discuss** an advantage of direct observation as a method of activity analysis.

APPLY your understanding

6. Consider the **AFL recording methods** weblinks found in your Resources panel.
   a. **Explain** the purpose of recording this data.
   b. **Suggest** a method of activity analysis that could have been used.
   c. **Discuss** an advantage and disadvantage of this method.
7. Use the weblink **Scotty James halfpipe**, found in the Resources panel, to watch Scotty James complete a halfpipe run.
   Explain how this digital recording could be used by Scotty James and his coaching team to improve his performance.

9.2 Exam questions

Question 1 (2 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.3.a;* © ACHPER

The following activity data analysis was obtained during a futsal game.

Rest periods (% of game time)	
standing	23%
walking	17%
jogging forwards	15%
jogging sideways	4%
jogging backwards	10%
sitting (bench)	6%
TOTAL REST	**75%**

Work periods (% of game time)	
sprint forwards	8%
sprint sideways	6%
sprint backwards	7%
defending/directional change	2%
with possession	2%
TOTAL WORK	**25%**

Average sprint distance	Directional changes
8 m	108

Skill	Frequency
short pass > 5 m	67
long pass < 5 m	23
attack on the ball	45

This data was collected through digital recording.

Outline one advantage and one limitation of this data collection method.

Question 2 (2 marks)

Explain why activity analysis is the first and most important step in developing any training program.

More exam questions are available in your learnON title.

9.3 Skill frequency analysis

Key knowledge	Key skill
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements

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9.3.1 Skill frequency tables

Skill frequency tables can be easily completed using direct observation but can also be collated using different technologies, such as video analysis and wearable technologies. Catapult is one such technology and is used by teams across the AFL, AFLW, cricket and rugby to name a few.

Skill frequency tables are generally referred to as 'stats'. Tables outline the frequency, and in many cases the effectiveness, of skill execution. The stats in table 9.1 were taken over a 5-minute period during a Year 12 practical class.

TABLE 9.1 Skill frequency tables record the number of times common skills are executed during a set time frame.

Volleyball	
Skill	**Frequency**
Block	3
Serve	6
Spike	3
Dig	4
Set	7

Football/soccer	
Skill	**Frequency**
Kick	12
Dribble	8
Sprint	4
Tackle	2

Badminton	
Skill	**Frequency**
Overhead	9
Serve	6
Forehand	5
Backhand	4
Lunge	13

Tennis	
Skill	**Frequency**
Overhead	3
Serve	6
Forehand	13
Backhand	8
Lunge	5

Skill frequency tables indicate the main fitness components and muscles/muscle groups of a sport or activity. For example:

- a skill frequency table that shows a high percentage of leaps or jumps would suggest the fitness component of muscular power of the legs.
- a high number of changes of direction would indicate that it is important for the athlete to develop their agility.

To allow training programs to be specific, the analysis also needs to identify the muscle groups and movements used in performing each skill. For example, if the skill frequency table shows a high percentage of leaps or jumps, the major muscle groups would be the hamstrings, quadriceps and gluteals.

on Resources

Weblink Catapult

9.3.2 Muscle-use analysis

Muscle-use analysis is often neglected. It must be done in isolation from data gathering because it relies on subjective observation. In muscle-use analysis, the player is observed and notes are made about:

- the major muscles or muscle groups most used
- which main muscle groups are used early in the match, and whether they are different from those used later in the match
- whether the muscle contraction is powerful and fast, or slow and repeated
- whether muscle strength or muscle endurance is most important
- what range of motion and flexibility is exhibited.

This can then help enhance the specificity of training.

For example:

1. The skill frequency table (data collection) shows a number of chest passes for a basketballer.
2. Analysis identifies the biceps and triceps are used in an explosive manner.
3. Upper body, plyometrics or resistance training could be used, targeting the bicep power.
4. Training could include medicine ball drops, 3 × 6 with 3 minutes recovery between sets.

on Resources

Digital Document Activity analysis (doc-41960)

doc-41961

PRACTICAL ACTIVITY Netball activity analysis

Goal

To collect data on the skills completed in a netball game.

Instructions

1. Divide the class in half and have the first group play a 10-minute game of netball.
2. The other half of the class will record the skills for the player they have been allocated.
3. After 10 minutes, the group swaps over so data can be recorded for the second group.
4. As a class, collate all the data, grouping the same positions together.

Primary data/Reflection

Position data collected for:

TABLE 1 Skill frequency table

Skill	Frequency
Pass	
Catch	
Dodge	
Sprint	
Defend	
Jump	
Rebound	
Running backwards	

Player

- Reflect on any challenges you encountered during the game. How did you adapt your play to overcome these challenges?
- As you performed the different skills, how were different energy systems or muscle groups working?

Data collector

- Did you experience any difficulties when collecting data for your player? How did you overcome these?

Questions

1. Using the data, identify and justify the important fitness components required.
2. Using the data, compare and contrast the different physiological requirements for different positions.
3. Using the data, explain the role of the energy systems in a successful netball performance for the different positions.

EXAM TIP

When asked to justify using the data or when using the data always include specific examples e.g. 34 lunges.

9.3 Activity

9.3 Quick quiz on | **9.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	3	4

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TEST your understanding

1. **List** five skills that you would include in a skill frequency table for each of the following sports.
   a. Hockey
   b. Basketball
   c. Rugby

2. For each of the following skills, **outline** what major muscles/muscle groups are involved.
   a. Vertical jump
   b. Dodging an opponent
   c. Shoulder pass
   d. Kick

APPLY your understanding

3. Develop a skill frequency table for a sport or activity of your choice, preferably using the highest level athlete possible. Use this table to record data for an individual athlete. You may undertake the analysis at school or outside school on the weekend, and you may record the data while watching the game or make a digital recording of the game. If making a digital recording, keep the focus athlete in view at all times.
   Using the results of your skill frequency table, answer the following questions.
   a. **Identify** the most important fitness components for the athlete in this sport. Use data to support your choice.
   b. **Discuss** what role each of the energy systems play for the athlete in this sport. Use data to support your choice.
   c. **Suggest** how the information gathered will affect the training program for this athlete.
4. During a game of volleyball, Carlos' performance during the match was analysed and the data was recorded in the following skill frequency table.

Skill	Frequency
Serves	15
Digs	33
Sets	20
Spikes (attacks)	12
Blocks	8
Aces	3
Errors (mistakes)	5

   a. **Explain** how the skill frequency table could be used to improve Carlos' performance in Volleyball.
   b. **Evaluate** the limitations of the skill frequency table in relation to Carlos' frequency and quality of serves performed.

9.3 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.14;* © ACHPER

This data was collected for a centre player over a quarter of netball.

Skill	Frequency
lob pass	0
bounce pass	1
chest pass	23
receive pass	9
defend	22

This data would determine the:
A. energy system usage for netball.
B. major fitness components required for netball.
C. causes of fatigue for netball.
D. arousal levels required for netball.

Question 2 (7 marks)
The following skill frequency table was taken from a Year 12 student during a 15-minute basketball game.

Movement	Frequency
Changing direction	90
Rebounds	8
Shooting	7
Passing	31
Defending with arms up	22

a. **Suggest** an advantage of using elite athletes compared to Year 12 students for activity analysis. **(1 mark)**
b. **Identify** and **justify** the fitness components associated with each movement recorded in the table. **(5 marks)**
c. Based on the data, **suggest** the most important fitness component for basketball. **(1 mark)**

Question 3 (5 marks)
Based on the following skill frequency table of badminton, **identify** and **justify** the predominant fitness component.

Skill	Frequency
Overhead shot	25
Lunge	5
Forehand	12

More exam questions are available in your learnON title.

9.4 Movement pattern analysis

Key knowledge	Key skill
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements

Source: VCE Physical Education Study Design (2017–2024) extracts © VCAA; reproduced by permission

9.4.1 Movement patterns

Movement patterns reveal typical activities completed by a performer during a game or an activity (see figures 9.4 and 9.5). They enable the coach or athlete to determine the fitness components and energy systems that are used, and they provide (along with work-to-rest ratios and skill analysis) specific information required to develop training programs relevant to the athlete or team.

Movement patterns are helpful for determining the distance and intensity of efforts. Knowing the distance of sprints can help to identify the major fitness component (aerobic power, speed or anaerobic capacity) and energy system. Shorter sprints with recovery suggest the ATP–CP system will be the most important, whereas longer lower-intensity efforts suggest aerobic power.

movement patterns the typical movements completed by a performer during a sport or activity

Equipment needed to record movement patterns of a player in a competitive setting includes:

- a diagram of the playing area, either on a piece of paper or a computer screen
- a stopwatch or other device for recording time (the period of time for the movement is recorded and extrapolated to the full game or performance time period)
- a method of recording player movement; this can be a manual recording method or an electronic method (e.g. GPS tracking device)
- a list of skills to be recorded (and a code for each) that are pertinent to the activity (see table 9.2 for an example).

TABLE 9.2 Example codes for various sports movements

Movement	Code	Movement	Code
Sprinting	— — —	Cruising	= = = = =
Mark	M	Tackle	T
Shepherd	S	Guarding	G
Backwards movement	B	Sideways movement	SI
Running	.....	Walking	~~~~~~
Kick	K	Punch	P
Jumping	J	Shuffling	SH
Rebound	R	Jump shot	JS

FIGURE 9.3 A movement pattern recorded for a tennis player at the elite level

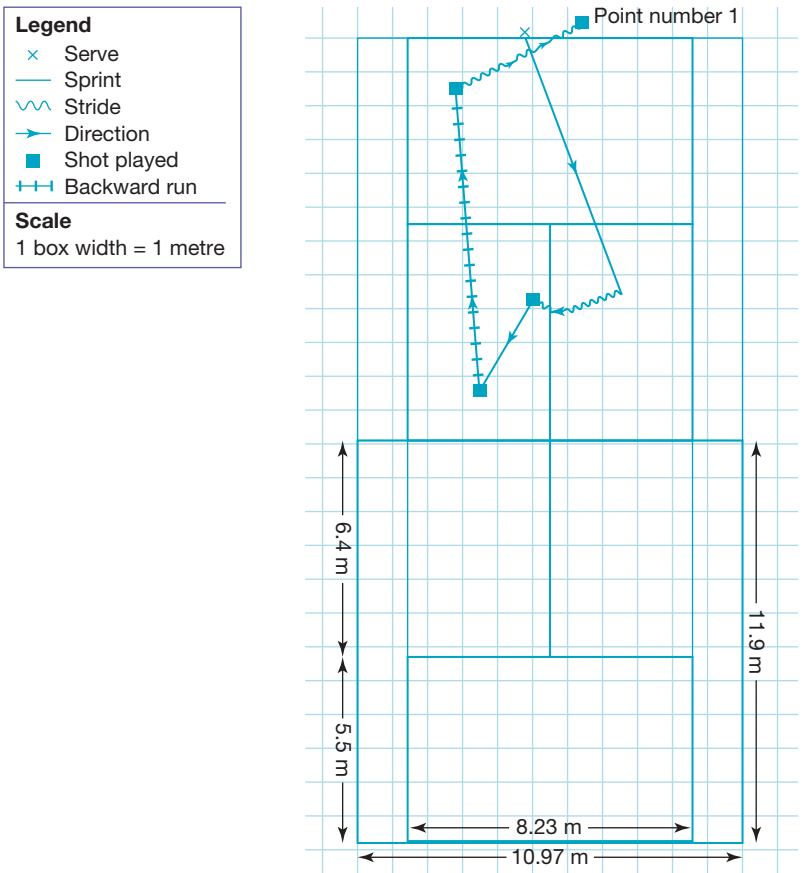
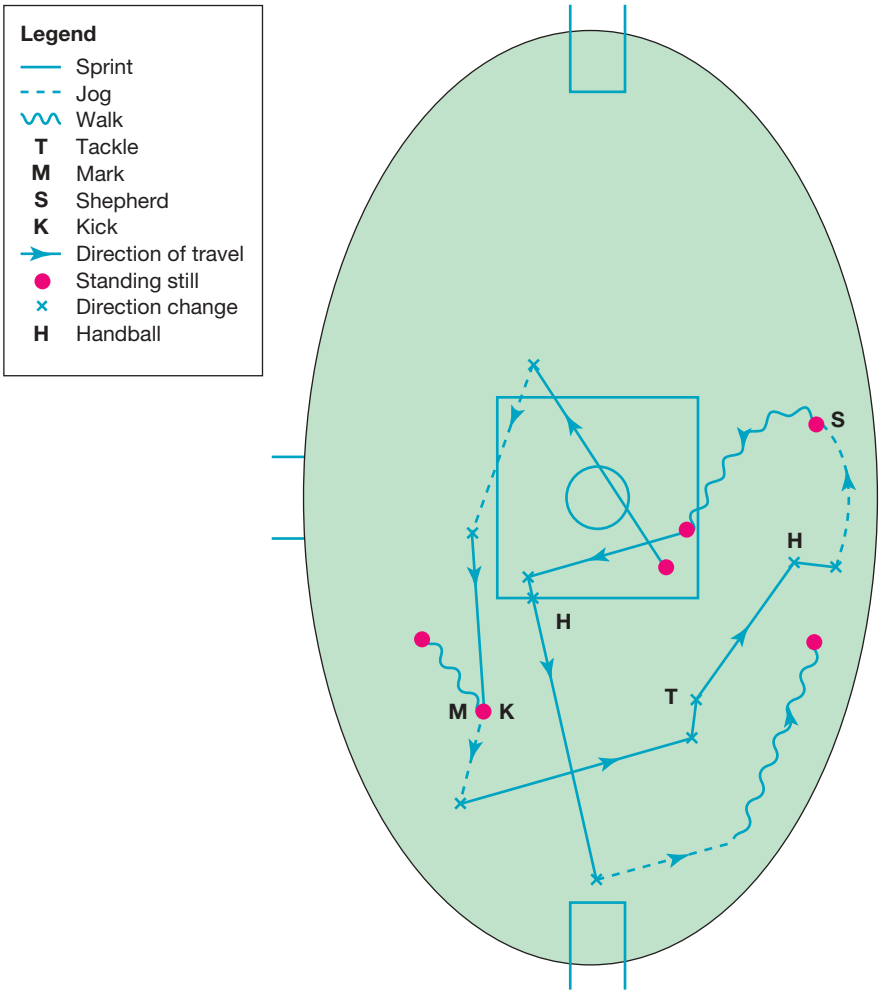


FIGURE 9.4 A movement pattern recorded for an 'on ball' player during 2 minutes in an AFL game



on Resources

Interactivity Movement analysis (int-6805)

9.4.2 GPS tracking

GPS, Global Positioning System, tracking devices are used for activity analysis at elite levels. Individual players wear these sophisticated devices, which record data indicating various movement patterns and efforts throughout the playing period (see figure 9.5).

GPS trackers are an easy and efficient way of collecting movement patterns. Multiple athletes can be recorded at the same time and data is easily stored and converted into information for analysis. However, GPS trackers can be expensive, especially for large groups and they are generally limited to outside activity. However, as technological advances continue, GPS trackers are becoming more accessible and accurate than manual recording, even indoors.

GPS Global Positioning System. This technology uses satellites to identify position and movement.

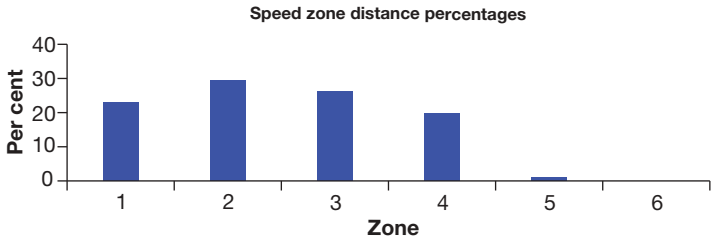
Many activity trackers also include total distances covered in efforts. While this information can be helpful in determining the major energy systems, GPS with movement patterns is required to determine the main fitness components.

FIGURE 9.5 AFL players wear GPS trackers to monitor how far they run and their speeds.

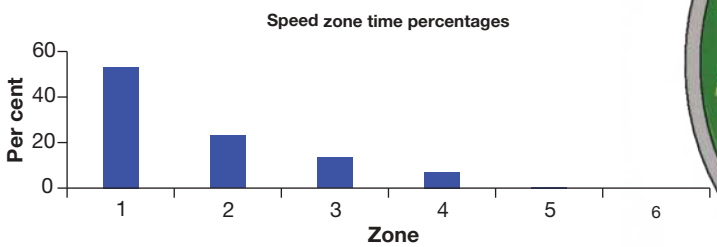


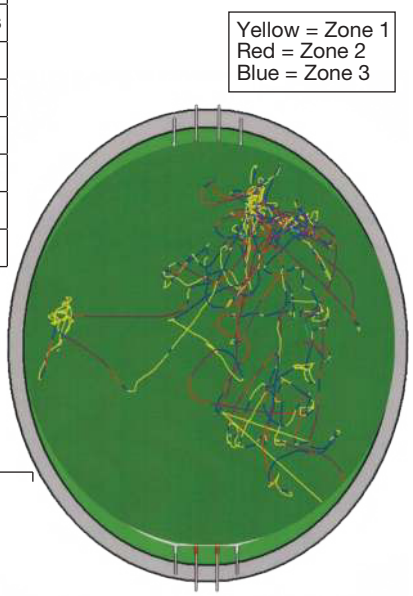
FIGURE 9.6 Collected AFL activity data from one game's quarter

Distance within speed zone					
Zone	**Lower**	**Upper**	**Distance (m)**	**Percentage**	**Entries**
1	0	6	932.9	23.2	108
2	6	12	1184.8	29.5	177
3	12	16	1062.8	26.5	109
4	16	25	795.4	19.8	40
5	25	30	36.9	0.9	2
6	30	35	0	0	0



Time within speed zone						
Zone	**Lower**	**Upper**	**Minutes**	**Percentage**	**Exertion**	**Entries**
1	0	6	17.6	53.9	1055	108
2	6	12	7.92	24.2	950	177
3	12	16	4.58	14	824	109
4	16	25	2.48	7.6	595	40
5	25	30	0.08	0.3	25	2
6	30	35	0	0	0	0





Source: GPSports.

Resources

Weblink AIS netball tracking technology

EXAM TIP

GPS and movement patterns will provide information about duration, intensity and distance of efforts. This can also be presented in tables.

CONCEPT CONNECTOR

Working in pairs, one person runs/walks in straight lines at various speeds of known lengths with a GPS tracker or smart watch recording their data. The second person makes direct observations. Compare the data collected from the GPS tracker or smart watch and the direct observations.

Discuss the advantages and limitations to GPS trackers and smart watches.

9.4 Activity

9.4 Quick quiz | **9.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3	1	4, 5

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TEST your understanding

1. **Discuss** the usefulness of movement patterns in activity analysis.
2. **List** the equipment needed to record movement patterns.
3. **Identify** the type of information gathered from movement patterns.
4. **Explain** how movement analysis adds to skill analysis to provide a more comprehensive activity analysis.

APPLY your understanding

5. The information in table 9.3 was gathered from four netballers. The positions played were goalkeeper, wing defence, goal attack and centre.

TABLE 9.3 GPS data of a netball game

	Game time	Game time %	Distance	m/min	Max. speed (km/h)
Player A	47.8	75%	2612	46.5	18.8
Player B	55.1	89%	4018	72.9	19.9
Player C	62.8	100%	3160	50.9	16.6
Player D	62.8	100%	3178	50.8	17.9
Team avg	**57**	**91%**	**3242**	**55**	**18.3**

a. Based on the data collected, **suggest** which player played centre.
b. Based on the data, **suggest** which player played goalkeeper.
c. Using players A and B, **discuss** how this information could be used to individualise training.
d. Using the data, **justify** the importance of speed in netball.

9.4 Exam questions

Question 1 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.5;* © VCAA

Use the following information to answer questions 1 and 2.

Below is a sample of data collected from an activity analysis.

Activity	Speed of movement (km/hr)	Total distance covered (m)	Percentage of time in activity (%)
Standing	0	0	32
Walking	≤ 6	1720	31
Jogging	6.1–12	1870	5.6
Running	12.1–18	928	4.5
Striding	18.1–24	406	2.4
Sprinting	> 24	763	2.8

Source: Adapted from C Castagna et al., 'Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness', *The Journal of Strength and Conditioning Research*, September 2010

What type of data is represented in the table above?

A. heart rates
B. skill frequencies
C. work-to-rest ratios
D. movement patterns

Question 2 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.6;* © VCAA

Based on the total distance covered and percentage of time spent completing each activity, which fitness component is the most important?

A. anaerobic capacity
B. muscular power
C. aerobic power
D. agility

Question 3 (6 marks)

Using the data in table 9.4, answer the following questions.

TABLE 9.4 GPS data of a VFL game, North Ballarat Roosters Football Club

Player	Time	Game time %	Odometer	Meterage/min	Low % <8 km/h	Moderate % <13 km/h	High % <18 km/h	Max. velocity (km/h)
A	101.8	83%	12991	128.7	32%	55%	13%	28.2
B	93.9	77%	13734	146.2	29%	58%	13%	25.9
C	73.8	61%	10171	137.4	22%	62%	15%	25.2
D	95.8	78%	11331	118.2	40%	46%	13%	29.0
E	96.9	79%	12122	125.6	26%	57%	16%	26.2
F	114.3	93%	12251	107.5	34%	54%	12%	28.9
G	103.2	85%	13307	129.3	34%	50%	16%	27.9
H	114.3	93%	13155	114.9	46%	44%	8%	27.6
I	84.5	69%	10518	124.5	28%	57%	14%	27.6
J	91.2	74%	12180	133.2	34%	45%	21%	27.6
K	110.6	91%	14071	127.4	38%	48%	13%	27.2
L	88.4	72%	12705	143.7	26%	57%	17%	29.1

a. **Identify** and **justify** what method of activity analysis has been used. **(2 marks)**
b. **Outline** one example of physiological information that can be obtained from this type of data. **(1 mark)**
c. **Explain** how the information could be used by a coach to plan training. **(3 marks)**

Question 4 (1 mark)
Suggest a limitation to using GPS tracking devices.

Question 5 (2 marks)
Explain why standing still is an important movement to record in movement patterns.

More exam questions are available in your learnON title.

9.5 Heart rate analysis

Key knowledge	Key skill
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements

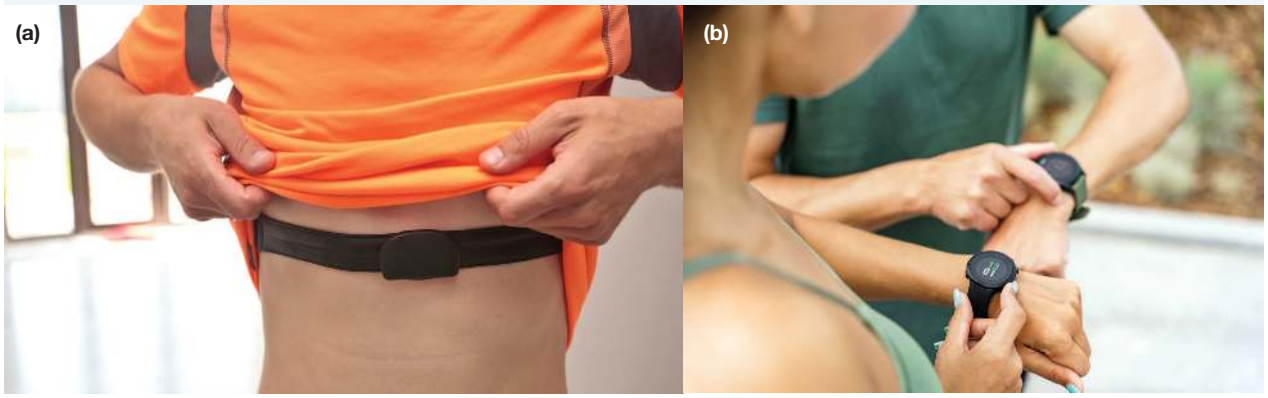
Source: VCE Physical Education Study Design (2017–2024) extracts © VCAA; reproduced by permission

9.5.1 Heart rates

A heart rate telemeter is a device (usually a watch or a chest strap) that provides data on a participant's heart-rate response to physical activity (see figure 9.7a). Heart rate is usually measured in beats per minute (bpm), and is used to estimate physical activity as energy expenditure (oxygen uptake). This is based on the assumption that there is a linear association between heart rate and energy expenditure. Heart rate monitors therefore provide important information about the role of the energy systems. For example, an intensity of over 85 per cent maximum heart rate (MHR) would suggest increased contribution from the anaerobic systems. Heart rate monitors can be used for most activities and involve reasonably low participant burden, especially now that many monitors do not even require a chest strap and are easily accessible given the cost of devices such as smart watches.

As technology improves, so does the information that smart watches (see figure 9.7b) and fitness trackers can collect. Many watches now measure heart rate and can track movements with intensity via apps like Strava to provide an indication of movement patterns, all by simply wearing an everyday watch. The accuracy of the data collected will vary depending on the device and the activity.

FIGURE 9.7 (a) There are currently a wide range of heart rate monitors and **(b)** fitness tracking devices on the market, in response to demand from consumers who are conscious about their health and fitness.



One major disadvantage of heart-rate monitoring is the need to calibrate the device to each individual. Another limitation is that during low-intensity exercise, the relationship between exercise intensity and heart rate is frequently not linear. At a low level of intensity, factors that affect heart rate, such as stress, fear, excitement and changes in body temperature, need to be considered as they may cause a false reading.

CONCEPT CONNECTOR

In pairs, complete the following procedure:

- choose one partner to perform some exercise and have their heart rate monitored
- monitor and record their heart rate with a smart watch or heart rate monitor and using their pulse for 1 minute before starting the exercise
- complete 1 minute of activity (e.g. running, cycling, rowing or skipping)
- record their heart rate for 1 minute (using both methods)
- rest until resting heart rate is achieved
- complete a short intermittent activity (e.g. a circuit)
- record their heart rate for 1 minute (using both methods).

Are there advantages and disadvantages to using heart rate monitors or smart watches over manually monitoring pulse? Discuss if one was more accurate than the other.

EXAM TIP

When considering heart rate graphs be aware of where max heart rate (220-age) and the aerobic training zone (60–85%MHR) is.

9.5 Activity

9.5 Quick quiz on | **9.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	2, 4	5

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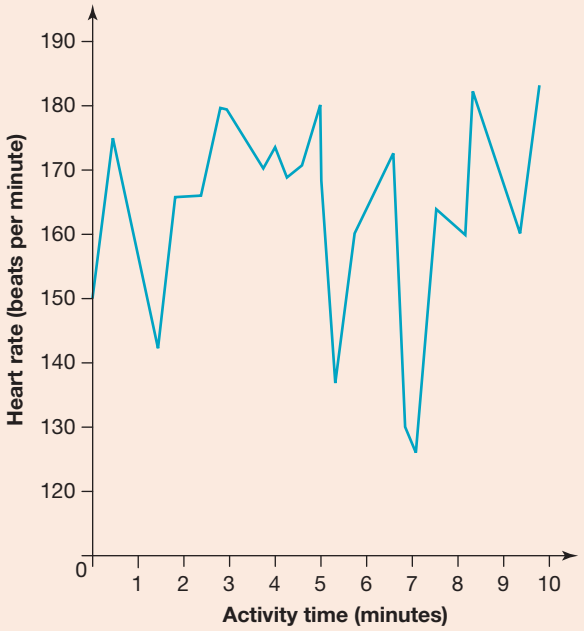
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TEST your understanding

1. **Describe** the information that can be gathered from a heart rate monitor.
2. **Provide** two limitations of using heart rate monitors.
3. **Identify** which energy system would be contributing most significantly if a heart rate monitor recorded:
   a. an average heart rate between 70–75% MHR for 10 minutes
   b. max heart rate.

APPLY your understanding

4. Consider the following graph for tennis.



   a. **Identify** what information the graph shows about the game of tennis.
   b. **Discuss** what conclusions can be made about tennis based on the heart rate.
   c. **Suggest** what is most likely to have occurred between 6 minutes 30 seconds and 7 minutes 30 seconds.
5. **Evaluate** the effectiveness of heart rate monitoring as a method of activity analysis for a variety of activities.

9.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2007, Physical Education Exam, Section A, Q.9*; © VCAA

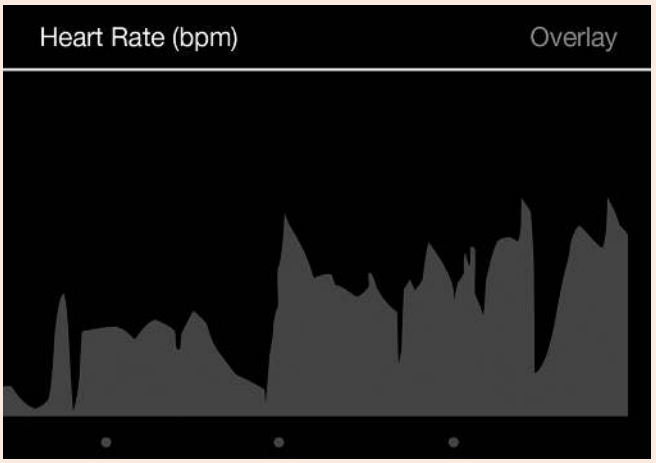
The best activity analysis method for long-distance cycling would be

A. simple observation.
B. simple observation with statistical records.
C. skill analysis.
D. heart rate monitoring.

Question 2 (1 mark)

Based on the graph, what is the role of the aerobic energy system?

A. It is the major energy system throughout the activity.
B. It is not the major energy system at all during the activity.
C. It would be the major energy system in the rest/recovery between efforts.
D. It is only the system contributing most significantly before and after the activity.



Question 3 (3 marks)

Explain how a coach could use the information gained from the heart rate graph in question 2.

Question 4 (6 marks)

Source: *ACHPER 2015, Trial Exam Units 3 & 4, Section B, Q.13.c;* © ACHPER

Sharon and Katherine decided that the Cooper 12-minute run test was a specific test to assess their aerobic power before undertaking their training program. They both completed the test to the best of their ability.

During the Cooper 12-minute run test, the students' heart rate data (measured in beats per minute) was collected and is presented in the table below.

Refer to the table below to answer question parts (a) and (b).

	Heart rate: Sharon	Heart rate: Katherine
Resting heart rate	72	61
Immediately before run	96	98
At the conclusion of 1st minute	160	170
At the conclusion of 2nd minute	170	171
At the conclusion of 3rd minute	171	170
At the conclusion of 4th minute	170	171
At the conclusion of 5th minute	170	172
At the conclusion of 6th minute	171	171
At the conclusion of 7th minute	172	172
At the conclusion of 8th minute	172	172
At the conclusion of 9th minute	172	172
At the conclusion of 10th minute	172	171
At the conclusion of 11th minute	185	188
At the conclusion of 12th minute	200	198
1 minute following run	185	172
2 minutes following run	171	161
3 minutes following run	165	133

a. **Identify** which energy pathways are likely to be used during the first minute of the test by both girls? **Justify** your selection. **(2 marks)**

b. **Discuss** two limitations of using heart rate monitors as the only method of data collection. **(2 marks)**

c. **Identify** and **justify**, using the data, if steady state was reached for Sharon. **(2 marks)**

More exam questions are available in your learnON title.

9.6 Work-to-rest ratio analysis

Key knowledge	Key skill
• types of data collected from an activity analysis, including skill frequencies, movement patterns, heart rates and work to rest ratios used to identify physiological requirements	• undertake an activity analysis and analyse associated data to justify the required physiological requirements

Source: VCE Physical Education Study Design (2017–2024) extracts © VCAA; reproduced by permission

9.6.1 Work-to-rest ratios

The **work-to-rest ratio** (W:R) is used to assess, during competition, the time spent physically working compared to the time spent resting or recovering. Data about work and rest periods is vital for determining an athlete's intensity of effort and therefore major energy systems. Activity analysis calculates the W:R to provide information that should underpin decisions about methods of training, work intervals and rest intervals.

work-to-rest ratio a summary of the time an athlete spends physically working compared to the time spent resting or recovering

To determine a W:R, standing still, walking and slow jogging may be classified as rest, while all other movements are classified as work. To record the W:R manually, record all work efforts on one stopwatch and all rest periods on another. Once the activity is complete, you have a W:R. For example, for 5 minutes' total work and 20 minutes' total rest, the ratio is 5:20 or 1:4. The intensity of the work efforts should also be noted because this information is important for determining energy system requirements (see table 9.5). Ideally, you would use a heart rate monitor to determine the intensity of each effort or work period, expressing the recorded heart rate as a percentage of the athlete's MHR.

When analysing work and rest data, determine the following information:

- total work time and total rest time
- average work time per effort and average rest time
- longest work time and longest rest time
- the W:R.

It is important to note the intensity of the work efforts for increased accuracy of energy system application.

TABLE 9.5 Work-to-rest ratios associated with each energy system

Work-to-rest ratio	Energy system
1:5 and above (rest significantly higher than work)	ATP–CP
1:3–1:4 (rest higher than work)	Anaerobic glycolysis
1:1–1:2 or 2:1 or above (work similar to rest OR work higher than rest)	Aerobic

The W:R can be very useful for intermittent sports such as team games (see table 9.6). It can, however, be very time-consuming and difficult to collect and analyse the information. Many computer programs and apps are making this easier. While they only provide information about the role of the energy systems, this can be vital information for training to ensure the athlete's specific needs are met.

TABLE 9.6 Work-to-rest ratio throughout a 75-second time sample during a game of basketball

W	R	W	R	W	R	W	R
10	21	5	10	6	10	4	9

The above W:R was manually calculated using observation and a stopwatch during a Year 12 PE class of basketball. The W:R above is equal to 25:50, which can be simplified to 1:2. This suggests that, for this passage of play for this player, the aerobic energy system was contributing most signficantly.

CONCEPT CONNECTOR

Complete three trials of 30 seconds of step-ups, followed by 2 minutes rest, then calculate the W:R.

After a short period of rest, complete three trials of 2 minutes of step-ups, followed by 30 seconds rest, then calculate the W:R.

Compare the energy systems and causes of fatigue for these two different tests. What other activities may have similar W:R?

9.6 Activity

9.6 Quick quiz on | **9.6 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4	

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TEST your understanding

1. **Define** the term *work-to-rest ratio*.
2. **Outline** two limitations of using the work-to-rest ratio.
3. **Identify** which energy system is associated with the following work-to-rest ratios:
   a. 1:4
   b. 1:6
   c. 3:1.

APPLY your understanding

4. Observe (directly or with a video recording) a sport of your choice for three 2-minute blocks.
   a. Record the work and rest times for each 2-minute block.
   b. Calculate the W:R.
   c. Which energy system does this W:R suggest is contributing most significantly?
   d. Compare the W:R and energy systems for each 2-minute block.

9.6 Exam questions

Question 1 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section A, Q.7; © VCAA*

The following data was collected during an activity analysis of an under-16 soccer game.

Work period			Rest period	
Sprint	Run	Jog	Walk	Stand
𝍸 |||	𝍸 |||	𝍸 𝍸 |||	𝍸 |||	||

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.

Question 2 (1 mark)

Source: Adapted from *VCE 2006, Physical Education Sample Exam, Section A, Q.3*; © VCAA

As the coach of a 16-year-old male tennis player, you performed a games analysis and observed a number of movement patterns and muscle actions performed by the player.

The work periods (high intensity) and rest periods were timed in the games analysis and the work to rest ratio was calculated to be 1:8.

The system that contributes most significantly used during the work periods by the player would be
A. ATP–CP
B. lactic acid
C. ATP
D. aerobic glycolysis

Question 3 (1 mark)

Source: *VCE 2008, Physical Education Exam, Section B, Q.18.a*; © VCAA

Touch rugby is a fast-paced game played by men and women. Teams are made up of six players on the field and up to six interchange players. Games consist of two 20-minute halves, with a 5-minute break at half-time.

The following data was obtained during an activity analysis of a touch rugby game.

Rest periods (% of game time)	
Standing (includes interchange)	26%
Walk forwards	16%
Jog backwards	7%
Walk sideways	5%
Slow jog	15%
Jog sideways	6%
Total	**75%**

Work periods (% of game time)	
Sprint forwards	9%
Sprint backwards	5%
Sideways intense shuffle	3%
Passing	2%
Fast jog	4%
Guarding/defending	2%
Total	**25%**

Calculate the W:R ratio for this game of touch rugby using the data provided.

Question 4 (6 marks)

A recent analysis of a game of grass-court tennis played between two competitors provided the following data:

- average rally time — 5.3 seconds
- average rest between rallies — 17.5 seconds
- length of the match in total — 3.5 hours
- length of time the ball was in play — 19 minutes, 20 seconds
- time spent changing ends and between games — 73 minutes.

a. **Explain** why it is important to undertake an analysis before developing a fitness program for an athlete. **(2 marks)**

b. **Calculate** the work-to-rest ratio from this data set. **(1 mark)**

c. **Justify** the role of each energy system in tennis using the data above. **(3 marks)**

Question 5 (1 mark)

Identify and **justify** when you would prefer to use W:R over heart rate telemetry to determine the energy system requirements of a sport or activity.

More exam questions are available in your learnON title.

9.7 Case study — Netball

Case study analysis

- Netball is a team sport that has seven very different positions. Each position has significantly different physiological requirements.
- Completing an activity analysis can help a coach ensure that each player, no matter what position they play, can achieve optimal results from training.

Source: VCE Physical Education Study Design (2017–2024) extracts © VCAA; reproduced by permission

9.7.1 Data collection

The first step of activity analysis is data collection. The following data was collected during an A-grade netball game from a 20-year-old playing centre. GPS and heart rate were recorded using digital recording (stored in electronic devices). Movement patterns, work-to-rest ratios and a skill frequency table were collected using direct observation.

TABLE 9.7 Data collected during an A-grade netball game from a 20-year-old playing centre

Digital recording	Direct observation (stored in electronic devices)
• GPS data • Heart rate with GPS	• Movement patterns • Work-to-rest ratios • Skill frequency table

TABLE 9.8 GPS data for netball centre

	Game time	Game time %	Distance (m)	m/min	Max speed (km/h)
Centre	55.1	89	4018	72.9	19.9

FIGURE 9.8 Heart rate data for netball centre

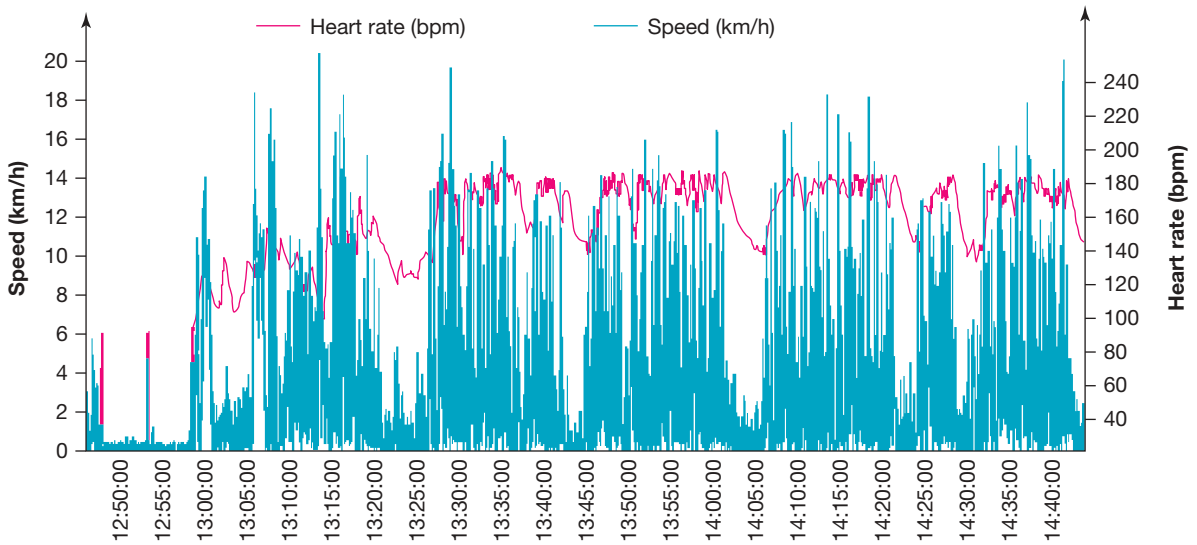


TABLE 9.9 Work-to-rest ratio for netball centre, where work is anything above walking pace

	Mean work period (seconds)	Mean rest period (seconds)	Mean work-to-rest ratio	Max. work duration (seconds)	Max. rest duration (seconds)	Max. work-to-rest ratio
Centre	2	4	1:2	9	69	1:8

TABLE 9.10 Skill frequency table for netball centre, taken from the first quarter (15 minutes)

Skill	Frequency
Pass	45
Catch	34
Dodge	23
Sprint	28
Defend	10
Jump	14
Walk	24
Run backwards	17

FIGURE 9.9 The Australian Kelpies team collects and analyses movement patterns, W:R, heart rate and skill frequencies data from games.



9.7.2 Data analysis

After the data has been collected, it needs to be analysed. The more data you can collect, the more accurate your analysis is likely to be.

TABLE 9.11 Data analysis of a netball game

Type of data	Example of data	Conclusion/What it means	Fitness test
Movement pattens	Total distance covered (4018 m)	Aerobic power and the aerobic energy system are important; need to work in the presence of oxygen	Aerobic power test: a test that involves changes of intensity and has a stop and start nature (e.g. yo-yo test)
	Maximum speed was 19.9 km/h	Speed is important	20-metre sprint
	GPS data movement patterns of many short and repeated efforts	Anaerobic capacity is important	Phosphate recovery test
HR or movement patterns GPS	Much of the game time is spend in the aerobic training zone (70–85% MHR)	Aerobic power is important	Cooper 12-minute run, working within aerobic training zone
	A significant amount of time is spent working at around 85% MHR	Working at LIP is important	Aerobic power test: shuttle run, as more time spent close to LIP
	Speed varies greatly	Anaerobic capacity is important	Phosphate recovery test
	The duration of the match is 1 hour	Aerobic power is important	Phosphate recovery test
W:R	Mean W:R (1:2)	Aerobic energy system contributes significantly	Aerobic power test
Skill frequency table	45 passes made in the game	Upper body muscular power is important	Basketball throw
	34 catches made in the game	Hand–eye coordination is important	NA
	23 dodges in the game	Agility is important	Illinois agility test
	28 sprints in the game	Speed is important	20-metre sprint test

9.7.3 Planning a training program

Once the analysis is completed, the information can be used to help plan a specific training program. It is important to note that the above process should be completed for all positions in a sport. While there may be similarities within sports, different positions often require different fitness components, energy systems and muscle movements.

Based on the data provided, figure 9.10 demonstrates what should be considered when planning a program (covered in topic 11) for a netball centre.

FIGURE 9.10 Considerations for program planning for a netball centre, based on activity analysis

Fitness components

Based on the data analysis, the important fitness components for a netball Centre are:
- aerobic power
- anaerobic capacity
- speed
- agility
- upper body power
- hand-eye coordination.

Energy systems

Based on the data analysis, the most important energy system for a netball Centre is the aerobic energy system. The ATP–CP system helps the athlete sprint and pass. Given that there is a lot of opportunity for recovery, the anaerobic glycolysis system is unlikely to contribute significantly, unless the sprints and passes are repeated with insufficient recovery.

Muscles and muscle groups

- Upper body (deltoids, pectorals, biceps, triceps, flexors and extensors)
- Lower body (quadriceps, hamstrings, gastrocnemius, soleus, glyteals)
- Core muscles for efficiency in running and changing direction (abdominals, obliques)

Fitness testing

This information should then be used to choose the most specific fitness tests. The following tests would be best as they replicate the requirements (muscles and movements) of netball.
- **Aerobic power:** a test that mimics the change of intensity, stop and start nature (e.g. yo-yo test)
- **Anaerobic capacity:** a test that has repeated sprint efforts (e.g. phosphate recovery test)
- **Speed:** a test that is not longer than 20 metres (e.g. 20-metre sprint)
- **Agility:** tests that either involve 'weaving' or short sharp changes of direction (e.g. Illinois agility test or 5-0-5 agility test)
- **Upper body power:** tests that involve the upper body muscles (e.g. basketball throw)

Training methods

- **Aerobic power:** fartlek or long interval training to replicate the change in intensity and stop and start nature
- **Anaerobic capacity:** short interval to replicate the distances typically covered (no more than 20 metres)
- **Speed:** short interval to replicate the distances typically covered (no more than 20 metres)
- **Agility:** short interval with changes of direction (e.g. shuttle runs) to replicate the movements and distances covered
- **Upper body power:** upper body plyometrics (e.g. medicine ball slams) to replicate the muscles and muscle groups used in passing

9.7 Activity

9.7 Quick quiz on | **9.7 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4	5

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TEST your understanding

1. **List** the different types of activity analysis used in the netball case study.
2. For each type of activity analysis listed in question 1, **outline** what information can be gained from this method.
3. **Identify** an advantage and a disadvantage of using digital recording.

APPLY your understanding

4. Watch a game of netball (preferably elite netball).
   Discuss whether the same fitness tests and training methods would be used for a goalkeeper or goal attack. Use specific examples to **justify** your response.
5. Complete an activity analysis for a sport of your choice.
   a. Collect at least three pieces of data.
   b. **Analyse** the data to **identify** and **justify** the predominant fitness components, energy systems and muscles.

9.7 Exam questions

Question 1 (8 marks)

Source: *ACHPER 2014, Trial Exam Units 3 & 4, Section B, Q.4a–c;* © ACHPER

Melissa is a Centre player for her secondary school netball team. The following data about Melissa was collected by her coach from the first quarter of a netball match. The match consisted of 4 × 10 minute quarters.

Work-to-rest ratio	
Work/Rest periods	**Time (seconds)**
Shortest work period	0.61
Longest work period	11.09
Shortest rest period	1.37
Longest rest period	31.21

	Work (seconds)	Rest (seconds)
Total	186.99	444.6
	1	2.378
Ratio (approx.)	1	2

Skills and their frequency	
Skill	**Frequency**
Chest pass	9
Overhead pass	15
Catch	18
Jump	13
Guard	8
Defend	13
Leap forwards	15
Leap sideways	7
Change of direction	55
Centre pass	5

Locomotor patterns									
Loco-motion	**Intensity**	**0–5 metres**	**6–10 metres**	**11–15 metres**	**16+ metres**	**Total (count)**	**Distance meters**	**% Total**	**Average metres**
Walk	Low	12	7	3	2	24	111	26	4.6
Jog	Low–medium	12	7	1	1	21	147	35	7.0
Sprint	High	11	9	1	0	21	127	30	4.8
Shuffle	Very high	18	4	0	0	22	36	9	1.6
Totals		**53**	**27**	**5**	**3**		**421**	**100%**	

a. **Outline** two reasons why data is collected before starting a training program. **(2 marks)**
b. **Identify** two fitness components that Melissa would require to be a successful Centre player. **(2 marks)**
c. Using the data provided, **justify** your choices in **part b** above. **(4 marks)**

More exam questions are available in your learnON title.

9.8 Key skills

Key skill
• undertake an activity analysis and analyse associated data to justify the required physiological requirements

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9.8.1 Tell me

To address this key skill, it is important to remember:

- activity analysis should be the first step in any training program
- the purpose of completing activity analysis is to determine the physiological requirements (energy systems, fitness components and muscles/muscle groups) required to develop a specific training program
- different types of data (movement patterns, W:R, heart-rate monitoring and skill frequency tables) provide information about different physiological requirements
- when determining the important physiological requirements, data should be used to support justifications.

9.8.2 Show me

Practice question (5 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Table from *ACHPER 2023, Trial Exam Units 3 & 4, Section B, Q.3.d;* © ACHPER

While playing a small-sided volleyball game over 10 minutes, data is collected. The information is displayed in the table below.

Skill/Movement	Frequency
Dig	10
Set	5
Spike	9
Jump	15
Change direction	30
Sprint	27
Back peddle	9
Serve	6

a. **Name** the *type of data* represented in the table. (1 mark)

b. **Explain** the purpose of *conducting* this activity analysis for *volleyball*. (2 marks)

c. Based on the *data*, **identify** and **justify** a fitness component that is *important* in volleyball? (2 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Name — identify or state
  Explain — provide detail to show the relationship between concepts
  Identify — determine the key characteristics or features
  Justify — prove with reasoning why an option chosen is the best
- **Key terminology** — *type of data*, *conducting*, *volleyball*, *data*, *important*
- **Key concepts** — activity analysis, fitness component
- **Marking scheme** — 5 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a. *Skill frequency table.*
Award 1 mark for identifying that the type of data represented is a skill frequency table.

b. To determine the *important* physiological components (fitness components and muscles/muscles groups) required to be *successful* in *volleyball* and to create a specific training program.
Award 1 mark for identifying fitness components and muscles/muscle groups as the physiological requirements for volleyball.
Award 1 mark for identifying that a specific training program can be created.

c. Agility — the ability to *change direction with speed and balance* would be required for the *30 changes of direction*.
Speed — the ability to *move from one point to another as quickly as possible* would be required for the *27 sprints*.
Award 1 mark for identifying a fitness component.
Award 1 mark for justifying how the fitness component is important in volleyball, referencing the data.

9.8.3 Let me do it

Question 1 (5 marks)

Source: Table from *VCE 2023, Physical Education Exam, Section A, Q.5*; © VCAA

Below is a sample of data collected from an activity analysis from a basket ball team.

Activity	Speed of movement (km/hr)	Total distance covered (m)	Percentage of time in activity (%)
Standing	0	0	32
Walking	≤ 6	1720	31
Jogging	6.1–12	1870	5.6
Running	12.1–18	928	4.5
Striding	18.1–24	406	2.4
Sprinting	> 24	763	2.8

Source: Adapted from C Castagna et al., 'Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness', *The Journal of Strength and Conditioning Research*, September 2010

a. **Identify** what type of data is represented in the table above. **(1 mark)**

b. **Explain** the purpose of conducting an activity analysis for a basketball team. **(2 marks)**

c. Based on the total distance covered and percentage of time spent completing each activity, **identify** and **justify** which energy system is the most important. **(2 marks)**

9.9 Review

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9.9.1 Summary

Data collection from activity analysis

- Data collection is the first step of activity analysis. The findings of the analysis of the data should then shape the fitness testing that is prescribed.
- Activity analysis is a key technique that can be used to determine the physiological requirements of a sport. It uses movement patterns, heart rates, GPS, skill frequency tables and work-to-rest ratios to determine the main energy systems, fitness components and muscles being used (see table 9.10).
- Observation is a practical method of data collection but it has low accuracy.
- Digital recording, while less practical than observation, is much more accurate.

Skill frequency analysis

- Skill frequency tables are generally referred to as 'stats'. These can indicate the important fitness components and muscles/muscle groups required to perform a sport or activity.

Movement pattern analysis

- Movement patterns are the typical movements completed by a performer during a sport or activity. They can indicate the important fitness components and muscles/muscle groups required for that sport or activity.

Heart rate analysis

- Heart rate is typically used to estimate physical activity as energy expenditure (oxygen uptake), based on the assumption that there is a linear relationship between heart rate and energy expenditure. This, in turn, indicates the contributions being made by the energy systems during a sport or activity.

Work-to-rest ratio analysis

- Work-to-rest ratios (W:R) summarise the time an athlete spends physically working compared to the time spent resting or recovering. They can be used to identify the contributions from the energy systems.
  - A W:R of 1:5 and above (rest significantly higher than work) is associated with the ATP–CP energy system.
  - A W:R of 1:3–1:4 (rest higher than work) is associated with the anaerobic glycolysis energy system.
  - A W:R of 1:1–1:2 or 2:1 or above (work similar to rest OR work higher than rest) is associated with the aerobic energy system.

9.9.2 Key terms

activity analysis the recording and analysis of movement and skill data from a game, sport or activity
data collection the process of gathering information
GPS Global Positioning System. This technology uses satellites to identify position and movement.
movement patterns the typical movements completed by a performer during a sport or activity
work-to-rest ratio a summary of the time an athlete spends physically working compared to the time spent resting or recovering

9.9 Exam questions

9.9 Section A — Multiple choice questions

Question 1 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.3;* © VCAA

An athlete has their heart rate data collected as part of an activity analysis. Heart rate data could be used to help design a training program by first identifying

A. the muscle groups used.
B. appropriate fitness tests.
C. the contribution of the energy systems.
D. any error correction required in the athlete's movement.

Question 2 (1 mark)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section A, Q.8;* © ACHPER

The type of data which would best determine the contribution of energy systems from an activity analysis would be

A. movement patterns.
B. skill frequency.
C. intensity and duration of work and rest intervals.
D. work to rest ratios.

Question 3 (1 mark)

Source: *VCE 2015, Physical Education Exam, Section A, Q.3;* © VCAA

Theo wants to design a training program for his hockey season. Which one of the following should he do first?

A. Complete fitness testing.
B. Undertake an activity analysis.
C. Design specific training sessions.
D. Determine the length and periodisation of the training program.

Question 4 (1 mark)

Source: Table from *VCE 2019, Physical Education Exam, Section B, Q.10;* © VCAA

Use the following data for questions 4 and 5.

Data	Jan's season average	AFLW player's season average
Total distance covered	5.9 km	7.2 km
Top speed	23 km/h	27 km/h
Number of repeated sprints over 18 km/h	7	10

The data collected is:

A. heart rate.
B. work-to-rest ratio.
C. movement patterns.
D. skill frequency.

Question 5 (1 mark)

The data shown at question 4, is most likely to provide information about:

A. energy system contributions.
B. muscles and muscle groups.
C. strengths and weaknesses.
D. position suitability.

Question 6 (1 mark)

Goalshooter	
Skill	**Frequency**
Passes • chest • overhead • shoulder **Total**	 10 4 5 **19**
Rebounds	6
Shot taken	13
Intercepts/steals	3
Penalties	4
Guards/defends	18

The data in this table suggests that the most important fitness component for the goal shooter is:

A. aerobic power.
B. muscular power.
C. muscular endurance.
D. muscular strength.

Question 7 (1 mark)

A very short high-intensity effort as measured by GPS data is most likely to require which fitness component?

A. Muscular power
B. Muscular strength
C. Aerobic power
D. Muscular endurance

Question 8 (1 mark)

Which form of activity analysis can best determine important muscles and muscle groups?

A. Heart rate telemetry
B. GPS
C. Movement patterns
D. Skill frequency table

Question 9 (1 mark)

In order to gather information about fitness components and energy systems, the best forms of activity analysis to use would be:

A. skill frequency table and GPS.
B. heart rate telemetry and work-to-rest ratio.
C. GPS and movement patterns.
D. movement patterns and heart rate telemetry.

Question 10 (1 mark)

A work-to-rest ratio that shows the anaerobic glycolysis system as the major contributor is:

A. 1:4
B. 1:6
C. 2:1
D. 6:1

More exam questions are available in your learnON title.

9.9 Section B — Short answer questions

Question 1 (8 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.6;* © ACHPER

The following table represents the movement patterns of a centre player in a game of interschool netball.

Locomotor movement pattern	Percentage of game time %
standing	14.3
walk forward.	24.5
wall backwards	8.8
shuffle	4.0
jog	18.3
stride	20.8
sprint	9.3

a. **Outline** two reasons for the collection of data. **(2 marks)**
b. **Suggest** two ways this data collection could be improved to enable the coach to have a better understanding of the physiological requirements of a centre player in netball. **(2 marks)**
c. **Discuss**, with reference to the data above, two important fitness components for the centre player. **(4 marks)**

Question 2 (2 marks)

Source: *VCE 2011, Physical Education Exam, Section B, Q7.b.i;* © VCAA

A local school runs an annual triathlon that involves students from all year levels and fitness abilities. The triathlon involves a 400-m swim, 10-km bike ride and 4-km run. The following is a description of two Year 10 students who competed this year.

Student	Description
Tiffany	Tiffany has been entering and competing in triathlons for two years. A year ago she joined a triathlon club and recently came third in her age group at a locally sponsored triathlon. Her coach believes she has great potential in the sport based on the improvement she has made in the last two years. Tiffany has an average resting heart rate of 55 beats per minute.
Michelle	Michelle does not play competition sport but recently joined a gym to improve her fitness and self-esteem. Her initial fitness assessment from the gym rated her fitness as average. The training program designed by the gym instructor involved basic weights as well as various aerobic machines to improve her aerobic fitness. Michelle has an average resting head rate of 75 beats per minute.

List two types of data that could be collected as part of an activity analysis on a triathlon.

Question 3 (8 marks)

TABLE 1 Korfball games analysis taken from player 1 throughout the first half

Passes	99
Catches	67
Dodges	103
Side steps	87
Intercepts	8
Shots	16
Lunges	110
Balancing on one foot	23
Defending stance	88
Holding position	45

TABLE 2 Work-to-rest ratio from player 1 throughout the second half (2-minute time sample)

W	R	W	R	W	R	W	R	W	R
17	20	15	10	8	10	13	9	9	9

a. Using data from above, **justify** an important fitness component required to be successful in Korfball. **(2 marks)**

b. Using the data above, **justify** the most important energy system. **(2 marks)**

c. Discuss an advantage of collecting multiple types of data. **(4 marks)**

Question 4 (3 marks)

Two Year 12 students, Katherine and Sharon, undertook an activity analysis in order to assess the requirements of training for, and then competing in, a 10-kilometre Fun Run event. The girls also analysed the heart rate data of an elite 10-kilometre runner as part of their data collection to determine the requirements of successfully completing the event.

a. **Outline** why it is important to analyse the performance data of an elite 10-kilometre athlete rather than that of a novice runner. **(2 marks)**

b. Other than using a heart rate monitor, **state** one type of data collection that could be used as part of an activity analysis for a 10-kilometre Fun Run event. **(1 mark)**

Question 5 (3 marks)

Daniel is a Year 12 student who trained to compete in an 8-kilometre Fun Run. The race was held on a flat course that comprised 2 × 4-kilometre. On the night of the race, the air temperature was 33 °C.

During the race, the following data was collected via a heart rate monitor and GPS.

Distance	Time (minutes)	Average heart rate
1 km	4:09	166 bpm
2 km	4:13	172 bpm
3 km	4:26	173 bpm
4 km	4:23	173 bpm
5 km	4:38	173 bpm
6 km	4:37	175 bpm
7 km	4:38	176 bpm
8 km	4:13	180 bpm

a. **Identify** the energy system that was contributing most significantly for Daniel during this event. **(1 mark)**

b. Complete the table below to indicate what data is collected using the different methods. **(2 marks)**

Method of data collection	Data collected
GPS	
Heart rate monitor	

Continue to build your exam skills

Access the Unit 4 Area of Study 1 Review at the end of Topic 10. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

10 Training program planning — assessment of fitness

10.1 Overview

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LEARNING SEQUENCE

10.1 Overview
10.2 The purpose of fitness testing
10.3 How to conduct fitness testing
10.4 Aerobic power and anaerobic capacity tests
10.5 Muscular strength, muscular power and muscular endurance tests
10.6 Speed and agility tests
10.7 Flexibility tests
10.8 Key skills
10.9 Review

10.1.1 Introduction

Fitness testing plays an important role in the development of a specific training program. The more specific a training program is, the more successful it is likely to be. Fitness testing should follow protocols to ensure participant safety. The tests need to be chosen carefully, based on activity analysis, and administered appropriately to ensure the results are valid, reliable and accurate. Fitness testing can provide feedback on the success of the training program and help to guide modifications. Knowing what needs to be done before testing and being able to describe and undertake the testing process are key skills in the development of an effective training program.

FIGURE 10.1 Why do we use fitness tests and what needs to be taken into consideration when deciding on a specific fitness test?

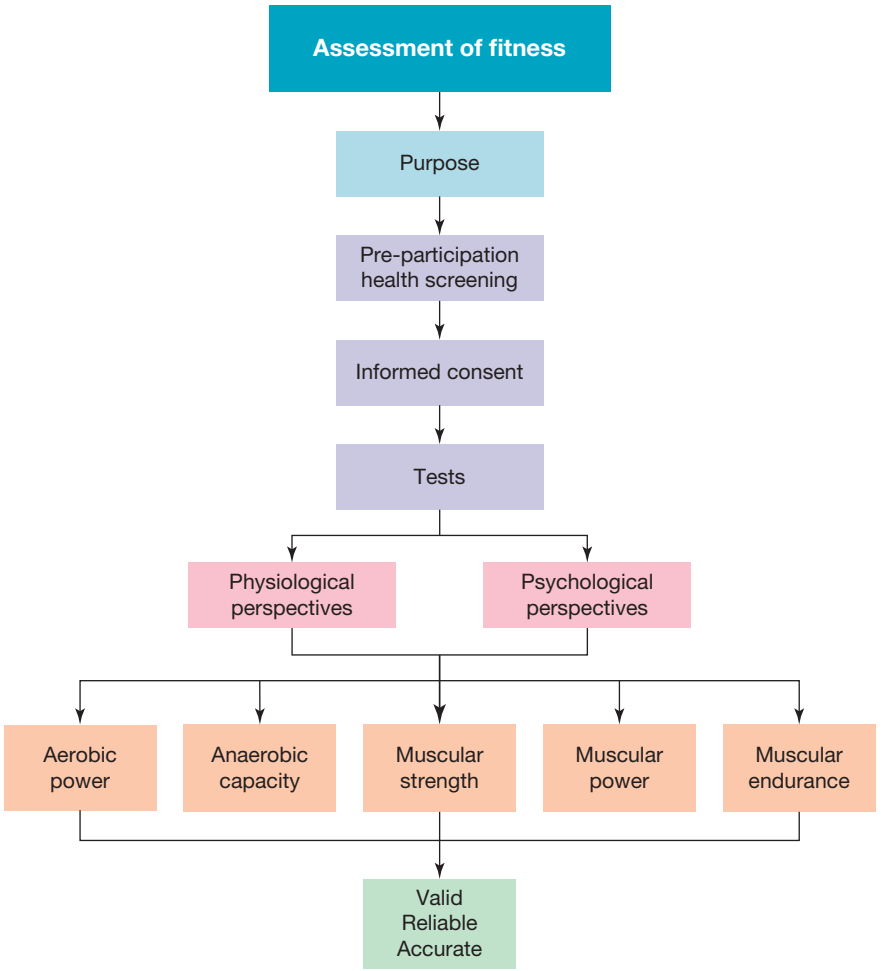


10.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• assessment of fitness for an activity: – the purpose of fitness testing from physiological and psychological perspectives	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity	**10.2**
– pre-participation health screening and informed consent		**10.3**
– standardised, recognised fitness tests that test appropriately identified physiological requirements	• 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	**10.4** **10.5** **10.6** **10.7**
– test reliability, validity and accuracy	• perform and observe a reliable, valid and accurate assessment of fitness	**10.3**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

10.1.3 Topic preview



10.2 The purpose of fitness testing

Key knowledge	Key skill
• 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	• justify the selection of standardised, recognised fitness tests for the specific physiological requirements of the activity

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

10.2.1 Importance of fitness testing

Fitness testing can be a very important part of a successful training program if used and administered correctly. Once activity analysis has been completed and the important fitness components have been identified, testing can begin. It is important that the tests are carefully selected, based on the physiological and psychological requirements of the athlete. When planning and administrating tests, steps should be taken to ensure both the safety of the athlete and that the tests are valid, reliable and accurate (see subtopic 10.3). This includes completing pre-participation health screening and gaining informed consent. Once completed, fitness test results can be used for a range of reasons, and the purpose will vary depending on the timing and the needs of the athlete and/or coach. However, if completed using the appropriate testing protocols, all testing aims to create the most specific, and therefore most successful, training program.

physiological perspective examination and understanding of the various bodily systems and functions that influence athletic performance

10.2.2 Physiological perspectives

Fitness tests should be chosen taking into account the **physiological perspective** of the participant, such as their current fitness level and health conditions, as this determines whether the participant is physically capable of completing certain tests. A number of factors need to be considered when choosing appropriate fitness tests to ensure specificity. The tests should replicate the requirements of the activity (e.g. in terms of distance, duration, movement patterns and directions) as identified in the activity analysis. For example, to test aerobic power, the Cooper 12-minute run test is more likely to be chosen for a triathlete due to its continuous nature, while the yo-yo test, which involves changes in direction and intensity, is more suitable for testing the aerobic power of a soccer midfielder. There are also physiological and psychological perspectives that need to be considered. One of the most effective ways to gain information about the physiological state of a participant is by using a pre-participation health screening tool, such as the Physical Activity Readiness Questionnaire (PAR-Q). Pre-participation health screening, most often done through a PAR-Q, is a vital component of fitness testing, particularly pre-training program testing. Pre-participation screening involves a series of questions about the participant's current health. These often include questions about heart health, previous and current injuries, and current exercise levels. This information can then be

FIGURE 10.2 Pre-participation health screening ensures the participant's physiological and psychological health status informs the testing and training program to be undertaken.



analysed to determine if fitness testing could be a risk for the individual. It can also be used to determine the level of risk and to help choose appropriate tests.

For example, you would not ask an overweight 50-year-old to complete a VO_2 max test or multistage fitness test; rather, you might choose the Rockport 1.6-kilometre walk. An overweight 50-year-old is unlikely to have high levels of aerobic power, so completing the VO_2 max test or multistage fitness test, which are exhausting in nature, may be physically dangerous for them. In contrast, the Rockport 1.6-kilometre walk is a submaximal test and is therefore unlikely to put the participant at risk.

10.2.3 Psychological perspectives

Like physiological perspectives, the current psychological state of a participant may influence the effectiveness of testing and should therefore be considered carefully when choosing appropriate fitness tests. Knowing the purpose of the testing for the individual is an important step in this.

A participant who wants to know their strengths and weaknesses may choose different tests from someone who is starting their first gym program. A coach and a personal trainer will test for different reasons and thus the tests chosen may differ.

A questionnaire, similar to a PAR-Q (see figure 10.5), can be used to determine the psychological state of the participant. Collecting such information is not only important in managing risks but can also provide vital information about the participant's motivation and goals, which can help when choosing specific tests.

For example, a participant who is undertaking testing and a training program to improve their overall health and wellbeing is more likely to undergo the seven-stage abdominal strength test than a 1 RM bench press. A participant wanting to improve their athletic performance for rugby is more likely to choose the 1 RM test.

Another important **psychological perspective** can be the way in which the tests are administered. Sometimes completing the multistage fitness test with teammates or classmates can be motivating; by contrast, it is challenging to become motivated for the cycle ergometer test due to its exhaustive nature.

psychological perspective examination and understanding of the mental and emotional aspects that influence athletic performance, behaviour and experiences

For an example of an adult pre-test screening questionnaire from Exercise and Sports Science Australia, access the **Pre-test screening questionnaire** in the digital documents section of the Resources panel.

10.2.4 Pre-training program testing

At a minimum, to ensure the specificity of the fitness program, fitness testing should be performed before the start of the training program once activity analysis has been completed and appropriate tests have been chosen. The results of pre-testing should provide the blueprint for the training program.

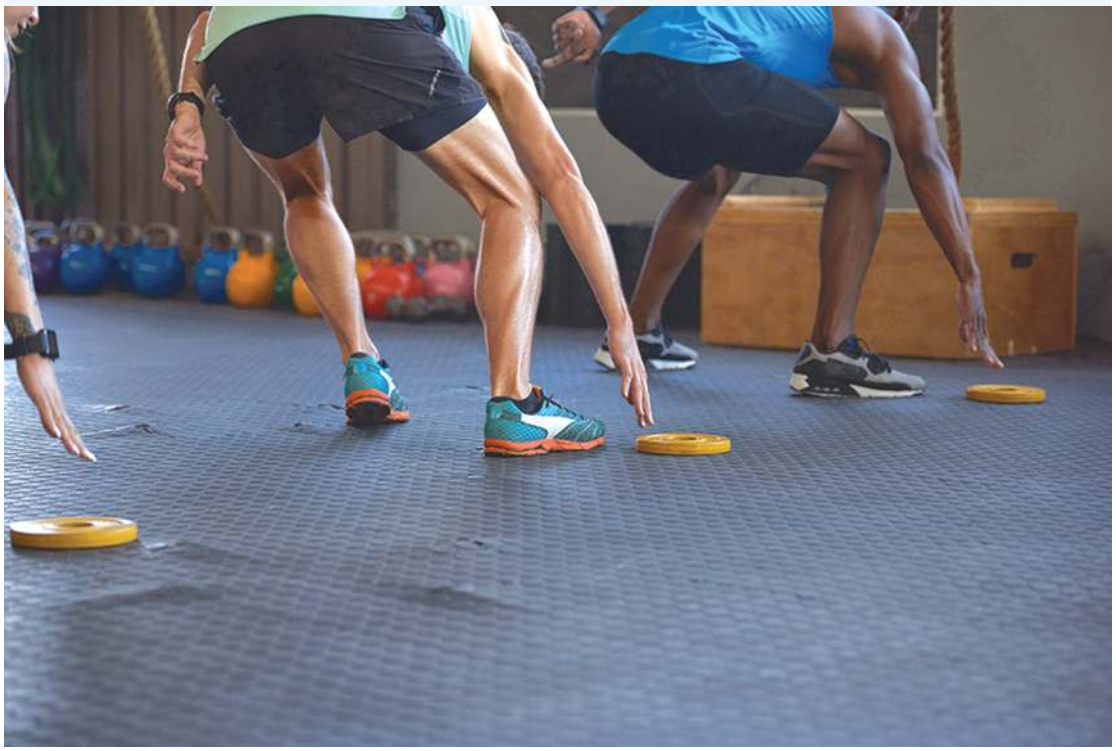
Pre-training program fitness testing aims to:

- *set benchmarks.* Collecting data from pre-training testing can allow the participant and coach to set 'benchmarks' for training. This data can also be referred to as baseline data. Collection of baseline data allows realistic and specific goals to be set and accurate evaluation to occur. This can be done at an individual level or at a group level for team sports.
- *assess strengths and weaknesses of participants.* Fitness tests identify an individual's strengths and weaknesses in the major components of fitness that are important to a particular sport or activity. This information allows for the most appropriate training methods (see topic 13) to be selected and therefore allows for the design of a specific individual training program that is geared towards maintaining strengths and improving weaknesses.
- *motivate participants.* Fitness test results that outline specific capacities and attributes, and identify individual strengths and weaknesses, can provide strong motivation and incentive for participants to continue training and to strive for improvement. This is particularly likely if the results are positively

and constructively presented. Fitness testing is a way of predicting future performance and allowing the participant to know to what level they can realistically aim.

- *assess suitability of participants for a sport or position.* Fitness test results enable participants to ascertain their capacity to perform certain tasks. The tests can indicate specific personal attributes that the participant and coach can use to help determine the types of event or playing position to which the player is best suited. A soccer player who scores highly in a test of aerobic power, for example, may be best suited to playing as a midfielder or on-baller — roles that involve covering greater distances in the game — rather than in a set position such as goalie.

FIGURE 10.3 Data collected from pre-training testing sets a baseline for the fitness on an athlete. Any data collected after this can be used and compared to the baseline to see if there have been any improvements or decline in fitness.



10.2.5 Testing during training

Fitness testing during a training program can help coaches evaluate how the participant and training program are going. The number of times testing is undertaken will depend on the length of the program. Testing should not occur any earlier than six weeks into a training program, to allow chronic adaptations to occur (see topic 14).

Testing during training aims to:

- *motivate participants*. Participants may have set goals and testing results may encourage the participant to maintain or improve in order to achieve their goal.
- *evaluate the effectiveness of the program*. Testing results will indicate if there have been improvements in fitness components. If the training program is effective, improvements would be expected. If this has not occurred, then the training program will need to be modified.

This type of feedback is vital in monitoring progress and training efficiency, as well as driving necessary modifications.

10.2.6 Post-program testing

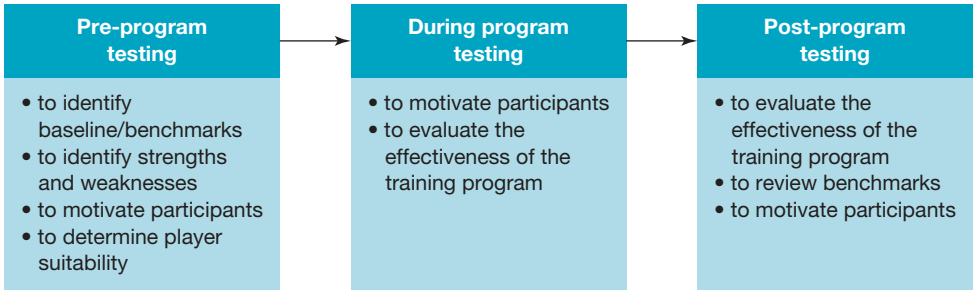
Post-program testing is completed once the training program is over. This provides vital information for the participant about the impact of the training program.

Post-training testing aims to:

- *evaluate the effectiveness of the training program*. If the training program has achieved its aims, this would suggest that the methods and principles (see topics 12 and 13) have been applied correctly and that a similar process should be put in place for the next training program. If the training program has failed to achieve its aims, significant modifications may be required. This would involve reviewing the methods and principles put in place.
- *review benchmarks*. This will help determine how effective the program has been and also help in the preparation of future programs.
- *motivate participants*. Participants may be motivated by either positive or negative results.

Figure 10.4 summarises the reasons for conducting fitness testing.

FIGURE 10.4 Reasons for fitness testing



on Resources

Digital documents Pre-test checklist for testing in the laboratory (doc-22229)
Pre-test screening questionnaire (doc-22227)

EXAM TIP

It is important to be specific to the tests and participant when discussing the purpose of the tests and the perspectives of testing.

For example, for someone who is beginning a program, pre-program testing can be motivating to improve or reach goals, but for an elite athlete it may be motivating to gain selection in teams or qualify for events.

10.2 Activity

10.2 Quick quiz on | **10.2 Exercise**

Learning pathways

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1, 3	2, 4, 5	6, 7

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TEST your understanding

1. **Outline** when you should complete fitness testing, and why.
2. **Suggest** how motivation can result from fitness testing.
3. **Outline** what is meant by *physiological perspectives* and *psychological perspectives*.
4. **Discuss** the difference between the purpose of activity analysis and fitness testing.

APPLY your understanding

5. **Suggest** why post-program testing may not be useful if pre-program testing was not completed.
6. Using an example, **explain** how doing a test with others may be psychologically appropriate.
7. A test may be physiologically appropriate, but not psychologically appropriate. Using an example, **explain** how this is possible.

10.2 Exam questions

Question 1 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.8*; © VCAA

Which of the following is not a purpose of pre-training testing?

A. evaluating effectiveness
B. motivating athletes
C. identifying strengths and weaknesses
D. assessing suitability

Question 2 (2 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.7.b;* © ACHPER

Elite athletes often undergo fitness testing to determine their strengths and weaknesses.

Outline two other purposes of performing fitness testing.

Question 3 (4 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.5.a,c;* © ACHPER

At the start of each school term a school requires students to participate in the 20 m Shuttle Run Test (SRT), also known as the 'Beep' test.

a. **Explain** one psychological purpose of conducting fitness testing. **(2 marks)**
b. **Outline two** reasons why a teacher may choose to use the 20 m SRT as a fitness test for students at the beginning of each school term. **(2 marks)**

Question 4 (4 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.2.b*; © VCAA

An under-14 secondary school volleyball team completed a day of fitness testing and training at the Australian Institute of Sport with the national women's volleyball team.

Throughout the day, the students completed fitness testing specific to volleyball. One of the tests was the vertical jump.

Justify the suitability of the vertical jump for the elite athletes of the national women's volleyball team from physiological and psychological perspectives. Make specific reference to validity in your response.

Question 5 (2 marks)

Source: *VCE 2013, Physical Education Exam, Section B, Q.10;* © VCAA

An activity analysis conducted on a basketball game found that the predominant fitness components required for the sport were muscular power (lower body) and agility.

What is the purpose of conducting fitness tests prior to writing a training program?

More exam questions are available in your learnON title.

10.3 How to conduct fitness testing

Key knowledge	Key skills
• assessment of fitness for an activity: – pre-participation health screening and informed consent – test reliability, validity and accuracy	• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

10.3.1 Test protocols

Ensuring the participant has a clear understanding of the testing process will help them to prepare from a psychological perspective. Players' rights and facilitators' responsibilities are an essential aspect of fitness and training. Before any fitness tests are carried out, it is essential that all facilitators clarify all testing procedures and risks to their participants. Participants should be clearly informed about the nature of the fitness testing they are being directed to undertake, including:

- aims of testing
- methods of testing
- safeguards for testing (those responsible for managing fitness testing procedures must be qualified and experienced in all fitness-testing protocols).

The best way to ensure the above is to get the participants' informed consent.

Informed consent

Most accredited fitness centres now have standard forms for their clients to complete that give their acknowledgement of risks associated with the fitness testing and training programs they are about to undertake. These forms may also acknowledge that all fitness test results are confidential and are only to be used for agreed personal fitness or sports training outcomes. Informed consent aims to protect the interests of both the testing organisation and the participants. It has both legal and ethical implications.

Informed consent should:

- clearly outline that the individual can withdraw consent, freely and without prejudice, at any time before, during, or after testing
- outline the specific uses of the information to be obtained from the testing sessions and guarantee the confidentiality of any information obtained during testing
- require participants to advise the tester if they have any injury, illness or physical defect at the time of testing. Ideally, also complete a health-screening questionnaire such as a PAR-Q (see figure 10.5).
- outline the risks of the testing
- allow participants to ask questions
- obtain the participant's signature. When the participant is less than 18 years of age and the consent of a parent or guardian is required, the consent documentation should provide a statement for the parent or guardian to sign.

Other things to consider regarding informed consent include clearly identifying the testing organisation and the departments and individuals involved in conducting the testing, and explaining the nature of any sport science test to be performed, along with any possible risks.

FIGURE 10.5 Health-screening questionnaires such as a PAR-Q should be used as a minimum for pre-participant screening.

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→ **DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT _____ WITNESS _____

or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

© Canadian Society for Exercise Physiology www.csep.ca/forms

FIGURE 10.6 Most accredited fitness centres have standard release forms.

INFORMED CONSENT FOR EXERCISE TESTING

I hereby voluntarily give consent to engage in a fitness test. I understand that the cardiovascular fitness test will involve progressive stages of increasing effort and that at any time I may terminate the test for any reason. I understand that during some tests I may be encouraged to work at maximum effort and that at any time I may terminate the test for any reason.

I understand there are certain changes that may occur during the exercise test. They include abnormal blood pressure, fainting, disorders of heart beat, and very rare instances of heart attack. I understand that every effort will be made to minimise problems by preliminary examination and observation during testing.

I understand that I am responsible for monitoring my own condition throughout testing, and should any unusual symptoms occur, I will cease my participation and inform the test administrator of the symptoms. Unusual symptoms include, but are not limited to, chest discomfort, nausea, difficulty in breathing, and joint or muscle injury.

Also, in consideration of being allowed to participate in the fitness test, I agree to assume all risks of such fitness testing, and hereby release and hold harmless _____, and their agents and employees, from any and all health claims, suits, losses or causes of action for damages, for injury or death, including claims for negligence, arising out of or related to my participation in the fitness assessments.

I have read the foregoing carefully and I understand its content. Any questions that may have occurred to me concerning this informed consent have been answered to my satisfaction.

Name	Date
Witness	Date

10.3.2 How to ensure test reliability, validity and accuracy

Test validity

An appropriate fitness test must be valid; that is, it should measure what it claims to measure. Table 10.1 shows examples of how to ensure the **validity** of different types of tests.

validity the degree to which a test, measurement, or assessment tool accurately measures what it claims to measure

TABLE 10.1 How to ensure a test is valid

Test focus	For the test to be valid, it must…
Aerobic power	be of sufficient duration to test the capacity of this energy system
Agility	include changes of direction and be able to be completed at maximal intensity (i.e. should not be too long)
Speed	be able to be completed at maximal intensity, which will require an appropriate distance/duration and recovery
Anaerobic capacity	use the anaerobic energy systems, which may include insufficient recovery time
Muscular strength	allow for maximal force to be developed by having maximal resistance and fewer repetitions
Muscular endurance	allow for repeated contractions
Upper body muscular power	isolate the upper body muscles for an explosive contraction

Test reliability

A fitness test must also be reliable; that is, it must be able to be replicated with consistency. For a test to be reliable, the only variable that should change between tests is the participant. Since **reliability** depends on a number of factors remaining constant, each test occasion should involve:

- performing the same warm-up
- conducting the same sequence of tests
- providing the same recovery period between tests
- testing participants at approximately the same time of day
- testing participants when they are in a similar hydration and nutritional state
- having a consistent way of measuring the tests
- conducting the tests in similar environmental conditions (e.g. heat, humidity and air movement).

reliability consistency and dependability of measurements, tests, or assessments used to evaluate

accuracy precision of measurements, observations, or actions

FIGURE 10.7 Reliable results would not be obtained if the testing environments were different (e.g. sometimes conducting a test on an outdoor track and sometimes on an indoor track).





Test reliability also requires having trained and experienced test administrators. It is important that the person conducting the testing always does so to the best of their ability, under the most stable and reliable conditions.

If tests are reliable, they allow for fair and accurate comparisons to norms and previous/other test results. This can make the testing process more meaningful.

The results of the selected tests must be interpretable and comparable, and the participant should receive feedback about:

- what the results represent (good, average or poor performance)
- how the results compare with previous results
- how the results compare with those of other participants in the reference group
- the consequences and implications of the results.

Test accuracy

Fitness test **accuracy** means that the results recorded are a true reflection of what is being tested. There are many ways to increase the accuracy of fitness testing, including:

- calibrating equipment
- using specialised technology (e.g. timing gates to decrease the impact of human error)
- increased participant understanding of instructions.

Having a reliable and valid test will help to increase the accuracy of testing.

Fitness test battery

Testing sessions should be scheduled to coincide with the beginning and end of each training phase so that the effectiveness of the training phase can be assessed. Likewise, if a specific intervention has been programmed, pre- and post-testing is recommended to assess the impact of the intervention.

All test sessions should be scheduled at the same time of day to avoid fluctuations in physiological responses due to circadian rhythm (Winget et al., 1985) and to promote consistency in how the participant presents themselves for each test session.

It is recommended that the field tests be completed in a standardised order. This order should be determined in light of physiological considerations; that is, the completion of one test should not adversely affect performance in subsequent tests, thus promoting optimal performance and allowing for a valid comparison to previous test results. This test order will also require minimal recovery time between tests such as tests that rely on the ATP–CP system being completed first or avoiding two upper body tests in a row, thus allowing for an overall efficient testing session.

For example:

Day 1: vertical jump, 20-metre sprint, Illinois agility test, yo-yo test

Day 2: phosphate recovery test.

doc-41988

PRACTICAL ACTIVITY Protocols of fitness testing (fitness centre)

Goal

To understand the procedures fitness centres use for their clients.

Instructions

1. In groups, visit a local fitness centre and interview management staff on their centre's procedures for conducting fitness testing with their clients.
2. Ask for samples of any paperwork used.
3. Write a report that assesses the centre's methods.

Primary data/Reflection

- How does the fitness centre and trainer create a comfortable testing environment for clients?
- What key insights did you gather from the interview with fitness center staff regarding fitness testing procedures?
- In what ways did the interview shed light on the importance of individualised approaches to fitness testing?
- What were your impressions regarding the documentation and paperwork used by the fitness centre? Did it seem comprehensive and well-organised?

Questions

1. What are the primary fitness tests conducted with clients?
2. How do the staff determine which fitness tests are appropriate for each client?
3. What role does client history play in determining the fitness tests administered?
4. What insight does their paperwork or documentation provide about the client?

EXAM TIP

While increasing validity can help increase reliability, students must be able to provide examples of how tests are valid and reliable.

For example, the vertical jump test is a valid test for lower body muscular power as it is a one-off explosive effort of the legs. The vertical jump can be made reliable by ensuring that the athletes complete the same warm up and recovery before efforts.

10.3 Activity

10.3 Quick quiz on | **10.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 7	3, 4	5, 6

These questions are even better in jacPLUS!



- Receive immediate feedback
- Access sample responses
- Track results and progress

Find all this and MORE in jacPLUS

TEST your understanding

1. **Outline** the essential criteria for successful fitness testing.
2. **List** three ways to ensure a fitness test can be accurately repeated after a period of weeks or months.
3. **Discuss** the importance of informed consent.
4. **Suggest** two situations in which informed consent may need to be gained from someone other than the participant.

APPLY your understanding

5. **Explain** what is meant by a valid, reliable and accurate fitness test.
6. Using an example, **explain** the importance of following the instructions to ensure test validity.
7. **Outline** three ways in which a testing facilitator can ensure testing can be completed with minimal risks.

10.3 Exam questions

Question 1 (1 mark)

Source: *VCE 2011, Physical Education Exam, Section A, Q.1*; © VCAA

As the coach, you are completing fitness testing on an under-15 soccer team. Some of your friends have siblings in the team. Your friends know you are completing the testing and ask you about how their brother or sister performed in the test.

As the person conducting the test, what do you need to consider about releasing information about the results?

A. accuracy
B. reliability
C. specificity
D. confidentiality

Question 2 (2 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.8;* © ACHPER

Tim is a 60-year-old semi-retired adult. He regularly rides a bike for his fitness. He would like to participate in a charity bike ride in six months. The ride will cover 600 km over four days.

His partner Jill is 56 years old and has lived a sedentary life for the past 10 years. Jill would like to join Tim on the bike ride as she has a passion for the charity Tim will be riding for.

Tim and Jill consult with Zara, the event manager of the ride, who is also an exercise scientist. Zara advises them to complete a battery of fitness tests to determine the type of training required in preparation for the event.

Zara has asked Tim and Jill to complete a PAR-Q. **Discuss** the purpose of a PAR-Q.

Question 3 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.2.a*; © VCAA

An under-14 secondary school volleyball team completed a day of fitness testing and training at the Australian Institute of Sport with the national women's volleyball team.

Throughout the day, the students completed fitness testing specific to volleyball. One of the tests was the vertical jump.

Explain how informed consent should be applied to the under-14 volleyball team.

Question 4 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section B, Q.7.a*; © VCAA

Rugby sevens is a version of rugby played with seven players on each team. The players are usually very mobile, as speed and agility are key fitness components of the game.

The Australian Institute of Sport implemented a talent identification program to identify athletes from other sports who could play rugby sevens. The program was so successful that the Australian women's rugby sevens team won a gold medal at the 2016 Olympic Games in Rio.

Before the fitness testing session, what documentation would the organisers need to obtain from participating athletes?

Question 5 (1 mark)

Source: *VCE 2015, Physical Education Exam, Section B, Q.1.a*; © VCAA

Prior to fitness testing, what must be obtained from participants?

More exam questions are available in your learnON title.

10.4 Aerobic power and anaerobic capacity tests

Key knowledge	Key skills
• assessment of fitness for an activity: – standardised, recognised fitness tests that test appropriately identified physiological requirements	• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

TABLE 10.2 Recognised standardised tests of aerobic power and anaerobic capacity

Fitness component	Test
Aerobic power	Multistage fitness test Yo-yo test Cooper 12-minute run test Astrand–Rhyming cycle ergometer test Harvard step-test
Anaerobic capacity	Phosphate recovery test 30-second Wingate test Repco peak power test

10.4.1 Aerobic power tests

Aerobic power — the rate at which aerobic metabolism can supply energy through the aerobic pathway — can be assessed in a number of ways. An individual can determine the efficiency of their aerobic pathway by assessing their maximum oxygen uptake. Maximal aerobic power can be determined by either maximal tests, in which the individual works to their maximum or exhaustion, or submaximal tests, in which the individual works less intensely to determine a predicted maximum oxygen uptake.

MULTISTAGE FITNESS TEST

The 20-metre multistage fitness test (also known as the beep test) was developed by Leger and Lambert. The nature of the short runs and turns in this test link closely with most team sports, but they are not a good indicator for sports that require consistent motion, such as cycling, running or rowing.

Goal

To keep up with the beeps for as long as possible.

Equipment

- Flat 20-metre stretch of suitable floor space
- Marking cones
- Multistage fitness test audio recording

Instructions

1. Measure out a 20-metre section of floor space (the shuttle).
2. The participant must arrive at the end of the shuttle before the beep.
3. For the first minute, the beeps on the audio recording will sound at the rate for the participant to travel at a speed of 8.5 kilometres per hour, and will then increase in speed by 0.5 kilometres per hour each minute following.
4. When the participant fails to arrive at the end of the shuttle by the beep, they withdraw and their level is recorded.

Results

1. Enter the participant's results into the **Multistage VO_2 calculator**, found in the interactivity section of the Resources panel.
2. Consult the ratings in table 10.3 for the participant's aerobic fitness level.

TABLE 10.3 Maximal oxygen uptake (VO_2 max) norms for men and women 18–35 (mL/kg/min)

	Age (years)			
	Males		Females	
Rating	18–25	26–35	18–25	26–35
Excellent	> 60	> 56	> 56	> 52
Good	52–60	49–56	47–56	45–52
Above average	47–51	43–48	42–46	39–44
Average	42–46	40–42	38–41	35–38
Below average	37–41	35–39	33–37	31–34
Poor	30–36	30–34	28–32	26–30
Very poor	< 30	< 30	< 28	< 26

It is important to note that different sports will have different means and ranges for aerobic power. For example, the AIS lists the norms shown in table 10.4A for AFL, tennis and hockey at the national level.

TABLE 10.4A Multistage fitness test norms (level achieved) for various sports according to the AIS

Sport	Sex	Age	Mean score
AFL — AIS	Male	Approx. 18	13.5
Hockey — national	Female	U21	11.9
Hockey — national	Male	U21	14.9
Tennis — national	Female	16+	11.2
Tennis — national	Male	16+	13.4

TABLE 10.4B Beep test norms for young people aged 16–25

Male							
16–17 yrs	< 5/1	5/1–6/8	6/9–8/2	8/3–9/9	9/10–11/3	11/4–13/7	> 13/7
18–25 yrs	< 5/2	5/2–7/1	7/2–8/5	8/6–10/1	10/2–11/5	11/6–13/10	> 13/10

Female							
16–17 yrs	< 4/2	4/2–5/6	5/7–7/1	7/2–8/4	8/5–9/7	9/8–11/10	> 11/10
18–25 yrs	< 4/5	4/5–5/7	5/8–7/2	7/3–8/6	8/7–10/1	10/2–12/7	> 12/7

Note: The results are presented as the level number followed by the number of shuttles.

YO-YO INTERMITTENT RECOVERY TEST

Goal

To keep up with the audio recording as long as possible.

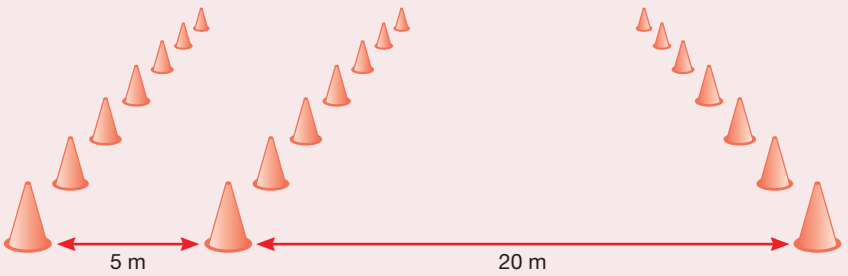
Equipment

- Measuring tape
- Cones/markers
- Yo-yo audio recording

Instructions

1. Measure out a 20-metre test course as per figure 10.8.

FIGURE 10.8 Set up for the yo-yo intermittent recovery test



2. Place markers 2 metres apart at both ends of the 20-metre test course (i.e. at the start and turning lines).
3. In addition to marking the 20-metre line, measure out a 5-metre distance behind the start line.
4. Place a marker on the recovery line aligned to the middle of the two markers on the start line.
5. Participants assume a starting position on the start line.
6. The yo-yo test audio is started. (There are two levels of audio available: level 1 is for beginners and level 2 is advanced. For VCE Physical Education, level 1 is recommended.)
7. At the time of the first signal, the participants run forward to the turning line. At the sound of the second signal, participants arrive and turn at the turning line and then run back to the start line, arriving on the next beep. When the start marker is passed, the participants continue forward at a reduced pace (jogging) towards the 5-metre mark, where they then turn around the cone and return to the start line. At this point, the participants stop and wait for the next signal to sound. It is important that the participants are stationary on the start line before the commencement of each sprint.
8. Participants are required to place one foot either on or over the start or turning lines at the sound of each beep.
9. Participants should continue running for as long as possible, until they are unable to maintain the speed as indicated by the audio.
10. The test ends for a participant when they are unable to maintain the required pace for two trials. The first time the start line is not reached, a warning is given; the second time, the participant must withdraw.

11. When the participant withdraws, the last level and the number of 2 × 20-metre intervals performed at this level are recorded on the appropriate recording sheet. (The last 2 × 20-metre interval is included, even if the participant did not complete it at the right pace.) For valid results, participants must attempt to reach the highest level possible before stopping.
12. The yo-yo test predicts VO_2 max as follows:

$$VO_2 \text{ max (mL/kg/L min}^{-1}) = \text{IRTI distance (metres)} \times 0.0084 + 36.4$$

Refer to table 10.3 for VO_2 max norms.
For example:
A 17-year-old female achieves a score of 15.6 = 1000 metres (refer to table 10.5)

$$\begin{aligned}\text{Predicted } VO_2 \text{ max} &= 1000 \times 0.0084 + 36.4 \\ &= 44.8 \text{ ml/kg/min}\end{aligned}$$

Using table 10.5, this would be considered good according to the VO_2 max norms.

Results

TABLE 10.5 Yo-yo test norms

Level 1 norms for adult men and women

	Males		Females	
Rating	**Metres**	**Level**	**Metres**	**Level**
Elite	> 2400	> 20.0	> 1600	> 17.5
Excellent	2000–2400	18.7–20.0	1280–1600	16.5–17.5
Good	1520–2000	17.3–18.7	1000–1280	15.6–16.5
Average	1000–1520	15.6–17.3	680–1000	14.6–15.6
Below average	520–1000	14.2–15.6	320–680	13.1–14.6
Very poor	< 520	< 14.2	< 320	< 13.1

Level 2 norms for adult men and women

	Males		Females	
Rating	**Metres**	**Level**	**Metres**	**Level**
Elite	> 1280	> 16.5	> 800	> 15.1
Excellent	1000–1280	15.6–16.5	720–800	14.7–15.1
Good	720–1000	14.7–15.6	480–720	14.1–14.7
Average	480–720	14.1–14.7	360–480	13.2–14.1
Below average	280–480	12.3–14.1	160–360	11.2–13.2
Very poor	< 280	< 12.3	< 160	< 11.2

It is important to note that different sports will have different means and ranges for aerobic power. For example, table 10.6 lists the norms the AIS uses for a range of sports at the national level.

TABLE 10.6 Yo-yo test norms for various sports according to the AIS

Sport	Sex	Age	Mean level
Netball — national	Female	U17	15.7
Soccer — national	Male	U17	20.6
Basketball — state	Female	U17	15.6
Basketball — state	Male	U17	16.2

COOPER 12-MINUTE RUN TEST

Dr Kenneth Cooper devised this test in 1968 and its popularity reflects its ease of implementation. It is based on the assumption that an individual will run a greater distance within the time limit if they have a well-developed aerobic capacity.

Goal

To run as far as possible in 12 minutes.

Equipment

- Athletics track or oval, preferably with a lap length of 200–400 metres
- One marking cone for every 20 metres of track
- Stopwatch
- Measuring wheel to calculate lap distance and intervals
- Whistle

Note: If students have access to tracking technology, such as an app or GPS watch, this can be a more efficient method of measurement.

Instructions

1. Place cones every 20 metres for easy calculation of distance covered.
2. The participant aims to complete as many laps as possible within the 12-minute time limit by running.
3. When the whistle blows to end the time period, the participant walks to the nearest marker.
4. Record the number of laps completed in the 12 minutes.

Results

1. Calculate the total distance completed in meters based on the number of laps completed.
2. Refer to table 10.7 to determine the participant's aerobic fitness rating.

TABLE 10.7 Norms for Cooper 12-minute run test (metres covered)

Rating	Males aged 15–16 years	Females aged 15–16 years	Males aged 17–19 years	Females aged 17–20 years
Excellent	> 2800	> 2100	> 3000	> 2300
Above average	2500–2800	2000–2100	2700–3000	2100–2300
Average	2300–2499	1700–1999	2500–2699	1800–2099
Below average	2200–2299	1600–1699	2300–2499	1700–1799
Poor	< 2200	< 1600	< 2300	< 1700

VO_2 MAX ASTRAND–RHYMING CYCLE ERGOMETER TEST

Goal

The lower the heart rate during the test, the more efficient the aerobic energy system.

Equipment

- Cycle ergometer
- Clock or stopwatch
- Heart rate monitor
- ECG monitor (optional)

Instructions

1. Participants pedal on a cycle ergometer at a constant workload for 7 minutes.
2. Heart rate is measured every minute, and the steady state heart rate is determined.

Results

Females: VO_2 max = (0.00193 × workload + 0.326) / (0.769 × HRss – 56.1) × 100

Males: VO_2 max = (0.00212 × workload + 0.299) / (0.769 × HRss – 48.5) × 100

Compare to VO_2 max norms (see table 10.3).

HARVARD STEP-TEST (SHORT FORM)

Goal

To maintain the stepping rate with a low heart rate. The higher the fitness index, the higher the aerobic power.

Equipment

- Step or platform 20 inches (50.8 centimetres) high
- Stopwatch
- Metronome or cadence audio recording

Instructions

1. The participant steps up and down on the platform at a rate of 30 steps per minute (every two seconds) for 5 minutes or until they cannot maintain the stepping rate for 15 seconds (see figures 10.9 and 10.10).
2. The participant immediately sits down on completion of the test, and their heart rate is measured for 30 seconds between 1 and 1.5 minutes after finishing.

FIGURE 10.9 Harvard step-test



FIGURE 10.10 Harvard step-test



Results

Fitness index (short form) = (100 × test duration in seconds) divided by (5.5 × heart rate between 1 and 1.5 minutes)

The fitness index score is determined by the above equation. For example, if the total test time was 300 seconds (i.e. the whole 5 minutes was completed), and the number of heart beats between 1 and 1.5 minutes was 90, then the fitness index would be 61.

Note: You are using the total number of heart beats in the 30-second period, not the rate (beats per minute) during that time.

TABLE 10.8 Harvard step-test fitness norms

Rating	Fitness index (long form)
Excellent	> 96
Good	83–96
Average	68–82
Low average	54–67
Poor	< 54

Source: Fox et al., 1973

10.4.2 Anaerobic capacity tests

Anaerobic capacity involves two energy systems — the ATP–CP system and the anaerobic glycolysis system. Anaerobic capacity tests are designed to measure the total amount of energy provided by the anaerobic energy systems.

PHOSPHATE RECOVERY TEST

This test was originally developed for Australian Rules football, but it is suitable for a variety of sports that involve repeated high-intensity, short-duration efforts. The test stresses the ability of the body to replenish high-energy phosphates between each repetition of the test.

Goal

To run past as many cones as possible for each sprint.

Equipment

- Marking cones of various colours, with two sets numbered 1–10
- Stopwatches
- Whistle
- Recording sheets
- Appropriate area such as an oval

Instructions

1. Set up the course as shown in figure 10.11. Place the cones numbered 1–10 every 2 metres from the centre, in the formation shown.
2. Participants work in pairs, with one partner running while the other records. They then reverse roles. Each participant should be thoroughly familiar with the test protocol.
3. A timekeeper, who works with two stopwatches and a whistle, controls the test.
4. Each participant performs one of the following sets: 8 × 7-second sprints, departing every 30 seconds (work-to-rest ratio of 1:3.3); 8 × 5-second sprints, departing every 30 seconds (work-to-rest ratio of 1:5).
5. Participants must perform each sprint at maximum effort. The timekeeper blows the whistle to start and stop each sprint.
6. Both stopwatches are started as the sprint begins. Watch 1 is clocked off at 7 or 5 seconds (according to the set), with an appropriate whistle signal to the runner. Watch 2 continues ticking over as the participant jogs or walks to the other end of the course.
7. At 30 seconds (watch 2), the timekeeper blows the whistle to begin the next sprint. Timing of the sprint should begin on watch 1.
8. This procedure is repeated until participants have completed eight sprints. Refer to table 10.9 for a sample procedure to follow.

FIGURE 10.11 Phosphate recovery test course

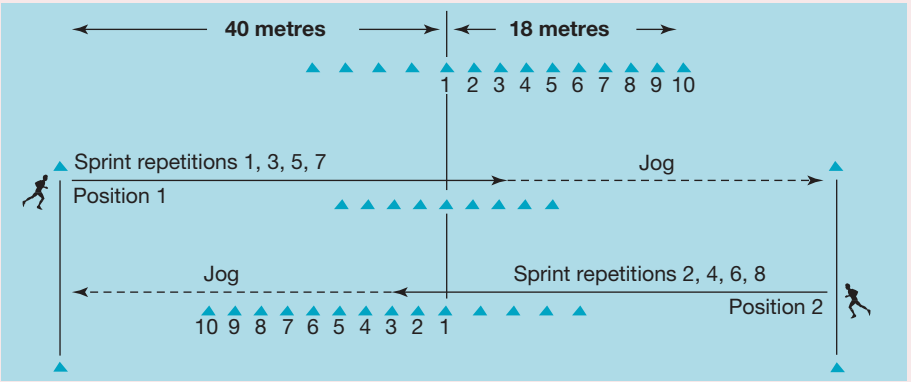


TABLE 10.9 Sample procedure for the phosphate recovery test, 8 × 7-second sprints departing every 30 seconds

Signal (stopwatch 2) (minutes: seconds)	Action — runners	Timekeeper	Scorer(s)
'Set'	Line up	Set both stopwatches to zero	Line up with markers in position 1 in direction of sprint
Whistle (go)	Sprint as quickly as possible for 7 seconds — sprint 1	Stopwatch 1: start Stopwatch 2: start	Ready
'Stop' (00:07)	Jog through to far line	Stopwatch 1: stop, reset Stopwatch 2: allow to run	Count number of markers passed at 'stop' (if between markers, count last marker passed). Record score (e.g. 8)
'Set' (00:25)	Line up to sprint back in opposite direction	Stopwatch 1: on zero Stopwatch 2: on 25 second 'set'	Move to line up with second lot of markers at position 2
Whistle (00:30)	Sprint 2	Stopwatch 1: start Stopwatch 2: on 30 second (whistle)	Ready
'Stop' (00:37)	Jog to end	Stopwatch 1: stop (7 second), reset Stopwatch 2: on 37 second	Record second score (e.g. 7) Move back to original position
'Set' (00:55)	Line up	Stopwatch 1: on zero Stopwatch 2: on 55 second 'set'	Move back to original position 1
Whistle (01:00)	Sprint 3	Stopwatch 1: start (whistle) Stopwatch 2: on 60 second	Ready
'Stop' (01:07)	Jog to end	Stopwatch 1: stop (7 second), reset Stopwatch 2: on 67 second	Record third score (e.g. 6)
'Set' (01:25)	Line up	Stopwatch 1: zero Stopwatch 2: 85 second 'set'	Move to position 2
Whistle (01:30)	Sprint 4	Stopwatch 1: start (whistle) Stopwatch 2: 90 second	Ready
'Stop' (01:37)	Jog to end	Stopwatch 1: stop (7 second), reset Stopwatch 2: 97 second	Record fourth score (e.g. 4)
Continue this procedure for eight sprints (total elapsed time = 3 minutes 37 seconds).			

Scoring

1. Record scores on the recording sheet.
2. Scorers must be in position to accurately read scores from the two sets of numbered cones. When the participants sprint from left to right, they are scored using the top set of numbered cones; when running right to left, they are scored using the bottom set of numbered cones.
3. The participants score points for each repetition according to the number of cones they have passed when the whistle blows to signify the end of the sprint.

Results

1. Calculate the total score by adding the points from each sprint repetition (see figure 10.12).
2. Calculate the best possible score by multiplying the best single score by the number of repetitions.
3. Calculate the total decrement score (value that reflects the decline in performance scores relative to a best possible score) by subtracting the total score from the best possible score.
4. Calculate the percentage decrement score by dividing the total decrement score by the best possible score and multiplying by 100.
5. Refer to table 10.10 to obtain ratings for the percentage decrement. The lower the total decrement and percentage decrement scores, the better the result.

FIGURE 10.12 Sample recording sheet for the phosphate recovery test

Phosphate recovery test score

Participant's name: **Maximum number of repetitions to be completed:**

× 5/7 seconds (delete 1)
Going every 30/40 seconds (delete 1)

Repetition number	1	2	3	4	5	6	7	8	Total
Score									
Decrement									

Calculations
Best possible score _____ – total score _____ = total decrement
(Repetition × best score)

$$\frac{\text{Total decrement}}{\text{Best possible score}} \times \frac{100}{1} = \text{_____ \% of decrement score}$$

TABLE 10.10 Percentage decrement ratings for the phosphate recovery test

Rating	Percentage decrement score
Excellent	< 12
Good	12–19
Average	20–29
Fair	30–40
Poor	> 40

Source: Adapted from Dawson, Ackland, Roberts & Lawson, 1991.

30-SECOND WINGATE TEST

Goal

To pedal as fast as possible for 30 seconds

Equipment

- Stationary exercise bike

Instructions

1. The participant should first perform a cycling warm-up of several minutes.
2. The participant is instructed to pedal as fast as possible for 30 seconds.
3. In the first few seconds, the resistance load is adjusted to the predetermined level, which is usually about 45 grams per kilogram of body weight (Fleisch) or 75 grams per kilogram of body weight (Monark) for adults.

FIGURE 10.13 Participant performing the Wingate anaerobic test



Results

Some of the measures that can be gained from this test are mean and peak power (ideally measured in the first 5-second interval of the test, expressed in watts), relative peak power (determined by dividing peak power by body mass, expressed as watts per kilogram), mean peak power, minimum peak power, and a fatigue index determined from the decline in power.

Power output (kpm • min^{-1}) = [revs × resistance (kg) × distance (m) × 60 (s)] / time (s)

Watts = kpm • min^{-1} / 6.123

Watts/kg = watts / body weight (kg)

Fatigue index = [(peak power output – min power output) / peak power output] × 100

TABLE 10.11 Wingate norms

% Rank	Male Watts	Female Watts
90	822	560
80	777	527
70	757	505
60	721	480
50	689	449
40	671	432
30	656	399
20	618	376
10	570	353

REPCO PEAK POWER (PHOSPHATE POWER) TEST

The Repco peak power test can be quickly and easily administered. It assesses phosphate power output while cycling on a bicycle ergometer. It can also be adapted to involve arm cranking.

Goal

To pedal as hard and fast as possible for 10 seconds.

Equipment

- Cycle ergometer (Repco is recommended)
- Stopwatch
- Weight scales

Instructions

1. Weigh the participant before the test (in kilograms).
2. Set up the cycle ergometer to suit the physique of the participant. Adjust seat height so that the leg is almost fully extended when the pedal is at the lowest point
3. The participant performs a light cycle as a warm-up.
4. When indicated, the participant stands on the pedals and accelerates to maximum power, which they maintain for 10 seconds.
5. Allow two trials with at least a 3-minute rest between trials.

Results

1. Record the maximum workload reached during the test (in watts, indicated on the speedometer of the Repco cycle ergometer).
2. Divide the maximum workload (watts) by the weight of the participant (kilograms).
3. Obtain a rating for peak power output from table 10.12.

TABLE 10.12 Peak power test index norms (watts per kilogram)

Rating	Males aged 14–34 years	Females aged 14–34 years
Excellent	19.6 or more	16.7 or more
Very good	17.0–19.5	14.3–16.6
Good	14.4–16.9	11.9–14.2
Average	11.8–14.3	9.5–11.8
Fair	9.2–11.7	7.1–9.4
Poor	< 9.2	< 7.1

CONCEPT CONNECTOR

Create a table similar to the one below. For each test, identify a sport and position that would complete the test and explain why it is used from a physiological perspective.

Test	Sport and position	Physiological perspective

on Resources

Interactivities Multistage VO_2 calculator (int-6808)
Yo-yo test calculator (int-6809)
Rockport 1.6 km walking test calculator (int-6813)
Astrand–Rhyming cycle ergometer test (int-6814)
Harvard step-test calculator (int-6807)
Phosphate recovery test calculator (int-6815)
30-second Wingate test calculator (int-6810)
Phosphate power (Repco peak power) test calculator (int-6816)

doc-41989

PRACTICAL ACTIVITY Aerobic and anaerobic tests

Goal

To complete and compare aerobic and anerobic tests.

Instructions

1. Complete as many aerobic power and anaerobic capacity tests as you can, recording your results and observations as each test is completed.

Primary data/Reflection

TABLE 1 Results of the fitness tests

Fitness test	Results

- Describe your experience during the tests.
- Did you experience any difficulties or success in the tests?
- Were there any differences in fatigue between the aerobic and anaerobic tests?
- What techniques or tactics did you use to optimise your performance in the tests?

Questions

1. Compare your ratings for at least two aerobic power tests. Were they similar or different? Explain why this might be so.
2. Compare your ratings for at least two anaerobic capacity tests. Were they similar or different? Explain why this might be so.
3. Describe each of the tests and identify one sport they might be suited to.

EXAM TIP

Students should ensure they link the tests to the relevant fitness components by using the key terms of the fitness components as discussed in topic 8.

For example, when describing the Cooper 12-minute run test, students should refer to working in the aerobic training zone or using the aerobic system to run as far as possible in 12 minutes.

10.4 Activity

10.4 Quick quiz on

10.4 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3, 4	1, 2	5, 6

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TEST your understanding

1. **Describe** *aerobic power*.
2. **Describe** *anaerobic capacity.*
3. **List** three common characteristics of a valid aerobic power test.
4. **List** three common characteristics of a valid anaerobic capacity test.

APPLY your understanding

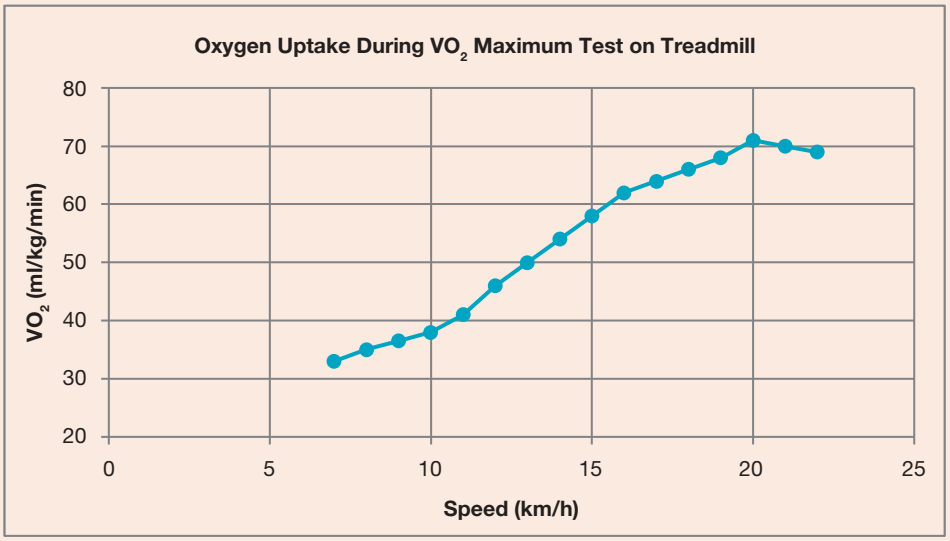
5. **Identify** and **justify** an appropriate aerobic power test for the following participants.
   - Olympic road cyclist
   - Beginner at the gym
   - Year 12 class
6. **Identify** and **justify** an appropriate anaerobic capacity test for the following participants.
   - AFL footballer
   - Beginner at the gym
   - Year 12 class

10.4 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.6.a;* © ACHPER

Taylor is an elite triathlete who completes a VO_2 maximum test on a treadmill. The results are presented in the graph below.



Identify the fitness component being assessed by this test.

Question 2 (3 marks)

Source: Adapted from *VCE 2017, Physical Education Exam, Section B, Q.13.a*; © VCAA

The Australian Football League (AFL) carries out a series of fitness tests at its annual draft camp to help clubs determine who is the best young talent. The Brisbane Lions selected Jarrod Berry after he performed very well at the draft camp. His results were as follows:

- 4th overall in the 6 × 30 m sprint test — 24.99 s
- 1st overall in the 20 m shuttle run — level 15.1
- 1st overall in the 3 km time trial — 9.46 min

Data: AFL news, 'Top-10 results from 2016 NAB AFL Draft Combine', 9 October 2016, www.afl.com.au

Name the fitness component assessed in each test above.

Question 3 (2 marks)

Source: Adapted from *VCE 2009, Physical Education Exam, Section B, Q.3.c.i*; © VCAA

The following table lists a fitness test battery that was developed for the US Women's National soccer team. This battery of tests was used by the local U/18 soccer club at the start of their pre-season training and was completed over two days. The test results and the corresponding norms are given for five of the team players. Use this information to answer the following questions.

Player	20-metre shuttle run (level)	Phosphate recovery test (decrement score)
Sam A	9.8 excellent	11 excellent
Steph C	6.8 good	23 average
Katie L	10.1 excellent	17 good
Rachel P	8.7 excellent	18 good
Sophie S	9.3 excellent	19 good

When looking at the overall team results, **state** the fitness component that requires the greatest amount of improvement and **justify** your answer.

Question 4 (1 mark)

Source: *VCE 2012 Physical Education Exam, Section B, Q.12.c*; © VCAA

Other than the 20-m shuttle run test and the yo-yo intermittent recovery test, **identify** another recognised field test that would be suitable to assess the same fitness component in secondary school students.

Question 5 (2 marks)

Identify a suitable standardised fitness test that could be used to test the anaerobic capacity of a midfielder and **describe** how to complete it.

More exam questions are available in your learnON title.

10.5 Muscular strength, muscular power and muscular endurance tests

Key knowledge	Key skills
• assessment of fitness for an activity: – standardised, recognised fitness tests that test appropriately identified physiological requirements	• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Muscular strength, power and endurance tests require high force. The difference between the tests is whether the movement is for maximal effort, needs to be explosive or needs to be repeated. Muscular strength and power rely heavily on the ATP–CP system, so it is vital that there is sufficient passive recovery between efforts. For muscular endurance, the test needs to go long enough for the athlete to work through fatigue.

TABLE 10.13 Recognised standardised tests of muscular strength, muscular power and muscular endurance

Fitness component	Test
Muscular strength	1 RM test (bench press, back squat, leg press) Grip strength dynamometer Seven-stage abdominal strength test
Muscular power	Basketball throw Vertical jump Standing long jump
Muscular endurance	60-second push-up test 60-second sit-up test Curl-up (Crunch) test Flexed arm hang test

10.5.1 Muscular strength tests

Muscular strength is the peak force that a muscle can develop. It is therefore classically assessed through tests that measure the amount of force produced with a single maximal effort. A range of tests can be used that assess the single or repeat maximal capacity (usually up to 3 RM) of different muscles and muscle groups. It is important to note that muscular strength can vary dependent on the muscle and/or muscle group. Therefore, a number of tests may be required to gain an accurate assessment of muscular strength.

ONE REPETITION MAXIMUM (1 RM) TEST

The one repetition maximum (1 RM) test is a popular method of measuring isoinertial muscle strength. It is a measure of the maximal weight a participant can lift with one repetition. The most commonly used movements are the leg press and bench press (see figures 10.14 and 10.15). This test may not be suitable for the elderly, cardiac patients, adolescents or some sedentary populations. For these groups, other options for assessing strength should be used.

FIGURE 10.14 1 RM leg press



FIGURE 10.15 1 RM bench press



Goal

To lift as much as you can for one repetition only.

Equipment

- Free weights (barbells) or other gym equipment

Instructions

A number of different procedural protocols exist. The following outline is one such protocol.

1. Begin with a warm-up of 5–10 repetitions at 40–60 per cent of the participant's estimated maximum weight.
2. After a brief rest period (3–5 minutes), increase the load to 60–80 per cent of the participant's estimated maximum, and the participant attempts to complete 3–5 repetitions.
3. At this point, a small increase in weight is added to the load and a 1 RM lift is attempted.
4. If successful, wait another 3–5 minutes, add a small amount of weight and have the participant attempt one more repetition.
5. Keep adding small amounts of weight until the participant cannot successfully lift the weight.
6. The goal is to determine the participant's 1 RM in 3–5 trials.
7. The participant should be allowed ample rest (at least 3–5 minutes) before each 1 RM attempt.
8. The last successful completed repetition, with no assistance from a spotter, is the participant's repetition maximum.

(*Note:* A spotter should always be employed during the performance of this test, and trained personnel should supervise the testing.)

Results

1. Take the participant's 1 RM weight and divide it by their body weight (in kilograms). For example, if they bench-pressed 120 kilograms and weigh 80 kilograms, the score is 1.5.
2. Refer to table 10.14 for the ratings for this test.

TABLE 10.14 1 RM norms for bench press and leg press

Rating	Bench press: males	Bench press: females	Leg press: males	Leg press: females
Excellent	1.4	0.7	2.8	2.2
Very good	1.2	0.6	2.4	2.0
Good	1.0	0.5	2.0	1.8
Fair	0.8	0.4	1.8	1.4
Poor	0.6	0.3	1.4	1.2

Source: Sport Fitness Advisor, www.sport-fitness-advisor.com.

GRIP STRENGTH DYNAMOMETER TEST

The grip strength dynamometer test is one of the most popular strength tests. It is easy to perform and reliable in providing an index of muscular strength because grip strength has a reasonably high correlation with total body strength. Norms for the test are also readily available, and the dynamometer is relatively inexpensive.

Goal

To squeeze the dynamometer as hard as possible.

Equipment

- Handgrip dynamometer

Instructions

1. First, adjust the dynamometer to suit the participant's hand size. The second joint of the fingers should fit comfortably under the handle.
2. The participant (in a standing position) holds the dynamometer above their body and lowers it to their side while squeezing vigorously (for approximately 5–10 seconds), exerting their maximum force. Ensure the dial of the dynamometer faces away from the participant's body.
3. During the test, do not allow either the dynamometer or the participant's hand to come into contact with the participant's body.
4. Three trials are recommended for each hand, with a 3-minute rest between trials.

Results

1. Record the best score for each hand (in kilograms), as read from the dial.
2. Refer to table 10.15 for the ratings for grip strength.

TABLE 10.15 Handgrip strength norms (kilograms)

Rating	Males aged 16–17 years	Males aged 18–39 years	Females aged 16–17 years	Females aged 18–39 years
Excellent	41 or more	54 or more	31 or more	39 or more
Good	36–40	50–53	29–30	36–38
Average	34–35	47–49	27–28	33–35
Fair	32–33	43–46	22–26	30–32
Poor	31 or less	42 or less	21 or less	29 or less

Source: Adapted from B Leelarthaepin, *Assessment of physical fitness: a practical approach*, Biomediscience Services, New South Wales, 1992.

SEVEN-STAGE ABDOMINAL STRENGTH TEST

Goal

To complete a sit-up as the difficulty increases.

Equipment

- Flat surface
- 5 lb (2.5 kg) and 10 lb (5 kg) weights

Instructions

1. The participant lies on their back, with their knees at right angles and feet flat on the floor.
2. The participant then attempts to perform one complete sit-up for each level in the prescribed manner (see table 10.16), starting with level 1.
3. Each level is achieved if a single sit-up is performed in the prescribed manner, *without the feet coming off the floor*. As many attempts as necessary can be made.

Results

TABLE 10.16 Norms for seven-stage abdominal strength test

Level	Rating	Description	
0	Very poor	Cannot perform level 1	
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	

(continued)

TABLE 10.16 Norms for seven-stage abdominal strength test *(continued)*

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 chest, holding the opposite shoulders, the athlete curls up so that the forearms touch the thighs	
5	Very good	With the hands held behind head, the athlete curls up so that the chest touches the thighs	
6	Excellent	As per level 5, with a 5 lb (2.5 kg) weight held behind head, chest touching the thighs	
7	Elite	As per level 5, with a 10 lb (5 kg) weight held behind head, chest touching the thighs	

Resources

Interactivity One repetition maximum (1 RM) test calculator (int-6817)

10.5.2 Muscular power tests

Muscular power is the ability to use strength quickly to produce an explosive movement. Muscular power depends on strength and speed. It is central to actions in most sports where successful performance requires distance, height or any quick generation of force.

Most tests of muscular power measure either upper body power (arm, shoulder, chest and upper back muscles) or leg power (hip, thigh and calf muscles).

SEATED BASKETBALL THROW TEST

Goal

To throw the ball as far as possible.

Equipment

- Basketball
- Measuring tape
- Wall

Instructions

1. The participant sits with their back flush against the wall and their legs fully extended, holding the ball at chest height (see figure 10.16).
2. Using their arms only (their back should stay against the wall), the participant pushes the ball out in front of them as far as they can.
3. Repeat three times with sufficient recovery (at least 1 minute) and record the best score.
4. Some tests will include a hoop on the participant's toes to ensure the ball is kept low and the movement isolates the arms and chest.

FIGURE 10.16 Seated basketball throw test



VERTICAL JUMP TEST

The vertical jump test, also referred to as the Sargeant jump test, is a test of leg power. It is easy to administer and has been used in test batteries for many years.

Goal

To jump as high as possible.

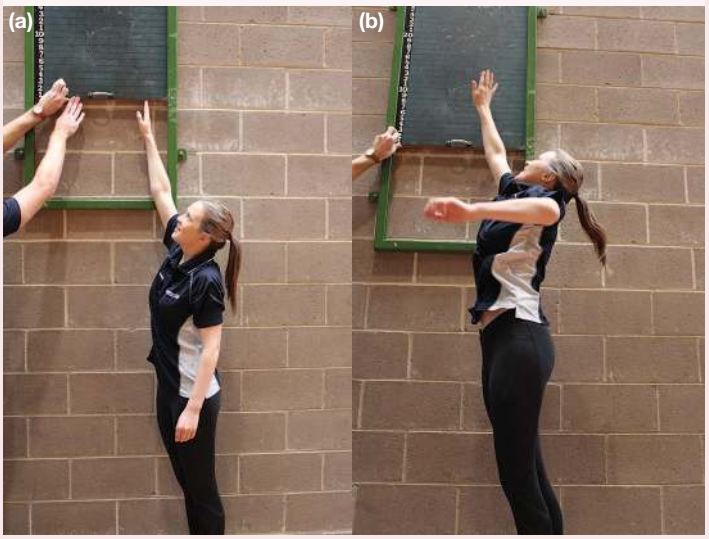
Equipment

- Vertical jump board (recommended) or measuring tape attached to a wall
- Magnesium chalk

Instructions

1. The participant chalks the tips of their middle fingers with magnesium chalk.
2. The participant determines their standing height by fully extending an arm overhead and recording the height reached (see figure 10.17a).
3. The participant stands side on to the jump board, takes a deep squat and springs as high as possible (see figure 10.17b), touching the jump board with the hand and fingers closest to the board. They should keep their arm extended above their head so a chalk mark shows the height reached. Record this height.
4. The result calculated is the difference between the height reached on the jump and the initial standing height.
5. The participant rests for at least 3 minutes, then attempts a second trial.

FIGURE 10.17 The vertical jump test



Results

1. Record the best score obtained from the two trials. (Subtract standing height from jumped height.)
2. Refer to table 10.17 for ratings of leg power.

TABLE 10.17 Norms for the vertical jump test (centimetres)

Rating	Males aged 15–17 years	Males aged 18–34 years	Females aged 15–17 years	Females aged 18–34 years
Excellent	59 or more	62 or more	39 or more	32 or more
Good	48–58	48–61	33–38	25–31
Average	30–47	33–47	20–32	15–24
Fair	13–29	20–32	8–19	5–14
Poor	12 or less	19 or less	7 or less	4 or less

Norms

It is important to note that different sports will have different means and ranges for muscular leg power and the vertical jump. For example, the AIS has the following norms for particular sports at various levels.

TABLE 10.18 AIS norms for the vertical jump test

Sport	Sex	Age	Mean score
Netball — national	Female	U17	44 cm
AFL	Male	Approx. 18	60 cm
Basketball — state	Female	U17	48 cm
Basketball — state	Male	U17	62 cm
Cricket — national	Female	Open	44 cm
Cricket — national	Male	U19	56 cm

STANDING LONG-JUMP TEST

The standing long-jump test is easily administered. It assesses a participant's leg muscle power (mainly the quadriceps and calf muscle groups).

Goal

To jump as far (horizontally) as possible.

Equipment

- Tape measure
- Safe jumping area, such as a sprung wooden floor, sandpit or fixed mat
- Gym shoes

Instructions

1. The participant stands behind a line with their feet shoulder-width apart.
2. The participant bends their knees and swings their arms back and forth (see figure 10.18), jumping as far forward as possible and landing on both feet. Allow two trials with at least 3 minutes' rest between each trial.
3. The score is the distance from the starting line to the point where the participant's heel lands closest to the line.

FIGURE 10.18 The standing long-jump test



Results

1. Record the best score obtained from the two trials.
2. Refer to table 10.19 for ratings of leg power.

TABLE 10.19 Ratings for the standing long-jump test (centimetres)

Rating	Males aged 17 years	Males aged 18+ years	Females aged 17 years	Females aged 18+ years
Excellent	230 or more	239 or more	175 or more	180 or more
Good	216–229	226–238	163–174	168–179
Average	204–215	213–225	151–162	157–167
Fair	192–203	201–212	134–150	142–156
Poor	191 or less	200 or less	133 or less	141 or less

on Resources

Interactivity Magaria Kalamen power test calculator (int-6818)

10.5.3 Muscular endurance tests

Muscular endurance is the ability of a particular muscle or muscle group to continue working at the desired level of effort for as long as the situation demands (see topic 8). Tests for muscular endurance will usually focus on one area of the body and therefore can readily be made specific for a particular sport's requirements in the competitive situation. Most muscular endurance tests require the participant to complete the exercise for as long as they can or to complete as many repetitions as they can in a set time, forcing the muscles/muscle group to work in the face of fatigue.

60-SECOND PUSH-UP TEST

Goal

To complete as many push-ups as you can to test the endurance of the upper body.

Equipment

- Flat surface

Instructions

Males should use the standard 'military-style' push-up position with only the hands and the toes touching the floor in the starting position.

Females have the additional option of using the 'bent knee' position.

1. To do this, the participant kneels on the floor, hands on either side of their chest and keeping their back straight.
2. Lower the chest down towards the floor, always to the same level each time, until either the elbows are at right angles or the chest touches the ground (see figure 10.19).
3. Do as many push-ups as possible until exhaustion or 60 seconds is reached.
4. Count the total number of push-ups performed.

FIGURE 10.19 The 60-second push-up test



Results

1. Compare the results to relevant norms (see table 10.20).

TABLE 10.20 Norms for 60-second push-up test (number completed)

Males	Age					
	17–19	20–29	30–39	40–49	50–59	60–65
Excellent	> 56	> 47	> 41	> 34	> 31	> 30
Good	47–56	39–47	34–41	29–34	25–31	24–30
Above average	35–46	30–38	25–33	21–28	18–24	17–23
Average	19–34	17–29	13–24	11–20	9–17	6–16
Below average	11–18	10–16	8–12	6–10	5–8	3–5
Poor	4–10	4–9	2–7	1–5	1–4	1–2
Very poor	< 4	< 4	< 2	0	0	0

Females	Age					
	17–19	20–29	30–39	40–49	50–59	60–65
Excellent	> 35	> 36	> 37	> 37	> 25	> 23
Good	28–35	30–36	31–37	25–31	21–25	19–23
Above average	21–27	23–29	22–30	18–24	15–20	13–18
Average	11–20	12–22	10–21	8–17	7–14	5–12
Below average	6–10	7–11	5–9	4–7	3–6	2–4
Poor	2–5	2–6	1–4	1–3	1–2	1
Very poor	0–1	0–1	0	0	0	0

60-SECOND SIT-UP TEST

The maximum sit-ups test is a basic item in many fitness test batteries. It is designed to measure the endurance of the abdominal muscles. There are many variations of the test: some have a time limit of 30 or 60 seconds, while others involve a predetermined number of repetitions.

The participant's body position also varies with different formats of this test — using leg positions from slightly bent to fully flexed, and using arm positions from hands clasped behind the head (not recommended) to arms folded across the chest. The test outlined here is a standardised protocol for the maximum sit-ups test performed with bent knees.

Goal

To complete as many repetitions as possible in the time permitted.

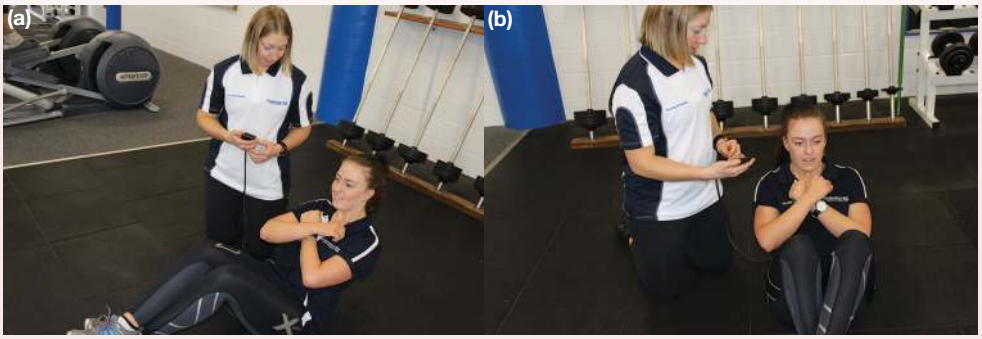
Equipment

- Gym mat
- Stopwatch

Instructions

1. The participant lies on a mat with their knees flexed so the angle of their lower legs to their thighs is approximately 90 degrees. They place their arms across their chest, with each hand on the opposite shoulder (see figure 10.20a).
2. On the start command, the participant curls upwards and forwards, raising their body trunk until their elbows make contact with their thighs (see figure 10.20b). Then they return to the starting position.
3. The participant repeats this procedure as many times as possible within the 1-minute time limit.
4. A partner should count the number of correct sit-ups completed and check for correct procedure.

FIGURE 10.20 Correct body form for the timed sit-up test



Results

1. Record the number of sit-ups completed within the time limit.
2. Compare the results with the ratings provided in table 10.21.

TABLE 10.21 Abdominal muscle endurance norms (number of sit-ups completed in 60 seconds)

Rating	Males aged 15–19 years	Females aged 15–19 years
Excellent	48 or more	42 or more
Good	42–47	36–41
Average	38–41	32–35
Fair	33–37	27–31
Poor	32 or fewer	26 or fewer

Source: Adapted from Nieman, 1993.

CURL-UP (CRUNCH) TEST

A modification of the traditional sit-ups test, the curl-ups test assesses the endurance of the abdominal muscles. The aim is to complete as many curl-ups as possible at a rate of 20 per minute (up to a maximum of 60).

Goal

To complete as many repetitions as possible.

Equipment

- Gym mat
- Cadence (or rate) audio recording

Instructions

1. The participant lies on the mat with their knees bent at a 90-degree angle, keeping their arms straight.
2. A partner kneels beside the participant and places a straight arm across the top of the participant's knees, forming a 'wall'.
3. Using the cadence audio recording, the participant curls up in time with the set rate. They must slide their hands along the top of their thighs until their hands touch the 'wall'. The 'up' position must be held for 1 second. The participant then returns to the starting position.
4. The participant repeats the action until they complete 60 curl-ups. However, if they do not perform two consecutive curl-ups satisfactorily, they must withdraw from the test.

Results

1. Record the number of correctly completed curl-ups.
2. Refer to table 10.22 for the ratings for this test.

TABLE 10.22 Norms for the curl-ups test (number completed)

Rating	Males aged 17–18 years	Females aged 17–18 years
Excellent	60	45–60
Good	60	32–44
Average	31–59	26–31
Fair	30	25
Poor	29 or fewer	24 or fewer

Source: Adapted from Wright, 1997.

FLEXED ARM HANG TEST

Goal

To hang with the chin above the bar as long as possible.

Equipment

- Stopwatch
- Horizontal overhead bar at an adequate height
- Stool (optional)

Instructions

1. The participant grasps the overhead bar using an overhand grip (palms facing away from body), with the hands shoulder width apart (see figure 10.21).
2. On the command 'ready, go', timing starts.
3. The participant should attempt to hold this position for as long as possible.

FIGURE 10.21 The flexed arm hang test



Results

TABLE 10.23 Norms for the flexed arm hang test (minutes)

Gender	Excellent	Above average	Average	Below average	Poor
Male	> 13	9–13	6–8	3–5	< 3
Female	> 6	5–6	3–4	1–2	0

Source: Table adapted from Davis et al., 2000.

doc-41990

PRACTICAL ACTIVITY Muscular strength, power and endurance tests

Goal

To complete and compare muscular strength, power and endurance tests.

Instructions

1. Complete as many muscular strength, muscular power and muscular endurance tests as you can, recording your results and observations as each test is completed.

Primary data/Reflection

TABLE 1 Results of the tests

Test	Results

- How did you feel about your performance in the tests compared to your expectations?
- Did you experience any difficulties or success in the tests? Explain.
- Were there any differences in fatigue between the different tests?
- What techniques or tactics did you use to optimise your performance in the tests?

Questions

1. Compare your ratings for at least two muscular strength tests. Were they similar or different? Explain why this may be so.
2. Compare your ratings for at least two muscular power tests. Were they similar or different? Explain why this may be so.
3. Compare your ratings for at least two muscular endurance tests. Were they similar or different? Explain why this may be so.
4. Describe each of the tests and identify one sport to which they may be suited.

EXAM TIP

Key terms are vital when differentiating between tests that assess muscular strength, power or endurance and commenting on the validity of tests.

For muscular strength, the test must test maximal force. For muscular power, the test must require explosive movements (strength and speed). For muscular endurance, the test must require as many repetitions as possible (until fatigue or in a set time).

10.5 Activity

10.5 Quick quiz on | **10.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	6	5

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TEST your understanding

1. **Describe** the term *muscular strength.*
2. **Describe** the term *muscular power.*
3. **Describe** the term *muscular endurance.*
4. **Describe** the 1 RM bench press test.

APPLY your understanding

5. **Identify** and **justify** an appropriate muscular strength test for the following participants.
   - Elite tennis player
   - Year 12 class
   - Beginner at the gym
6. **Discuss,** using specific examples, the differences between tests for muscular strength, muscular power and muscular endurance of the lower body.

10.5 Exam questions

Question 1 (2 marks)

Identify and **justify** which of these tests assess muscular strength and muscular power.

- grip strength test
- yo-yo test
- vertical jump test
- 1 RM squat
- Illinois agility test
- phosphate recovery test

Question 2 (3 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.3.e;* © ACHPER

The following activity data analysis was obtained during a futsal game.

Average sprint distance	Directional changes
8 m	108

Skill	Frequency
short pass > 5 m	67
long pass < 5 m	23
attack on the ball	45

An activity analysis can provide coaches and participants with valuable information about movement patterns and fitness components. Referring to the data provided, complete the table below.

Relevant fitness component	Recognised fitness test	Justification
Muscular power		

Question 3 (2 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.7.a;* © ACHPER

Sailboarding is an Olympic event with each race typically lasting for twenty to thirty minutes. Participants grip a horizontal bar and stand in a balanced position to guide the sailboard around a series of course markers in the water.

Participants require excellent muscular endurance of their arms, legs, and abdominals to complete each race.



In the table below, **identify** a recognised test of muscular endurance for both the upper body and abdominals.

Muscle group	Recognised fitness test
Abdominals	
Upper body	

Question 4 (4 marks)

Source: Adapted from *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.6;* © ACHPER

Distinguish between muscular strength and muscular power and **identify** a fitness test for each, using sporting examples to support your answer.

Question 5 (3 marks)

Dancers require muscular strength, power and endurance of the lower leg muscles. Using your understanding of these fitness components, **design** a test for each of these fitness components for a dancer.

More exam questions are available in your learnON title.

10.6 Speed and agility tests

Key knowledge	Key skills
• assessment of fitness for an activity: – standardised, recognised fitness tests that test appropriately identified physiological requirements	• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

As speed and agility tests need to be completed as quickly as possible, they are shorter tests that allow sufficient recovery before attempts to enable maximal intensity. The difference between the tests will be the change of direction. For increased reliability of these tests, timing gates should be used where possible.

TABLE 10.24 Recognised standardised tests of speed and agility

Fitness component	Test
Speed	20-metre sprint test 35-metre sprint test 50-metre sprint test
Agility	Illinois agility test Semo agility test 5-0-5 agility test

10.6.1 Speed

Speed can refer to either whole-body speed — where the aim is to cover a specified distance in the shortest possible time — or part-body speed — where the aim is to move one or more parts of the body as quickly as possible to complete a movement (see topic 8). Methods of assessing part-body speed are necessarily dependent on sophisticated recording methods, so most tests of speed take whole-body measurements.

20-METRE SPRINT TEST

Goal

To run as quickly as possible for 20 metres.

Equipment

- Measuring tape or marked track
- Stopwatch or timing gates
- Cone markers

Instructions

1. The participant completes a standardised warm-up.
2. On the start command, the participant runs the 20-metre course as quickly as possible.
3. Record the time taken to cover the distance to the nearest one-hundredth of a second.
4. The participant rests for 3–5 minutes between sprints, then completes two more trials.

Results

1. Record the lowest time taken to complete the test.
2. Refer to table 10.25 for the norms for this test (for Australian sportspeople).

TABLE 10.25 AIS norms for the 20-metre sprint test

Sport	Sex	Age	Mean (seconds)
Netball — national	Female	U17	3.52
AFL	Male	Approx. 18	3.04
Basketball — state	Female	U17	3.56
Basketball — state	Male	U17	3.24
Tennis — national	Female	16+	3.49
Tennis — national	Male	16+	3.09

35-METRE SPRINT TEST

Goal

To run as quickly as possible for 35 metres.

Equipment

- Measuring tape or marked track
- Stopwatch or timing gates
- Cone markers

Instructions

1. The participant completes a standardised warm up.
2. On the start command, the participant runs the 35-metre course as quickly as possible.
3. Record the time taken to cover the distance to the nearest one-hundredth of a second.
4. The participant rests for 3–5 minutes between sprints, then completes two more trials.

Results

1. Record the lowest time taken to complete the test.
2. Refer to table 10.26 for the norms for this test (for Australian team sport players).

TABLE 10.26 Norms for the 35-metre sprint test for Australian team sport players (seconds)

Rating	Men	Women
Very good	< 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

50-METRE SPRINT TEST

The 50-metre sprint test measures whole-body speed over a short distance.

Goal

To run as quickly as possible for 50 metres.

Equipment

- Measuring tape or marked track
- Stopwatch or timing gates
- Cone markers

Instructions

1. The participant completes a standardised warm up.
2. On the start command, the participant runs the 50-metre course as quickly as possible.
3. Record the time taken to cover the distance to the nearest one-hundredth of a second.
4. The participant rests for 3–5 minutes between sprints, then completes two more trials.

Results

1. Record the lowest time taken to complete the test.
2. Refer to table 10.27 for the norms for this test.

TABLE 10.27 Norms for the 50-metre sprint test (seconds)

Rating	Males aged 16–17 years	Females aged 16–17 years
Excellent	Under 7.1	Under 8.0
Good	7.1–7.3	8.0–8.4
Average	7.4–7.8	8.5–8.9
Fair	7.9–8.2	9.0–9.3
Poor	Over 8.3	Over 9.4

Source: Adapted from Wright, 1997.

10.6.2 Agility tests

Agility is a combination of speed and flexibility and refers to the ability of a performer to change direction with maximal speed while maintaining balance.

Tests to assess this component of fitness generally involve running around and between obstacles (e.g. hats, chairs or cones) as quickly as possible. A number of recognised tests exist, but it is also possible to design tests that are specifically relevant to particular sports.

ILLINOIS AGILITY TEST

The Illinois agility test has been incorporated into test batteries for many years. It measures the ability to quickly change direction without losing control or balance.

Goal

To complete the course, changing direction and moving around cones, as quickly as possible.

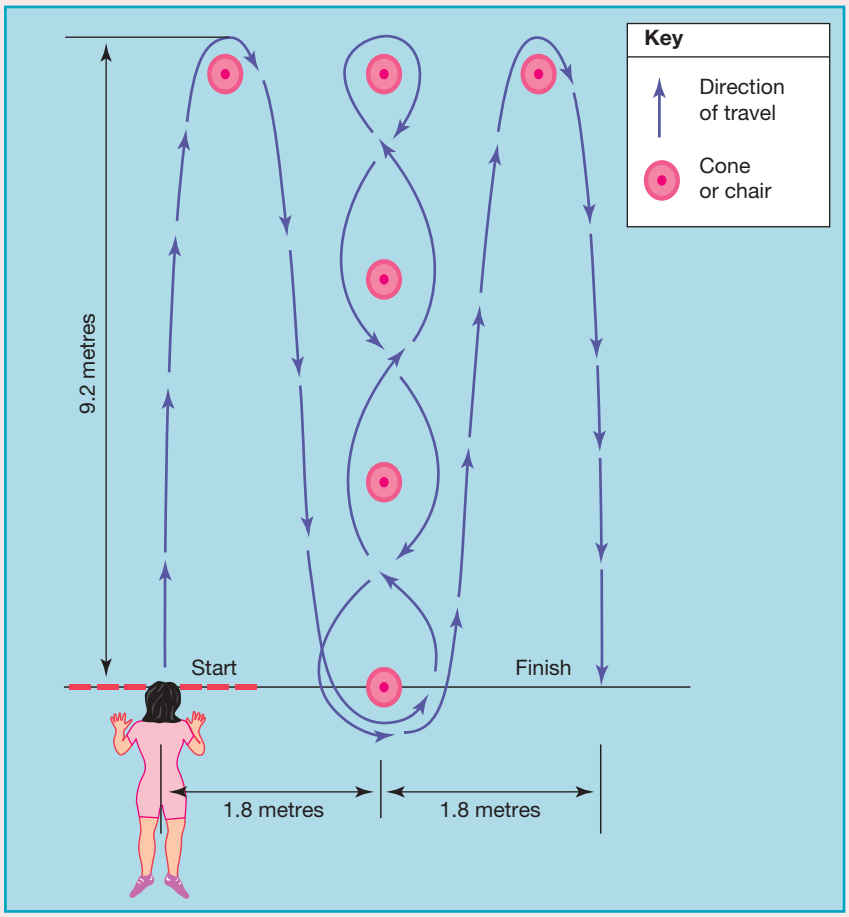
Equipment

- Six chairs or cones
- Tape measure
- Stopwatch

Instructions

1. Set up the course as shown in figure 10.22.
2. The participant lies on their stomach with their hands beside their chest and their forehead on the starting line.
3. On the start command, the participant jumps up and completes the course as quickly as possible. To finish, one foot must touch the end line.
4. Record how long it takes the participant to complete the course.
5. Run two trials if necessary (so the participant has some practice), allowing a period of rest between trials.

FIGURE 10.22 Floor plan for the Illinois agility test



Results

1. Record the best time taken to complete the course to the nearest tenth of a second.
2. Compare the results with the ratings shown in table 10.28.

TABLE 10.28 Norms for the Illinois agility test (seconds)

Rating	Males	Females
Excellent	Under 15.9	Under 17.5
Good	15.9–16.7	17.5–18.6
Average	16.8–18.6	18.7–22.3
Fair	18.7–18.8	22.4–23.4
Poor	18.9 or over	23.5 or over

Source: Adapted from Schell & Leelarthaepin, 1994.

SEMO AGILITY TEST

The Semo agility test assesses the agility of a participant in manoeuvring forwards, backwards and sideways. It is particularly well suited to sports such as tennis, volleyball, badminton and basketball.

Goal

To complete the course, using a variety of movements (sprinting, running backwards and side-stepping) and moving around cones, as quickly as possible.

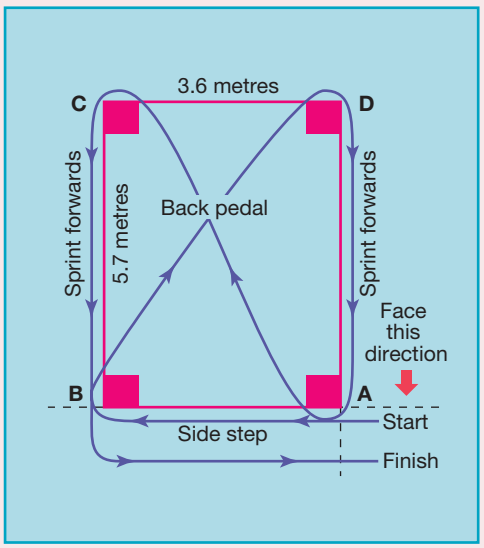
Equipment

- Four cones or chairs
- Stopwatch
- Tape measure

Instructions

1. Set up the course as shown in figure 10.23.
2. The participant completes the course, beginning at point A with their back to the square.
3. The participant always faces the same direction, therefore requiring sideways, backwards and forwards movement.
4. Allow at least one practice trial and two re-trials, with a period of rest between trials.

FIGURE 10.23 Floor plan for the Semo agility test



Results

1. Record the best time taken to complete the course to the nearest tenth of a second.
2. Compare the results with the ratings shown in table 10.29.

TABLE 10.29 Norms for the Semo agility test (seconds)

Rating	Males	Females
Excellent	Under 10.7	Under 12.19
Good	11.49–10.7	12.99–12.19
Average	13.02–11.50	13.90–13.00
Fair	13.79–13.03	14.49–13.91
Poor	13.80 or over	14.50 or over

Source: Adapted from R Malpeli, M Horton & G Davey, *Physical education, VCE Units 3 and 4*, Thomas Nelson, South Melbourne, 1994.

5-0-5 AGILITY TEST

Goal

To sprint, change direction and sprint back as quickly as possible.

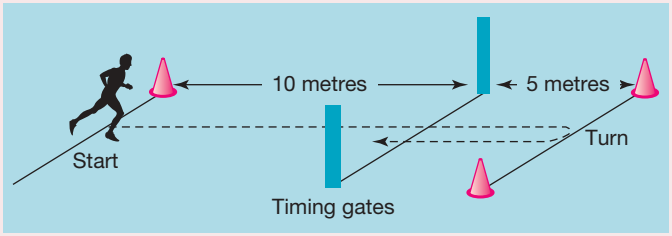
Equipment

- Start/stop timing gates or stopwatch
- Non-slip running surface
- Cone markers

Instructions

1. Set up markers 5 and 15 metres from a line marked on the ground (see figure 10.24).
2. The participant sprints from the 15-metre marker towards the line (run in distance to build up speed) and through the 5-metre markers, turns on the line and runs back through the 5-metre markers.
3. The time is recorded from when the participant first runs through the 5-metre markers until they return through those markers (i.e. the time taken to cover the 5-metre up and back distance — 10 metres total).
4. Repeat after at least 3 minutes passive recovery. The best of two trials is recorded.
5. The turning ability on each leg should be tested. The participant should be encouraged to not overstep the line by too much, as this will increase their time.

FIGURE 10.24 5-0-5 agility test



Results

There are limited norms available for the 5-0-5 agility test; however, the following data can be used as a guide (see table 10.30).

TABLE 10.30 Norms for the 5–0–5 agility test

Age (years)	Sex	N	Average 5-0-5 COD performance time (s)
Under 16	Combined	64	NA
	Male	64	2.66 ± 0.21
	Female	0	N/A
16–19	Combined	102	2.49 ± 0.23
	Male	58	2.39 ± 0.29
	Female	44	2.63 ± 0.15
Over 20	Combined	234	2.46 ± 0.15
	Male	178	2.46 ± 0.12
	Female	18	2.72 ± 0.18

on Resources

Weblink 5-0-5 agility test

doc-41991

PRACTICAL ACTIVITY Speed and agility tests

Goal

To complete and compare speed and agility tests.

Instructions

1. Complete as many speed and agility tests as you can, recording your results and observations as each test is completed.

Primary data/Reflection

TABLE 1 Results of the tests

Test	Results

- How did you feel about your performance in the tests compared to your expectations?
- Compare and contrast your performance in the different speed and agility tests. Which test did you perform best in, and why do you think that is?
- Reflect on the factors that may have influenced your performance in each test (e.g. technique). How did these factors contribute to your results?
- Were there any differences in fatigue between the different tests?
- What techniques or tactics did you use to optimise your performance in the tests?

Questions

1. Compare your ratings for at least two speed tests. Were they similar or different? Explain why this may be so.
2. Compare your ratings for at least two agility tests. Were they similar or different? Explain why this may be so.
3. Describe each of the tests and identify one sport to which they may be suited.

EXAM TIP

When comparing speed and agility tests, be sure to highlight that while both speed and agility tests need to be completed as quickly as possible, agility tests will have changes in direction or different movements.

10.6 Activity

10.6 Quick quiz on

10.6 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	6	4, 5

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TEST your understanding

1. **Describe** the term *speed*.
2. **Describe** the term *agility*.
3. **Outline** the main differences between the three agility tests.

APPLY your understanding

4. **Identify** and **justify** an appropriate agility test for the following participants.
   - Elite rugby player
   - Year 12 class
   - Beginner at the gym
5. **Identify** and **justify** which recognised agility test would be most appropriate for a squash player.
6. **Discuss** how the semo agility test is a valid agility test.

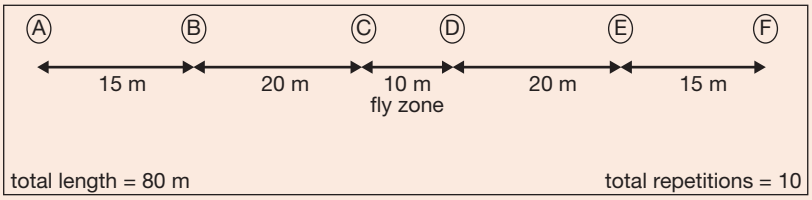
10.6 Exam questions

Question 1 (2 marks)

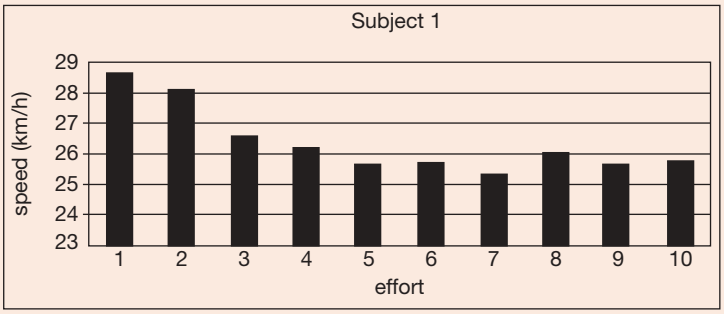
Source: Adapted from *VCE 2008, Physical Education Exam, Section B, Q.9.a*; © VCAA

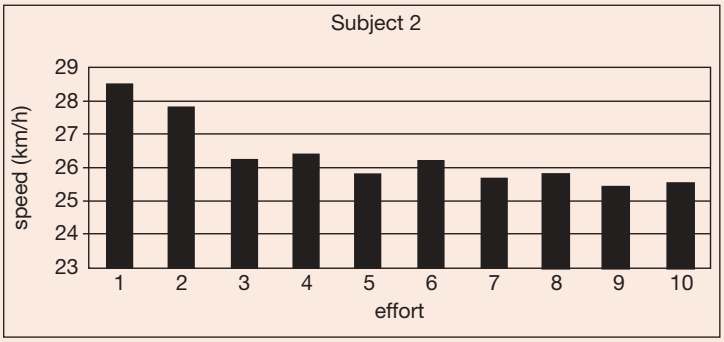
The following data refers to the scores obtained from two subjects in a repeated sprint test. The subjects were elite level AFL footballers. Below is a summary of how the test was conducted.

- Subjects jog from point A to point B.
- At point B subjects accelerate so that when they get to point C they are at maximum speed.
- Maximum speed is maintained over 10 m from point C to point D (fly zone). The time taken to cover the 10 m in the fly zone is recorded and the speed is calculated.
- From point D to point E the subject decelerates (slows down).
- Subjects jog from point E to point F.
- Subjects rest for 25 seconds between sprints.
- Subjects perform 10 repetitions.



The graphs show the maximum speed reached in the fly zone by the two subjects.





Justify the 20-metre sprint test for a netball centre.

Question 2 (2 marks)

a. **Identify** the fitness test for agility that would be the most appropriate for a soccer goalie. **(1 mark)**

b. **Justify** your answer to **part a**. **(1 mark)**

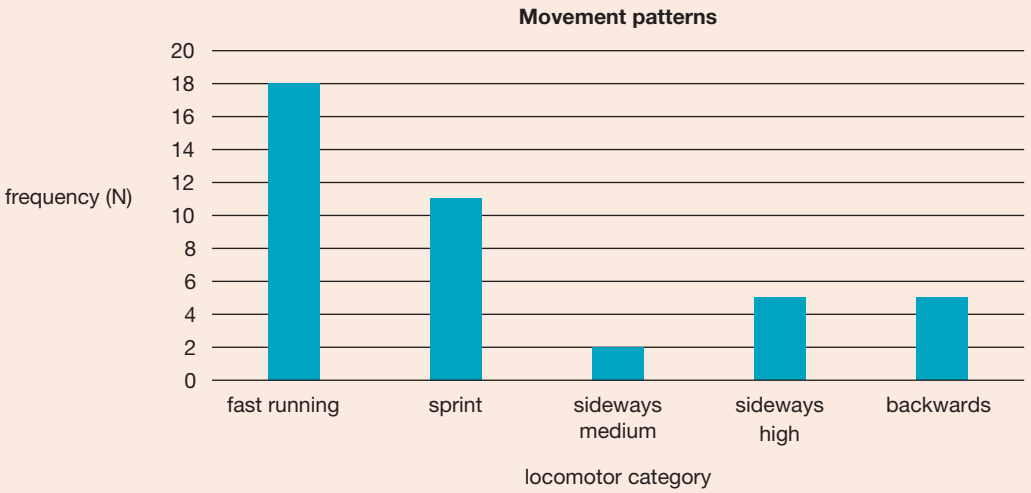
Question 3 (3 marks)

Discuss how the Illinois agility test could be completed with increased reliability.

Question 4 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.1.a;* © VCAA

A coach collected data on one player during a 60-minute recreational European handball match. The data is presented in the following graph and table.



Source: Data and ideas from SCA Povos et al., 'Physical and physiological demands of recreational team handball for adult untrained men', *BioMed Research International*, 2017, p. 5

throws	20
jumps	27
changes of direction	13

The coach wants to assess the level of agility of his recreational European handball team.
Name a suitable standardised fitness test and **justify** why this test is suitable, based on the physiological requirements of the European handball team.

Question 5 (2 marks)

Source: *VCE 2013, Physical Education Exam, Section B, Q.10.a;* © VCAA

An activity analysis conducted on a basketball game found that the predominant fitness components required for the sport were muscular power (lower body) and agility.
Name one recognised fitness test to assess each of these fitness components.

More exam questions are available in your learnON title.

10.7 Flexibility tests

Key knowledge	Key skills
• assessment of fitness for an activity: – standardised, recognised fitness tests that test appropriately identified physiological requirements	• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

10.7.1 Flexibility tests

Flexibility may be dynamic or static. Most tests of flexibility measure static flexibility because dynamic flexibility tests are difficult to implement.

TABLE 10.31 Recognised standardised tests of flexibility

Fitness component	Test
Flexibility	Trunk flexion (sit-and-reach) test Shoulder and wrist elevation test Trunk and neck extension test Shoulder rotation test

Flexibility testing requires careful monitoring and adherence to safety measures. The participant should be thoroughly warmed up before attempting maximal stretches — it is essential that a full and measurable total body warm up is carried out before testing commences. This ensures a full range of movement is safely possible at a particular joint or sequence of joints. Safety is paramount in these tests.

TRUNK FLEXION (SIT-AND-REACH) TEST

The sit-and-reach test has been a standard assessment in most fitness test batteries for many years. However, there are variations in the method and scoring of this test. The following protocol is for the modified sit-and-reach test, which measures the flexibility of the hamstrings and lower back.

Goal

To reach forward as far as possible.

Equipment

- Sit-and-reach box (recommended) or bench and ruler

Instructions

1. The participant sits on the floor with legs stretched out straight ahead. Shoes should be removed.
2. The participant places the soles of their feet flat against the box/bench (see figure 10.25). Both knees should be locked and pressed flat to the floor — the tester may assist by holding them down.
3. With the palms facing downwards, and the hands on top of each other or side by side, the participant reaches forward along the measuring line as far as possible. Ensure that the hands remain at the same level, not one reaching further forward than the other.
4. After some practice reaches, the participant reaches out and holds that position for at least one or two seconds while the distance is recorded. Make sure there are no jerky movements.

Note: An alternative, modified method is to complete the test with one leg bent and the other straight, and test each leg separately.

FIGURE 10.25 The sit-and-reach test



Results

1. Record the best score measured in centimetres to the nearest half-centimetre.
2. Refer to table 10.32 for the norms for this test using the one-legged method. For norms using the two-legged method, use the **Sit-and-reach norms: two legs straight** weblink in the Resources panel.

TABLE 10.32 Norms for the modified sit-and-reach test using one leg at a time (centimetres)

Rating	Males aged 17 years	Males aged 18 years	Females aged 17 years	Females aged 18 years
Left leg				
Greatly above base standard	33 or more	35 or more	35 or more	39 or more
Well above base standard	29–32	28–34	31–34	29–38
Above base standard	22–28	22–27	24–30	24–28
Below base standard	21 or less	21 or less	23 or less	23 or less
Right leg				
Greatly above base standard	34 or more	37 or more	36 or more	38 or more
Well above base standard	30–33	30–36	31–35	30–37
Above base standard	22–29	22–29	24–30	24–29
Below base standard	21 or less	21 or less	23 or less	23 or less

Source: Adapted from Wright, 1997.

SHOULDER AND WRIST ELEVATION TEST

The shoulder elevation test measures the flexibility of the shoulder joint. It is sometimes referred to as the shoulder hyper-extension test.

Goal

To reach as high as possible.

Equipment

- 2-metre rulers
- Tape measure

Instructions

1. Use the tape measure to determine the length of the participant's arm from their acromion (see figure 10.26) to their fingertips.
2. The participant lies on the floor with their arms fully extended overhead. They grasp one ruler with their hands shoulder-width apart.
3. The participant raises the ruler as high as possible while keeping their chin on the floor. Read the measurement off the other ruler, which is held vertical (see figure 10.27).

FIGURE 10.26 The location of the acromion



FIGURE 10.27 The shoulder and wrist elevation test



Results

1. Calculate the score obtained by subtracting the measurement of the height reached from the participant's arm length. Record this score.
2. Refer to table 10.33 for the norms for the shoulder elevation test.

TABLE 10.33 Norms for the shoulder elevation test (centimetres)

Rating	Males	Females
Excellent	14 or less	13 or less
Good	15–19	14–19
Average	20–29	20–27
Fair	30–32	28–30
Poor	33 or more	31 or more

Source: Adapted from Malpeli, Horton & Davey, 1997.

TRUNK AND NECK EXTENSION TEST

This is a static flexibility test of the trunk and neck.

Goal

To lift head as high as possible.

Equipment

- Ruler or measuring tape
- Assistant

Instructions

1. The participant lays prone on the floor with their hands clasped at the side of their head.
2. They raise their trunk as high as possible while still keeping their hips in contact with the floor.
3. Record the height from the tip of their nose to the floor.
4. Repeat the test three times.

Results

1. Select the best recorded height.
2. Refer to table 10.34 for the norms for this test.

TABLE 10.34 Norms for the static flexibility test (trunk and neck) (centimetres)

Rating	Males	Females
Excellent	> 25	> 24.8
Good	25.0–20.3	24.7–19.7
Average	20.2–15.2	19.6–14.6
Fair	15.1–7.6	14.5–5.1
Poor	< 7.6	< 5.1

Source: Adapted from BL Johnson & JK Nelson, *Practical measurements for evaluation in PE*, 4th ed., Macmillan, 1986.

SHOULDER ROTATION TEST

Goal

To move an object over the head with the shortest distance between the hands.

Equipment

- Stick or towel
- Ruler or tape measure

Instructions

1. The participant holds a towel or a stick in front of their body with both hands wide apart and palms facing downwards.
2. Maintaining their handgrip on the object, the participant lifts it over their head to behind their back.
3. Repeat the test, with the participant moving their hands closer together each time until the movement cannot be completed.
   Alternatively, if the participant's hands can slide along the stick or towel, start with the hands close together and, as they swing the object over their head, they can slowly slide their hands apart just enough to enable it to go over their head and behind them.
4. Repeat a few times.
5. Measure the minimum distance between the hands.

Results

1. Compare the results with the norms shown in table 10.35.

TABLE 10.35 Shoulder rotation test norms (centimetres)

Rating	Men	Women
Excellent	< 7.00	< 5.00
Good	7.00–11.50	5.00–9.75
Average	11.51–14.50	9.76–13.09
Fair	14.51–19.75	13.10–17.75
Poor	> 19.75	> 17.75

on Resources

Weblinks Fitness tests
Sit-and-reach norms: two legs straight
Trunk rotation test

Interactivity Shoulder rotation test calculator (int-6812)

doc-41992

PRACTICAL ACTIVITY Flexibility tests

Goal

To complete and compare flexibility tests.

Instructions

1. Complete as many flexibility tests as you can, recording your results and observations as each test is completed.

Primary data/Reflection

TABLE 1 Results of the tests

Test	Results

- How did you feel about your performance in the tests compared to your expectations? Were you surprised by your results in any of the tests? Why or why not?
- Compare and contrast your performance in the different flexibility tests. Which test did you perform best in, and why do you think that is?
- Compare your flexibility scores to normative data for your age and gender. How do your scores compare, and what implications does this have for your overall flexibility?

Questions

1. Compare your ratings for at least two flexibility tests. Were they similar or different? Explain why this may be so.
2. Describe each of the tests and identify one sport to which they might be suited.

EXAM TIP

Ensure that the flexibility tests chosen are specific to the joints to be used. For example, testing for an athlete who performs a high frequency of kicking should include the sit-and-reach test (which assesses the hamstrings and hip joint).

10.7 Activity

10.7 Quick quiz on

10.7 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 8	6, 7

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- Track results and progress

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TEST your understanding

1. **Describe** the term *flexibility*.
2. **List** the main characteristics of reliable flexibility tests.
3. **List** the upper body flexibility tests.
4. **List** the lower body flexibility tests.
5. **Suggest** why a warm up is vital before flexibility tests.

APPLY your understanding

6. **Identify** and **justify** an appropriate flexibility test for the following participants.
   - Elite badminton player
   - Year 12 class
   - Beginner at the gym
7. For the shoulder and wrist elevation test and the sit-and-reach test, **identify** and **justify** the type of participant who is likely to use each test due to the test replicating their flexibility requirements.
8. If an athlete scores well on the sit-and-reach test, can you assume they will also score well on the shoulder rotation test? **Discuss** your reasoning.

10.7 Exam questions

Question 1 (3 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.1.b,c* © ACHPER

a. **Name** one recognised standardised fitness test which assesses flexibility of the lower body. **(1 mark)**

b. **Describe** the method of the fitness test named in **part a**.
You may use a diagram to support your response. **(2 marks)**

Question 2 (2 marks)

Describe a recognised standardised fitness tests that assesses flexibility of the upper body.

Question 3 (2 marks)

A swimmer completes the sit-and-reach and shoulder rotation flexibility tests. They score above normal for one and below normal for the other. **Identify** and **justify** which of the tests they are most likely to have scored highly on.

Question 4 (2 marks)

Discuss two athletes who are likely to score highly on the sit-and-reach test.

Question 5 (3 marks)

Explain why the order of flexibility tests is not as important within a fitness test battery when compared to other tests such as the phosphate recovery test and 1 RM bench press.

10.8 Key skills

Key skills
• 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

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

10.8.1 Tell me

To address these key skills, it is important to remember:

- the key terms for each fitness component (e.g. agility is the ability to change direction quickly without losing balance)
- justifications should include the key terms for the fitness components as well as supporting data
- links to data should be specific (e.g. '24 sprints', rather than 'some sprints')
- when describing a test, make sure you include the aim of the test (e.g. to complete as many repetitions as possible)
- even though reliability, validity and accuracy are interrelated, make sure you use different key terms and examples when discussing these for the one test
- there are many ways a test can be physiologically appropriate (e.g. if it replicates the physiological requirements of the sport or activity, and if the participant is psychologically capable of completing it)
- there are many ways a test can be psychologically appropriate (e.g. if it can be done with others to increase motivation and if it is achievable for the participant).

10.8.2 Show me

Practice question (6 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *VCE 2023, Physical Education Exam, Section B, Q.2.a.ii*; © VCAA

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.



The VO_2 maximum cycle ergometer test is a common fitness test performed by professional cyclists.

a. **Justify** the selection of the *VO_2 maximum cycle ergometer test* from a physiological and psychological perspective for Jai Hindley. (2 marks)

b. **Explain** how the *VO_2 maximum cycle ergometer test* is *valid* and *accurate* in testing aerobic power. (4 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Justify — prove with reasoning why an option chosen is the best
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *VO_2 maximum cycle ergometer test*, *valid*, *accurate*
- **Key concepts** — fitness test, physiological, psychological perspective, aerobic power
- **Marking scheme** — 6 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a. From a physiological perspective, it is *suitable* for Jai as he performs on a bike, which *replicates* the *muscle action* and *movements in cycling*.
Psychologically, as Jai is an elite cyclist, he will be *motivated* to push himself to his *maximal capacity* as required in the test.
Award 1 mark for justifying the physiological perspective with reference to performance or movement.
Award 1 mark for justifying the psychological perspective with reference to motivation.

b. As the *VO_2 maximum cycle ergometer test* records the amount of oxygen being taken in and used through the *direct measurement* of breathing using a computer, it has *less room for human error*, and thus *increased accuracy*.
As the *VO_2 maximum cycle ergometer test* involves *large muscles*, goes for a *long duration* and works from *sub maximal to maximal intensity*, it relies heavily on the aerobic energy system. Thus, it tests aerobic power, making it a *valid test*.
Award 1 mark for explaining how the measurement is being taken.
Award 1 mark for explaining how the measurement being taken is accurate.
Award 1 mark for explaining how the VO_2 max test works with reference to the aerobic energy system.
Award 1 mark for explaining how the test is valid.

10.8.3 Let me do it

Question 1 (8 marks)

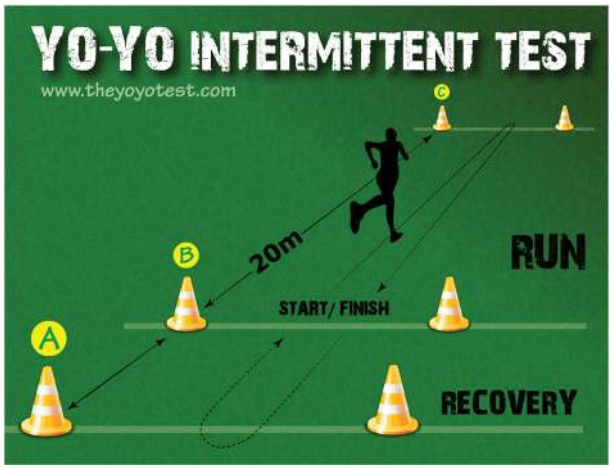
Source: Adapted from *VCE 2022, Physical Education Exam, Section B, Q.6.a–c*; © VCAA

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: MS 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

a. **Name** and **describe** the fitness component that is assessed in the yo-yo intermittent recovery test. **(2 marks)**

b. Using the data provided in the table, **justify** why, from a physiological perspective, the yo-yo intermittent recovery test was selected to assess the handball players' fitness. **(3 marks)**

c. **Outline** how an alternative fitness test, assessing the same fitness component as the yo-yo intermittent recovery test, could correctly be conducted. Include a diagram in your response. **(2 marks)**

d. **Outline** the possible advantage, from a psychological perspective, of using the alternative test from **part c**. **(1 mark)**

10.9 Review

Hey students! Now that it's time to revise this topic, go online to:

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10.9.1 Summary

The purpose of fitness testing

- Fitness testing is integral to any serious fitness training program and to any participant. It should be completed after activity analysis.
- Fitness assessment provides a measurement of physiological responses to physical activity within a controlled environment.
- Participants can undergo fitness testing before, during and after a training program. Testing can identify the specific attributes of the participant, determine the participant's strengths and weaknesses, monitor progress and provide motivation.

How to conduct fitness testing

- Pre-participation health screening (e.g. PAR-Q) and informed consent are an important part of the testing process.
- There are clear testing protocols that should be put in place to ensure safety and ultimate test reliability and validity.
- A wide variety of tests are available to assess each fitness component.
- Selecting a particular test is a matter of deciding which test best suits the needs of the individual and the activity and should take into account physiological and psychological perspectives.

Aerobic power and anaerobic capacity tests

- Understanding both aerobic power and anaerobic capacity provides insights into an individual's overall fitness level and performance potential in various physical activities.
- Aerobic power tests, such as the multistage fitness test, yo-yo test, Cooper 12-minute run test, Astrand-Rhyming cycle ergometer test and the Harvard step-test, assess the body's ability to use oxygen efficiently to produce energy during sustained physical activity.
- Anaerobic capacity tests, such as the phosphate recovery test, 30-second Wingate test and Repco peak power test, test the body's ability to produce energy without oxygen, typically during short bursts of intense activity.

Muscular strength, muscular power and muscular endurance tests

- Muscular strength is required for lifting, pushing and pulling and is the maximum force a muscle or muscle group can generate against resistance in a single or repeated maximal capacity.
- A number of tests may need to be completed to accurately assess muscular strength. These tests include a 1 RM test, grip strength dynamometer and seven-stage abdominal strength test.
- Muscular power is crucial for activities requiring quick, explosive movements (maximal force is exerted in the shortest time possible), such as sprinting and jumping actions.
- Muscular power tests include the basketball throw, vertical jump or standing long jump.
- Muscular endurance is needed in activities that require a sustained effort over time, such as distance running and cycling. It is the ability of a particular muscle or muscle group to work at a desired effort for as long as possible.
- Muscular endurance tests includes 60 seconds of push-ups or sit-ups, the curl-up (crunch) test and the flexed arm hang test.

Speed and agility tests

- Speed is important for a variety of sports and activities, including sprinting, basketball and track and field events, where specific distances need to be covered in the shortest time possible.
- Tests to assess speed include the 20-metre, 35-metre and 50-metre sprint tests.
- Agility is important in sports such as soccer, tennis and basketball, where a change of direction with maximal speed is required.
- Agility tests include the Illinois, Semo and 5-0-5 agility tests.

Flexibility tests

- Flexibility tests assess the range of motion around specific joints or muscle groups.
- It is essential that a full body warm up is completed before testing commences to reduce the chance of injury.
- Flexibility tests include the trunk flexion (sit-and-reach) test, shoulder and wrist elevation test, trunk and neck extension test and shoulder rotation test.

10.9.2 Key terms

accuracy precision of measurements, observations, or actions
physiological perspective examination and understanding of the various bodily systems and functions that influence athletic performance
psychological perspective examination and understanding of the mental and emotional aspects that influence athletic performance, behaviour and experiences
reliability consistency and dependability of measurements, tests, or assessments used to evaluate
validity the degree to which a test, measurement, or assessment tool accurately measures what it claims to measure

10.9 Exam questions

10.9 Section A — Multiple choice questions

Question 1 (1 mark)

Which of the following is a maximal test for aerobic power?

A. VO_2 max treadmill test
B. Yo-yo test
C. Cooper 12-minute run
D. Cycle ergometer test

Question 2 (1 mark)

Which of the following tests does not require the participant to run as long as they can?

A. 20-minute shuttle run
B. Yo-yo test
C. Cooper 12-minute run
D. Cycle ergometer test

Question 3 (1 mark)

The cycling track sprint ranges from 600 metres to 1000 metres. An athlete who scores highly in which test would be best suited to this event?

A. Phosphate recovery test
B. Wingate cycling test
C. VO_2 max cycle test
D. Squat test

Question 4 (1 mark)

Which test requires the participant to complete as many repetitions as possible?

A. Flexed arm hang test
B. 1 RM squat
C. 3 RM bench press
D. 60-second push-up test

Question 5 (1 mark)

Pre-training program testing does not:

A. motivate athletes.
B. set benchmarks.
C. identify strengths and weaknesses.
D. identify predominant muscle groups and energy systems required for activity.

Question 6 (1 mark)

Which of the following shows the correct order of tests to ensure the most accurate results?

A. Least to most fatiguing
B. Most to least fatiguing
C. Aerobic tests first then anaerobic tests, as the aerobic tests act as a warm up
D. Flexibility tests first

Question 7 (1 mark)

To ensure the reliability of tests when comparing a number of participants on the same fitness component, what should be the only variable that changes between tests?

A. The participant
B. The test, as long as it still tests the same fitness component
C. When the testing is held
D. The norms used

Question 8 (1 mark)

Post-season testing:

A. should not be done unless the athlete is elite.
B. should use the same tests as used in any pre- or in-season testing.
C. can use different tests but must test the same fitness components and energy systems.
D. is a waste of time as the season is finished.

Question 9 (1 mark)

Which fitness test is most likely to be used if the activity analysis shows a W:R of 1:1?

A. 20-metre sprint
B. Phosphate recovery test
C. 20-metre multistage shuttle run test
D. Vertical jump test

Question 10 (1 mark)

If an 18-year-old male scored 58 centimetres on the vertical jump, it would be considered:

A. excellent.
B. good.
C. fair.
D. poor.

10.9 Section B — Short answer questions

Question 1 (2 marks)

Explain how to ensure the safety, validity and reliability of a fitness test battery.

Question 2 (4 marks)

Flexibility decreases as we age. What are two other factors that affect flexibility? **Explain** how each factor affects this fitness component.

Question 3 (3 marks)

Discuss how the accuracy of tests in a battery can be improved by considering order and recovery time.

Question 4 (2 marks)

Identify and **justify** which aerobic power test is best used for people wanting to complete a 5-kilometre fun run.

Question 5 (3 marks)

Explain why the results for the muscular strength tests and VO_2 max tests take body weight into account.

Continue to build your exam skills

Access the Unit 4 Area of Study 1 Review at the end of Topic 10. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

AREA OF STUDY 1 What are the foundations of an effective training program?

OUTCOME 1

On completion of this unit, the student should be able to undertake an activity analysis to justify the physiological requirements of an activity that informs an appropriate assessment of fitness.

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

REVIEW CONTENT SEQUENCE

U4 AOS1 Extended response — Build your exam skills
U4 AOS1 Practice examination online only
U4 AOS1 Practice school-assessed coursework online only

U4 AOS1 Extended response — Build your exam skills

Tell me

To address these questions, it is important to remember:

- to reference data provided in the stimulus
- there may be parts to the question that need to be addressed; look out for 'and' and plurals
- how fitness components are described
- the different fitness test and what fitness components they test
- the purpose of activity analysis; that is, to determine the most important physiological requirements, energy systems, fitness components and muscles groups of an activity
- how energy systems are linked to fitness components
- the causes of fatigue and the type of recovery needed for each energy system.

Show me

Practice question (6 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.4.b;* © VCAA

Sport climbing is a new addition to the 2020 Summer Olympics. It features three disciplines, two of which are described below:

- Speed climbing involves two climbers attempting to scale a 15-metre-high wall faster than their opponent. The men's world record is 5.48 seconds and the women's world record is 7.32 seconds.
- In lead climbing, climbers have a maximum of 6 minutes to climb as high as possible along a specific route on a wall that is more than 15 metres in height.

FIGURE Climbers competing in **(a)** speed climbing and **(b)** lead climbing



Using the information provided, **compare** the interplay of energy systems that enable movements to occur in speed climbing and lead climbing by discussing the *intensity and duration* of the events. In your response, **justify** the need for the fitness components of *muscular power* and *muscular endurance* in the different climbing events.

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Compare — recognise similarities and differences and their significance
  Justify — prove with reasoning why an option chosen is the best
- **Key terminology** — *intensity and duration*, *muscular power*, *muscular endurance*
- **Key concepts** — interplay of energy systems, fitness components
- **Marking scheme** — 6 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response

In the speed and lead climbing events, both athletes *use all three energy systems at all times in varying amounts*.

For speed climbing, the duration of the event *is approximately 5.48–7.32 seconds*; this means the ATP–CP system is providing most of the energy. The ATP–CP system provides ATP at a fast rate but has a low yield, allowing the climber to scale the 15-metre wall quickly at a rate 2.05-2.74 metres per second. There would be a negligible contributions from the anaerobic glycolysis system in the speed climb. To be able to scale the wall quickly, muscular power is needed as the climber performs *explosive efforts of movement* up the wall.

At the beginning of lead climbing, the ATP–CP system would be used due to *oxygen deficit and energy being required at a fast rate*. As the lead climbing event lasts a total of *6 minutes*, this means the aerobic system is providing most of the required ATP. The energy supplied by the aerobic system is produced at a slower rate, yet has a greater yield. The speed of climbing is *slower*, at 0.004 metres per second (using a maximum time of 6 minutes). There would be a greater contribution from the anerobic glycolysis system during lead climbing as there would be times during the 6 minutes where the *intensity of movement would increase* and the *ATP for muscular movements would be derived from the anaerobic glycolysis system.* The climber in this scenario would need muscular endurance due to the need to *perform repetitive movements over an extended period* while in a *fatigued state*.

Marking guide

High range response	• Detailed links between the intensity and duration of both events to the correct energy systems • Correctly apply energy system interplay with specific details for the two climbing events • Justify the correct fitness components that may link energy systems and events using key terms • Use data within a coherent discussion
Mid range response	• Some links between the intensity and duration of both events to energy systems • Some mention of energy system interplay with links to the two climbing events • Some attempt to justify the correct fitness components • Some data referenced
Low range response	• Limited links between the intensity and duration of both events to energy systems • Limited mention of energy systems, without interplay, for the climbing events • Limited links to fitness components • Limited data used

Let me do it

Extended response questions learn on

Question 1 (8 marks)

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.10;* © VCAA

Jan is an under-18 Australian Rules football midfield player who wants to be drafted in the Australian Football League Women's (AFLW) in the next two years. She collected the following data on her past season to plan her off-season training.

TABLE 1 Global positioning system (GPS) data

Data	Jan's season average	AFLW player's season average
total distance covered	5.9 km	7.2 km
top speed	23 km/h	27 km/h
number of repeated sprints over 18 km/h	7	10

TABLE 2 Jan's fitness testing results

Test	Pre-season	Rating	Before finals	Rating
yo-yo intermittent recovery	level 13.0	below average	level 14.5	below average
vertical jump	35 cm	average	38 cm	average
Semo agility	13 s	below average	12.2 s	below average

(continued)

TABLE 2 Jan's fitness testing results *(continued)*

Test	Pre-season	Rating	Before finals	Rating
20 m sprint	3.24 s	above average	3.35 s	average
1.6 km run	9 min 20 s	below average	9 min	below average
stork stand	3 s	poor	15 s	fair

Analyse the data in tables 1 and 2. Explain why the tests chosen have been included and how they could be completed to ensure increased validty, reliability and accuracy.

Your response should include reference to how the following affect how fitness testing is done:

- activity analysis
- energy systems, including fatigue and recovery
- fitness components.

Question 2 (8 marks)

Source: Adapted from *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.13;* © ACHPER

A group of elite field hockey players are trying out for a position for a college in the USA. They need to undertake several tests at an elite training facility and the results will be sent to the USA for analysis.

The following tests were selected as part of a test battery and the coach wants to ensure the testing procedure is conducted in a controlled manner with careful attention to pre-health screening and testing protocols.



- grip strength test
- yo-yo test
- vertical jump test
- 1 RM squat
- Illinois agility test
- phosphate recovery test.

Discuss the considerations for this test battery for the field hockey players by evaluating the appropriateness and order of these tests.

Ensure you refer to the following in your response:

- physiological and psychological perspectives
- reliability and validity of testing
- fitness components
- energy systems, including fatigue and recovery.

Hey students! Now that you have completed the Extended Response, access the following in learnON

Practice examination

Practice SAC

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Assign the quarantined school-assessed coursework

Track your students' results

Identify strengths and weaknesses

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UNIT 4

AREA OF STUDY 2

How is training implemented effectively to improve fitness?

OUTCOME 2

On completion of this unit, the student should be able to participate in a variety of training methods; design and evaluate training programs; and explain performance improvements that occur due to chronic adaptations, depending on the type of training undertaken.

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TOPIC SEQUENCE

11 Training program — planning, implementation and evaluation 486

12 Training program principles 530

13 Training program methods 571

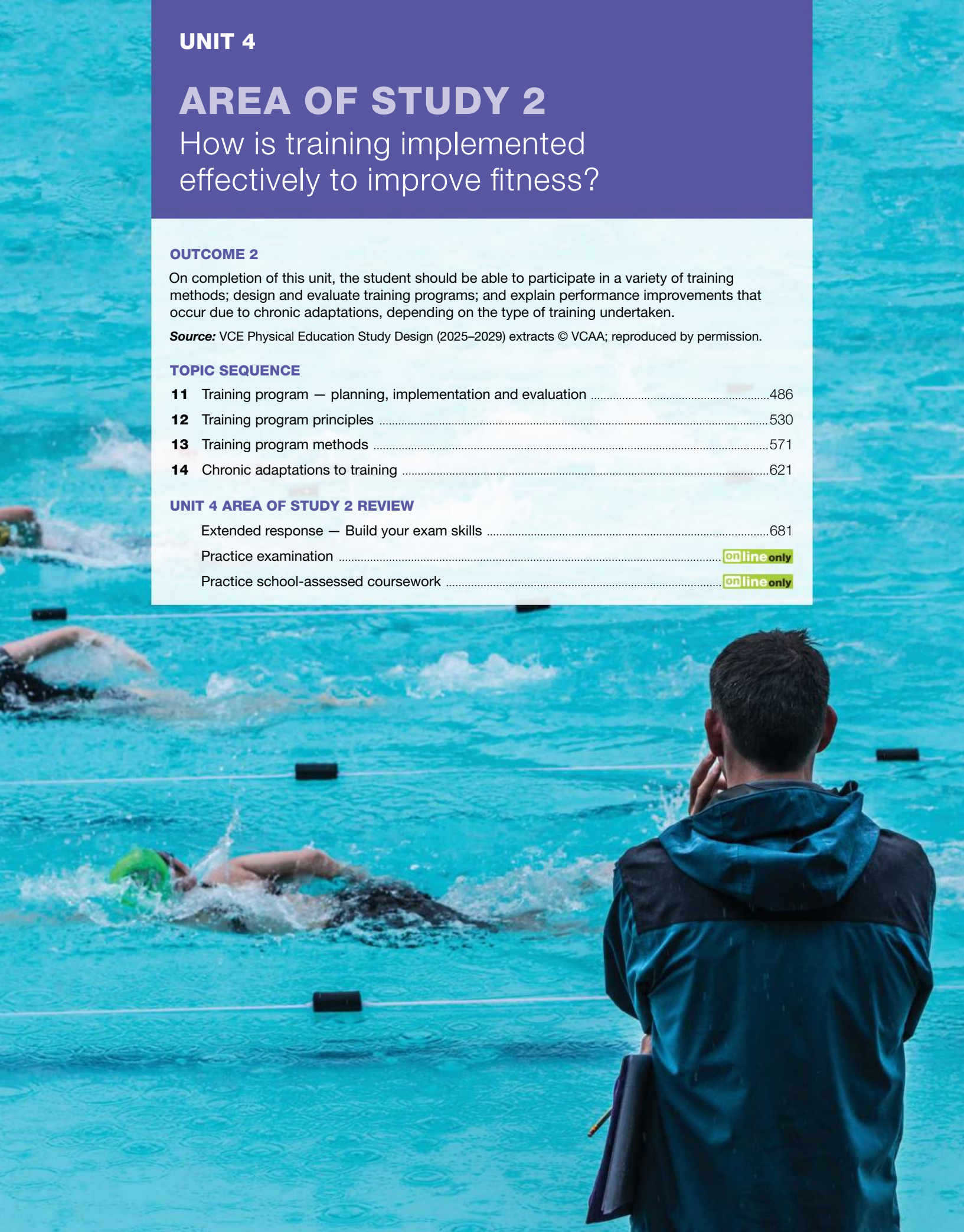
14 Chronic adaptations to training 621

UNIT 4 AREA OF STUDY 2 REVIEW

Extended response — Build your exam skills 681

Practice examination ..... online only

Practice school-assessed coursework ..... online only



11 Training program — planning, implementation and evaluation

11.1 Overview

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LEARNING SEQUENCE

11.1 Overview
11.2 Designing a training program
11.3 Components of an exercise training session
11.4 Strategies to monitor and record training data
11.5 Analysis and evaluation of training data
11.6 Key skills
11.7 Review

11.1.1 Introduction

The ultimate purpose of a training program is to achieve the specific chronic adaptations that an athlete requires for them to perform the best they can in their chosen sport or activity. Topic 9 analysed the importance of undertaking an activity analysis and topic 10 examined the purpose of fitness testing as a part of the planning process. This topic continues to investigate the planning process and also explores the important implementation aspects that need to be considered when planning a training program, including the components of an exercise training session. It is essential that a training program is frequently evaluated for its effectiveness. Strategies to monitor and record physiological, psychological and sociological training data to track the progress of an athlete, and to check that the training program is achieving the specified goals, will also be investigated in this topic.

FIGURE 11.1 If you were the coach of the Australian Matildas, how would you plan and implement the team's training program? What strategies would you use to record, monitor and evaluate each player's physiological, psychological and sociological responses to the training program?

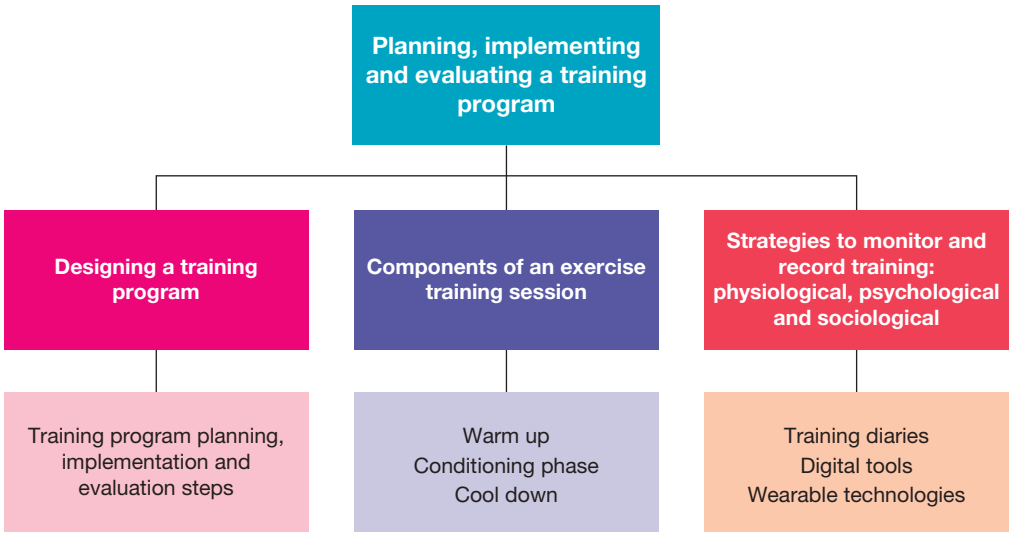


11.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital tools and wearable technologies	• participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio	**11.2** **11.4** **11.5**
• components of an exercise training session including warm up, conditioning phase and cool down	• participate in and conduct components of an exercise training session	**11.3**

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11.1.3 Topic preview



11.2 Designing a training program

Key knowledge	Key skills
• strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital tools and wearable technologies • components of an exercise training session including warm up, conditioning phase and cool down	• participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio • participate in and conduct components of an exercise training session

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11.2.1 Training program steps

Designing, planning and implementing a training program requires a carefully considered, step-by-step approach in which the coach and/or athlete incorporates the activity analysis, fitness assessment, training principles, training methods and monitoring and recording into the overall process.

In order to design and implement the most effective training program for achieving the desired chronic adaptations and improving the physiological, psychological and sociological capacities of an athlete and their performance, some important steps need to be undertaken. Figure 11.2 provides a summary of these steps.

FIGURE 11.2 Summary of the steps involved in a training program

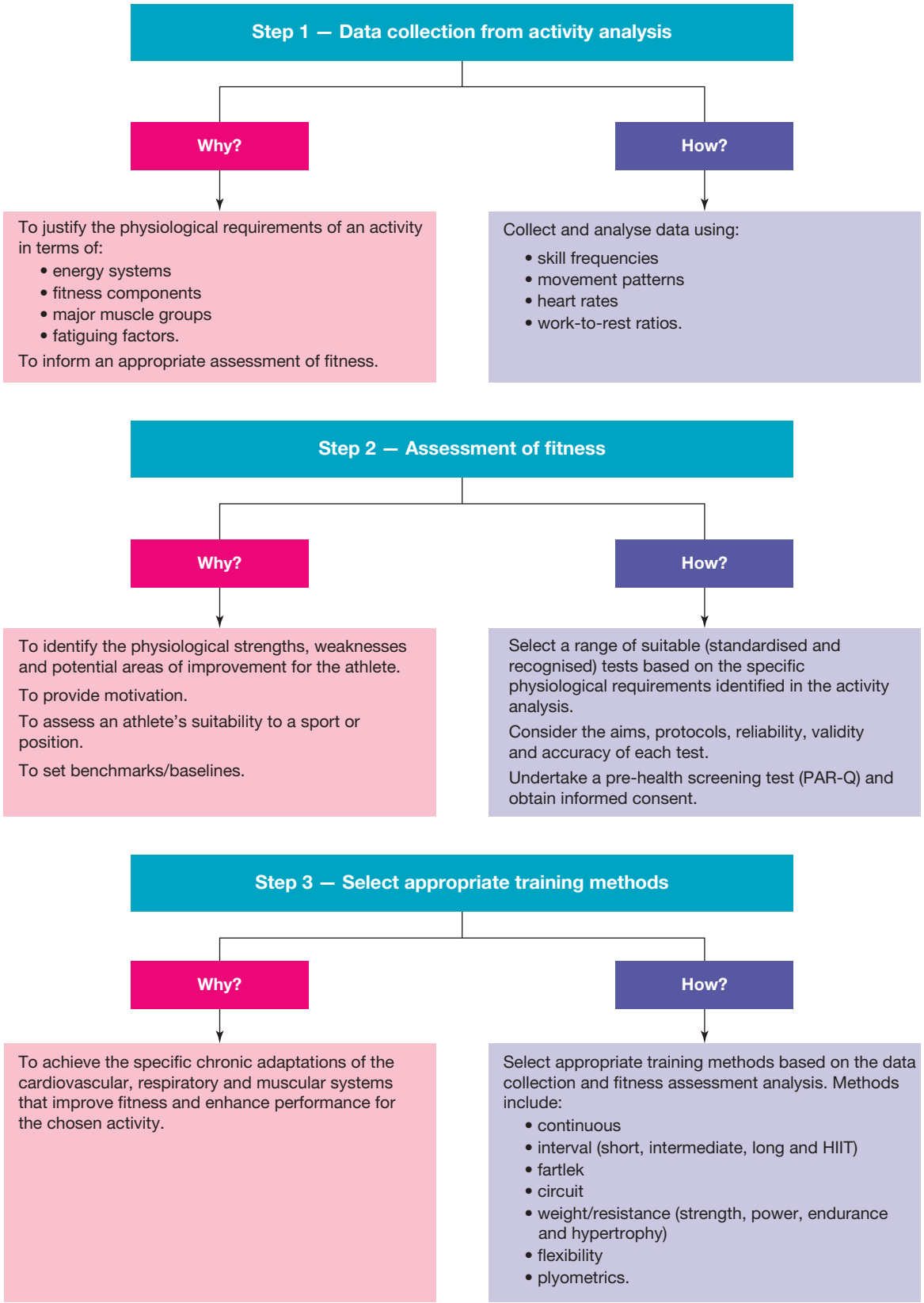
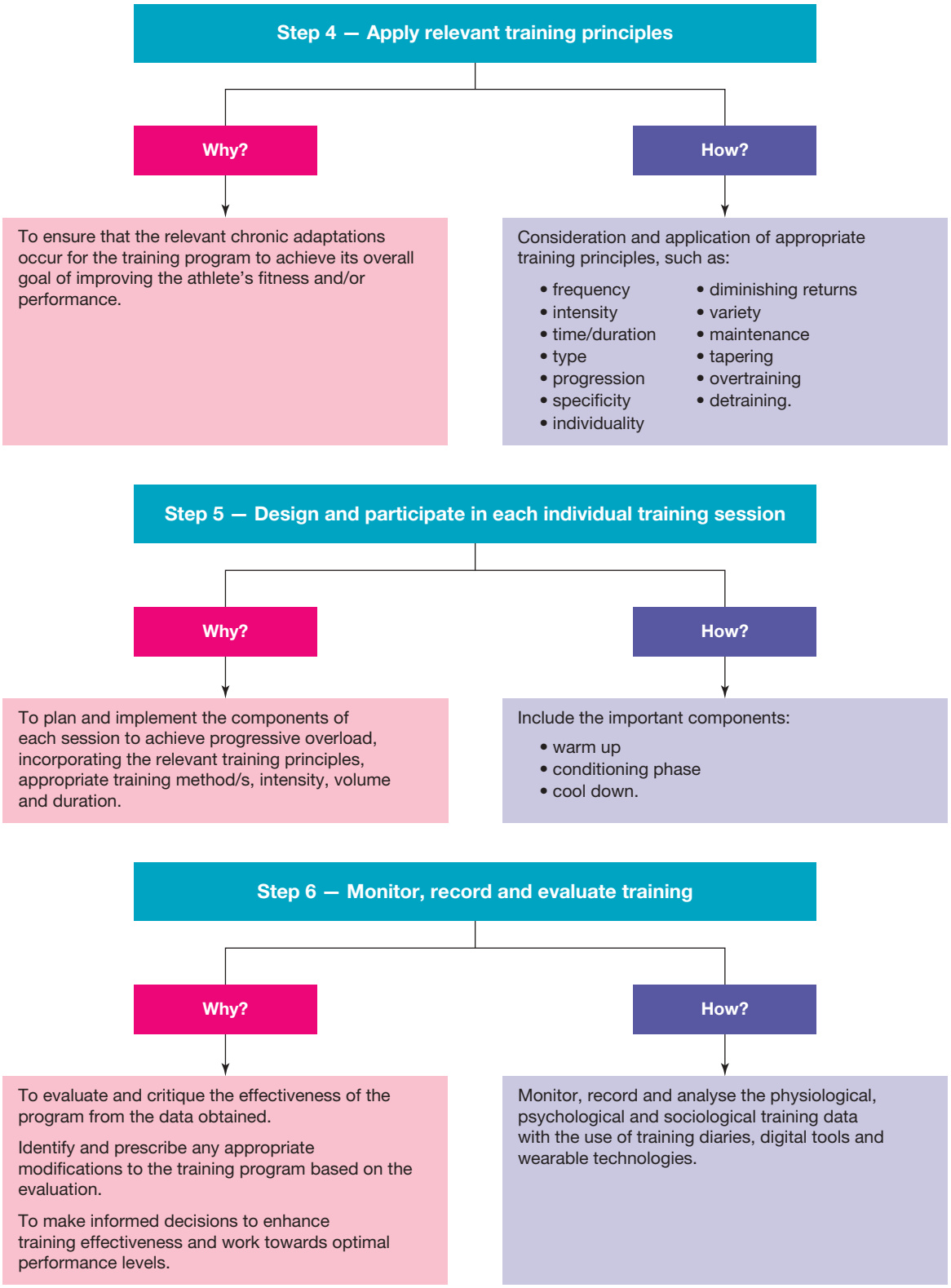


FIGURE 11.2 Summary of the steps involved in a training program *(continued)*



EXAM TIP

Be able to outline the sequence, purpose and process of each step.

When designing and planning a training program, all steps should be considered and then implemented in order for the program to be successful (see figure 11.3).

FIGURE 11.3 All training sessions require careful planning to ensure that athletes can perform at their peak performance.



11.2.2 Activity analysis

Collect data in order to undertake an activity analysis to determine the physiological requirements of a sport or activity, including the relevant energy systems, fitness components, muscle groups and the associated fatiguing factors. (Refer to topic 9 for more detail about conducting an activity analysis.) Undertaking an activity analysis should be the first step in planning a training program. The activity analysis provides valuable insights about the requirements of the sport or activity and contributes to informed decision making with regard to the training program planning process. The actual training program must be specifically designed to develop the physiological capacity of the athlete to meet the identified requirements.

on Resources

Interactivity Training program steps (int-6821)

11.2.3 Assessment of fitness

After an activity analysis has been conducted, the next step is to undertake an assessment of fitness. Carry out a pre-training fitness assessment using a range of suitable (standardised and recognised) fitness tests that have been selected based on the results of the activity analysis. (Refer to topic 10 for more detail about conducting a fitness assessment.) This pre-training fitness assessment allows the athlete's physiological strengths and weaknesses to be identified, determines a suitable starting point (baseline) in terms of training workloads, and provides motivation for the athlete to continue training. The tests selected as part of the pre-training fitness battery can be repeated during and post the training program as a part of monitoring and evaluating it.

11.2.4 Training methods and principles

Equipped with the data, findings and information that both the activity analysis (fitness components) and assessment of fitness (strengths, weaknesses and benchmarks) have provided, the next step is to plan and implement the overall training program. This involves selecting the appropriate training methods (refer to topic 13) to be incorporated into the training program and correctly applying the important training principles to each of the training methods selected in each training session (refer to topic 12).

11.2.5 Periodisation of the training program

Periodisation is simply a process of dividing the training program into a series of manageable phases, with each phase designed to target a specific goal to be developed within a designated period of time. The aim of periodising a training program is to optimise performance and prevent **overtraining**. The specific goal of each phase of training will determine the volume and intensity of training that is required. Training program periodisation plans will differ according to the specifics of the sport. Some sports will have a number of different competition phases interspersed throughout a 12-month period, some will have only one major competition as the main focus in order to peak, and for others there will be weekly matches within the defined competition phase. Typically, a traditional or linear periodisation model involves the training program plan being divided into the following three phases which may be manipulated according to the specific requirements of a particular sport or activity.

periodisation a systematic approach to training that involves dividing the training program into specific phases each with distinct goals, including the planned manipulation of training variables (volume, frequency and intensity)

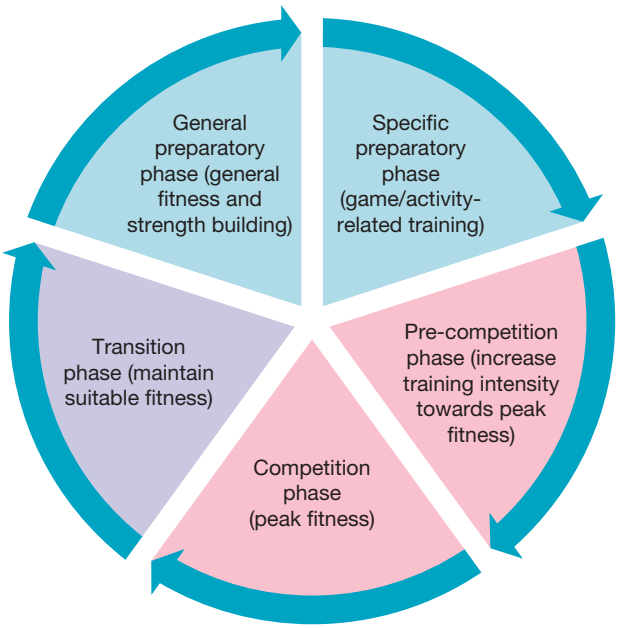
overtraining often caused by an overload of training volume and/or intensity, limiting recovery. It is characterised by a decline in an athlete's performance and an increase in their susceptibility to injury/illness.

Typically, a traditional or linear periodisation model involves the training program plan being divided into the following three phases, which may be manipulated according to the specific requirements of a particular sport or activity.

1. Preparatory phase (pre-season)
2. Competitive phase (in-season)
3. Transition phase (off-season)

Within each of these three phases, the athlete will train to accomplish certain goals. There will be a shift from an emphasis of high volume and low intensity in the preparatory phase to an emphasis of low volume and high intensity as the competition phase nears (see figure 11.4).

FIGURE 11.4 Periodisation is a cyclic process where each phase transitions into the next.



Preparatory phase

The **preparatory phase** of training is commonly referred to as the pre-season or conditioning phase of training. It usually lasts 2–4 months and is arguably the most important phase in an overall training program plan. In this phase of training, the major objective is to provide a suitable fitness and skill base for the competition phase. It forms the foundation on which all subsequent training is built.

preparatory phase (pre-season phase) the first phase of training within a yearly training program. The major objective of this phase of training is to provide a suitable fitness and skill base for the phases of training that follow.

competition phase (in-season phase) the phase of training in which the emphasis is on maintaining the fitness and skill level developed during the preparatory phase, and further developing and refining strategies, tactics and game plans

The preparatory phase can be further divided into two sub-phases based on the characteristics of training:

1. *The general preparatory sub-phase.* This sub-phase is concerned with obtaining a general fitness base and developing the main physiological requirements of the athlete's sport or activity. Strength-building exercises are introduced during this phase. Emphasis is placed on maximising the capacities of the relevant energy systems, particularly the aerobic energy system. Fitness testing and specific skill correction are also a common focus of this period of training. The volume of training is generally high, but the intensity is low to begin with, slowly increasing as the phase progresses. This sub-phase usually lasts 4–10 weeks.
2. *The specific preparatory sub-phase.* As the competition phase approaches, there is a shift in training towards more specific game-related training. There should be a gradual reduction in the volume of training as the intensity starts to progressively increase. A greater amount of variety is also introduced into the training program during this sub-phase, and it usually lasts 2–6 weeks.

Competition phase

The **competition phase** is preceded by a short pre-competition phase so that by the time the competition phase, or in-season phase, of training begins, the athlete should have achieved optimal fitness and skill levels. The focus of the pre-competition phase is to ensure that the athlete is at their peak fitness for competition. This is where an athlete continues to increase the intensity of their training and adjust the volume appropriately. This sub-phase may also incorporate practice matches and tactical training in readiness for competition. A taper period to allow the athlete to recover and reduce any residual fatigue for subsequent competition is often included towards the end of this sub-phase. The emphasis of the competition phase of training should be on maintaining these attributes, and further developing and refining strategies, tactics and game plans.

Because of the demands of competition, particularly if games are weekly (as is the case with many sports such as football, basketball and netball), training needs to be planned carefully (see figure 11.5). This is to allow for recovery and to ensure that players are at their peak both physiologically and psychologically on game day. Individual training sessions in the couple of days following competition should allow for adequate recovery. Subsequent sessions early in the week should be relatively longer and/or more intense. Sessions towards the end of the week should be shorter and less intense, so that players are fully recovered by the day of competition. The competition phase usually lasts 4–6 months for most sports played at an elite level.

FIGURE 11.5 Ahmed Kelly (Australian Paralympic swimmer) will divide his training plan into a series of manageable phases to be at his peak performance for competition.



Transition phase

The **transition phase** (off-season phase) is designed to provide the athlete with both a physiological and psychological respite from the rigours of competition and training. The key to the transition phase of training is to create a balance between recovery and maintenance of training. It is imperative that adaptations do not revert to pre-training levels during this phase. This phase should begin with a short period of active rest and little formal training. Thereafter, the aim during this phase should be for the athlete to remain reasonably active through involvement in a range of recreational activities and low-intensity training to maintain a suitable level of fitness. Cross-training provides variety and is a good way to allow for active recovery both physiologically and psychologically while preserving a base level of fitness. It is essential that the athlete's diet is carefully monitored during this period of time. The off-season phase usually lasts for 6–12 weeks.

transition phase (off-season phase) designed to provide the athlete with a break from the physiological and psychological demands of competition and training. The aim in this phase is for an athlete to remain reasonably active through participation in recreational and low-intensity activities.

peaking refers to the planning of training so that an athlete reaches their optimum state of readiness to perform at a particular predetermined time

tapering a reduction in training that allows the athlete time for extra recovery and for their energy stores to be fully replenished

Peaking and tapering

The main goal of a training program is to prepare an athlete to perform at their best. However, it is not generally possible for an athlete to remain at their optimum level of performance all year round. Instead, athletes often aim to be at their best performance state for particular competitions. The nature of the sport determines when the athlete needs to be performing at their optimum level. A triathlete may aim to be at their best level of performance for major events such as National and World Championships and the Olympic Games, whereas an Australian Rules football player would aim to perform at their best on a weekly basis and to be at their optimum level of performance during finals. Each program needs to be individualised to cater for these differences and also take into account the particular athlete's overall goals (see figure 11.6).

Peaking and **tapering** are important parts of the periodisation of training. Peaking aims to allow an athlete to reach their optimal fitness to perform at a predetermined competition. Periods of intense training can have a negative effect on an athlete's performance capacity, and it is therefore essential that a reduction in training load occurs in preparation for optimal performance.

This reduction in training — known as tapering — allows the athlete time for extra recovery and for their energy stores to be fully restored. At the end of a taper, the athlete should be in peak condition and in their ultimate readiness to compete. Tapering used to involve a reduction in both the volume and the intensity of training. However, now it is widely recognised that the quantity of training should be reduced but the intensity should remain at the same level (or may in some cases even be increased).

FIGURE 11.6 Collingwood Captain, Darcy Moore, would have followed a very well-designed training program to be at his peak and contribute to his team's success in winning the 2023 Premiership Cup.



While most athletes and coaches agree that tapering is a good thing, there are wide differences in opinion on how tapering periods should be constructed. These debates revolve around:

- how long a tapering period should be
- the extent to which training volume and frequency should be reduced during tapering and the rate at which these variables should be reduced.

The above variables are adapted according to the needs of the athlete and the particular sport or activity for which they are training. The concept of tapering is not appropriate for all sports, particularly sports that have weekly competitions, However, these athletes still require periods of recovery to perform at their peak. The most prominent change that occurs as a result of effective tapering is an increase in muscular strength. Some coaches have a certain amount of apprehension about allowing their athletes to undertake a period of tapering; they worry that it will cause a reduction in their aerobic conditioning. Research reveals that although a considerable amount of training is required to achieve significant improvements in aerobic capacity when starting a training program, much less training is required to maintain them, and reducing the load with appropriate tapering should not cause any detraining. Every individual athlete will respond differently to tapering; however, most athletes will improve or at least maintain their current level of performance.

Some of the benefits of tapering include:

- allows for replenishment and increased storage of fuel substrates such as glycogen
- provides an opportunity for psychological refreshment
- heightens enzyme activity
- increases red blood cell volume
- allows for the repair of muscle micro-trauma.

EXAM TIP

Be able to outline the benefits of tapering and when it should be incorporated into an athlete's training program.

Training program matrix or planner

An overall training program matrix or planner that includes all the training methods and sessions to be incorporated can be used to map out the periodisation of a training program. Developing a training program planner begins with identifying and setting specific dates for achieving competition or personal goals. These dates form the basis for assigning the specific training phases. The general preparatory phase develops a fitness foundation and incorporates work of increasing intensity. The athlete's aim is to reach their peak fitness in readiness for the competition phase and this may include preceding tapering periods. Between the end of the competition phase and the beginning of the next preparatory phase, the athlete is provided an opportunity for physiological and psychological recovery through a reduced training load.

on Resources

Weblink How to taper for competition

11.2.6 Specific exercise training sessions

For each method of training that will be incorporated into the overall program, it is necessary to determine the total number of training sessions to be undertaken per week and over the duration of the program. It is then possible to plan the components of each training session in terms of training method, activities to be performed, intensity, volume and duration. When planning the specifics of each training session, it is important to consider and appropriately apply the principles of training, especially specificity, intensity and progressive overload.

To obtain maximum benefit from each training session, it is also necessary to carefully consider how the session is structured. All training sessions should consist of a warm up, a conditioning phase and a cool down. More specific detail about the components of a training session are provided later in subtopic 11.3.

11.2.7 Monitor, record and evaluate training

Monitoring, recording and evaluating training program data is a crucial aspect of the overall success of a training program. Systematically and frequently collecting and analysing the physiological, psychological and sociological training program data helps the athlete and coach to make informed decisions about the effectiveness of the program. Training diaries, digital tools and wearable technologies can all be used to obtain important training data. This data can then be analysed to make evidence-based decisions regarding any necessary and appropriate modifications to a training program. Regularly tracking the progress of an athlete's training program increases the likelihood of achieving the training program goals.

Resources

Digital document Athlete's training program planner template (doc-20128)

11.2 Activity

11.2 Quick quiz on

11.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 5, 6, 7, 8, 9	11, 13	2, 10, 12

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TEST your understanding

1. **Outline** the key steps that need to be addressed when planning, implementing and evaluating a training program.
2. **Explain** why it is important to select appropriate training methods when planning a training program.
3. **Define** the concept of *periodisation*.
4. **List** three important training principles that need to be considered in each training session.
5. **Identify** the three main components of a specific training session.
6. **Identify** the role of the preparatory phase of training and make a distinction between the general and specific preparatory sub-phases.
7. **Identify** the role of the competitive phase of training and make a distinction between the pre-competition and competition sub-phases.
8. **Identify** the role of the transition phase of training and **explain** the types of activities that could be included during this phase.
9. **State** why it is important to monitor, record and evaluate a training program.
10. **Explain** the relationship between peaking and tapering.

APPLY your understanding

11. **Discuss** the importance of undertaking step 1 (Data collection from activity analysis) as a part of the training program design process.
12. **Explain** the purpose of completing step 2 (Assessment of fitness).
13. Use a copy of the **Athlete's training program planner template** in the digital documents section of the Resources panel to **construct** a training program plan for a sport of your choice.

11.2 Exam questions

Question 1 (1 mark)

Source: *VCE 2015, Physical Education Exam, Section A, Q.3;* © VCAA

Theo wants to design a training program for his hockey season.

Which one of the following should he do first?

A. Complete fitness testing.
B. Undertake an activity analysis.
C. Design specific training sessions.
D. Determine the length and periodisation of the training program.

Question 2 (8 marks)

Source: Adapted from *VCE 2021, Physical Education Exam, Section B, Q.8;* © VCAA

Alex is a 20-year-old athlete at state level who has been playing tennis for 10 years. Prior to the start of the new tennis season, his coach has presented him with data that was collected from Alex's last match of the previous season.

Data from Alex's last match

Measurements	Total
total number of forehands	85
total number of backhands	56
first serves in	40%
first serves won	60%
second serves in	50%
second serves won	42%
average speed of first serve	130 km/h
total metres covered in a match	1200 metres
total time of match	125 minutes
total time spent above 70% HR max.	60 minutes
time spent above 85% HR max.	20 minutes
time spent above 95% HR max.	5 minutes

a. **Identify** 4 types of information that can be obtained from an activity analysis. **(4 marks)**
b. **List** 3 methods for conducting an activity analysis that might be used for the game of tennis. **(3 marks)**
c. **Determine** the subsequent step after conducting an activity analysis when planning a training program. **(1 mark)**

Question 3 (6 marks)

Source: Adapted from *VCE 2020, Physical Education Exam, Section B, Q.8;* © VCAA

The Ironman Triathlon consists of a 3.86-kilometre swim, a 180.25-kilometre bicycle ride and a 42.20-kilometre marathon, raced in that order. Races generally last 8 hours for world-class performers.

a. **Outline** the concept of periodisation in relation to a triathlete's training program. **(2 marks)**
b. **Describe** the purpose of the general preparatory phase of a training program. **(1 mark)**
c. **List** 3 benefits the triathlete may gain from tapering their training prior to competition. **(3 marks)**

Question 4 (7 marks)

Source: Adapted from *ACHPER 2010, Trial Exam Units 3 & 4, Section B, Q.11;* © ACHPER

Soccer is one of the most popular sports in the world today. A game of soccer consists of two 45-minute halves. Makenzie Arnold is a goalkeeper and Tamika Yallop is a midfielder for the Australian Matildas World Cup team.

A goalkeeper's role is mainly defensive and involves staying in the penalty area environs to prevent the opposition from scoring a goal. A goalkeeper's movements mostly involve short sprints, kicking, throwing, leaping and jumping, with frequent rest periods between work bouts.

A midfielder's role involves offensive and defensive plays. A midfielder covers far more of the playing field, with extended movement patterns involving sprinting, cruising, jogging and walking, in addition to kicking, dribbling and heading the ball, with far fewer rest periods compared to a goalkeeper.

a. With reference to the game of soccer, **discuss** why it is important to conduct an activity analysis prior to designing a training program. **(4 marks)**
b. **Identify** the purpose of conducting fitness testing on Arnold and Yallop. **(1 mark)**
c. **Outline** why Arnold and Yallop's coach would develop a training planner or matrix. **(2 marks)**

Question 5 (3 marks)

In the days leading up to a major competition, a triathlete reduces his intensity and training load in preparation.

a. **Identify** what this is known as. **(1 mark)**
b. **Outline** how this period may benefit the triathlete. **(2 marks)**

More exam questions are available in your learnON title.

11.3 Components of an exercise training session

Key knowledge	Key skill
• components of an exercise training session including warm up, conditioning phase and cool down	• participate in and conduct components of an exercise training session

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

The most important part of any training program is the athlete participating in the exercise training sessions. These sessions require the appropriate application of the relevant training principles for the selected training method. Training principles and methods are discussed in detail in topics 12 and 13. The content of each training session will depend on various factors, such as the overall goal of the training program, competition timing, the motivation of the athlete and the athlete's fatigue and energy levels. However, all training sessions should be structured to include the following components:

1. a warm up component
2. a conditioning component (skill development and/or fitness conditioning)
3. a cool down component (including stretching).

11.3.1 The warm up component

Each training session should begin with a **warm up**. Essentially, the warm up is designed to prepare the body both physiologically and psychologically for the conditioning phase of the training session. The athlete gradually increases the intensity of the physical activity performed to increase:

- their heart rate
- their blood flow
- the temperature of the muscles to be used.

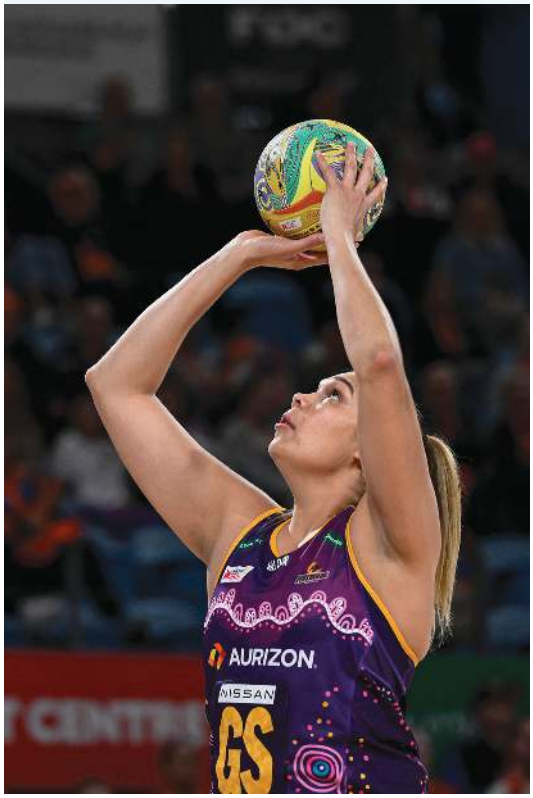
warm up activities and exercises undertaken at the beginning of a training session that are designed to prepare the body, both physiologically and psychologically, for the conditioning phase of the training session

A warm up allows the body to transition from a resting state to meet the higher physiological demands of the conditioning phase of training (see figure 11.7). A well-executed warm up is tailored to the specific needs of the athlete and the activity and/or sport they are preparing for. The length and types of activities included in a warm up are dependent on:

- the intensity of the conditioning phase
- the ability level of the athlete
- the age of the athlete
- the weather conditions (longer warm up if cold, shorter warm up if warmer).

The warm up should produce mild sweating without any feelings of fatigue and should consist of movements that mimic the muscle actions required in the conditioning phase of the training session.

FIGURE 11.7 An effective warm up was a crucial part of Donnell Wallam's preparation for the Fast5 Netball World Series.



neuromuscular the connection between the nervous (neural) system and muscular system. Motor neurons transmit signals to muscular fibre/s, causing a muscle contraction.

The phases of a warm up

An effective warm up prepares the respiratory, cardiovascular and muscular systems to be at their optimum readiness for subsequent activity. Table 11.1 identifies the different phases of a warm up.

TABLE 11.1 Phases of a warm up

Phase	Example
General (first phase)	Low- to moderate-intensity cardiovascular continuous whole body cyclic exercise that engages large muscle groups. Could include jogging, swimming or cycling to begin to increase the heart rate, blood flow to the muscles and core body temperature. This phase should be about 5–10 minutes in length.
Dynamic range of movement and muscle activation (second phase)	Dynamic range of movement exercises (dynamic stretching) such as leg kicks, side swings, lunges, trunk rotations and so on, appropriately selected to target the specific muscles and joints to be used in the conditioning phase (see figure 11.8). The aim of this phase is to enhance **neuromuscular** activation, and to loosen and increase the mobility of the joints, muscles and connective tissue.
Sport/activity-specific (third phase)	Activities that involve agility, speed, acceleration and sport/activity-specific skills. This prepares the body for the intensity required during the conditioning phase of training. It also increases neuromuscular efficiency and consequently the speed at which muscles can respond to stimuli.

The warm up also helps the athlete to prepare psychologically for the cognitive demands of the activity, by facilitating their focus and concentration.

EXAM TIP

Be able to identify the order, purpose (physiological and psychological) and some activity examples for each phase of a warm up.

A common acronym that can be used to describe the phases of a warm up is RAMP:

- **R**aise core temperature and increase cardiovascular activity.
- **A**ctivate and **M**obilise the joints, muscles and nervous system.
- **P**otentiation or **P**erformance — prepare for maximum or competition level.

Examples of a RAMP warm up can be seen in table 11.2.

FIGURE 11.8 Each component of a warm up serves a distinct purpose in preparing the athlete physiologically and psychologically for performance.



TABLE 11.2 RAMP warm up

Warm up phase	Purpose	Example activities
Raise	↑ body's core temperature ↑ heart rate ↑ respiratory rate ↑ blood flow ↑ joint viscosity	Low-intensity movements Dynamic range of movement
Activate and Mobilise	↑ mobilisation and length of joints to allow for full range of motion ↑ neuromuscular firing ↑ activation of muscle groups	Dynamic stretches Resistance band exercises Balance activities Activation movements corresponding to the demands of the sport or activity
Potentiation and Performance	↑ increase intensity in readiness for maximum capacity ↑ immediate competition performance level	Agility exercises Plyometrics Speed Power Game or competition-like activities

It is important to note that while research has found that a warm up has many benefits for performance, warming up can be detrimental to performance if it causes the core body temperature to increase two degrees or more above the normal range of 36.5–37.5 °C. The optimal combination of intensity, duration and type of activity for the warm up is highly individualised; however, the time between the conclusion of the warm up and the start of the event or conditioning phase should be less than 15 minutes.

The general benefits of a warm up

The warm up prepares an athlete both physiologically and psychologically for the activity or training session. The changes produced are outlined in table 11.3.

TABLE 11.3 Physiological and psychological benefits of a warm up

Physiological	Psychological
• Increased blood flow to the muscles, resulting in an increase in muscle temperature and muscle fibre elasticity, which allows the muscles to contract more forcefully and relax more quickly. This permits the joints to work at their full range of movement and lessens the likelihood of injury • Increased heart rate and dilation of blood vessels, which results in greater oxygen and nutrient delivery to the muscle cells • Increased enzyme activity within the muscle cells due to increased muscle temperature, facilitating faster fuel breakdown and energy release within the muscle • Increased respiratory rate and pulmonary diffusion, resulting in increased delivery of oxygen to working muscles • Increased availability of oxygen in the contracting muscle, which reduces the size of the oxygen deficit in subsequent higher-intensity activity	• Enhanced neural pathways, resulting in an increased rate, speed and strength of nerve impulses, allowing for more forceful muscular contractions, enhanced coordination and faster muscle reactions to a stimulus • Enhanced psychological readiness through being mentally prepared for the upcoming activity demands, and being more concentrated and focused

The FIFA 11+ warm up consists of three parts and includes 15 exercises in a specified sequence. This warm up structure has been proven to reduce the risk of major injuries, but it is only effective when performed regularly.

The FIFA 11+ warm up consists of:

1. slow-speed running, active partner stretching and change of direction
2. strength and conditioning, including balance and plyometric exercises
3. higher speed running.

Review the weblink **FIFA 11+ warm up poster**, available in the Resources panel. You may like to undertake this warm up as a class.

on Resources

Weblinks FIFA 11+ warm up poster
Newcastle Sports Medicine — 11+ warm up Part 1 and 3
Newcastle Sports Medicine — 11+ warm up Part 2 Level 1
Newcastle Sports Medicine — 11+ warm up Part 2 Level 2 with adductor updates
Newcastle Sports Medicine — 11+ warm up Part 3 Level 1 with adductor updates

11.3.2 The conditioning component

The conditioning component is the main focus of the training session, and it may include a skill development phase and/or a fitness conditioning phase. The nature of the sport, activity or event will determine the percentage allocation of the skill and the fitness conditioning required. In sports such as golf that require a high level of skill and a lesser fitness conditioning need, there will be a greater emphasis on the skill development phase. In sports like triathlons, the fitness conditioning phase will have a greater emphasis in most sessions. In some sports, there is an equal need for both skill development and fitness conditioning (see figure 11.9).

FIGURE 11.9 Alyssa Healy would train like she plays in order to perform at her best as captain of the Australian women's cricket team.



The conditioning component will include the application of specific training methods (discussed in topic 13) that have been selected based on the data/activity analysis. During the conditioning component of the training session, the focus is on improving the relevant fitness components, muscle groups, energy systems and motor skills required in the chosen sport, activity or event. The important training principles (discussed in topic 12) should be applied appropriately during each session.

11.3.3 Skill development phase

skill development phase includes activities designed to develop and/or practise skills, game plans, tactics and strategies

Activities designed to provide practice of skills, game plans, tactics and strategies are incorporated into the **skill development phase** of the training session. The skill development component can either precede or follow the fitness conditioning phase. If these activities are performed prior to the fitness conditioning phase, the athletes are generally less fatigued, more alert and better able to focus. However, the coach may want the athletes to practise skills while experiencing fatigue, as would be the case in a game. Therefore, they may schedule these activities to take place after the fitness-oriented work of the fitness conditioning phase. The goal of the skill development phase is to enhance neuromuscular activation, improve coordination and technique, and refine movement patterns. The movements undertaken during this phase should mimic those that are performed during the activity that is being trained for. Alyssa Healy would incorporate reaction catching practice as a part of her training to increase her ability to react to balls as quickly and effectively as possible.

11.3.4 Fitness conditioning phase

The primary objective of the **fitness conditioning phase** of the training session is the development and/or maintenance of the specific fitness components, muscle groups, energy systems and motor skills required for the particular sport or activity. Empirical evidence suggests the following order of priority to ensure optimum effectiveness when developing fitness attributes.

1. Sprint and speed work should normally be undertaken first, while the athlete's fatigue levels are low.
2. Strength and power training should follow next, while fatigue levels are still relatively low.
3. Aerobic activities and the development of local muscular endurance should usually be undertaken as the final part of the conditioning phase.

fitness conditioning phase the part of a training session that focuses on the development and/or maintenance of the specific fitness components, muscle groups and energy systems required for a particular sport or activity

cool down low-intensity activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling, gradually returning the body to its resting physiological state

venous pooling an accumulation of blood in the veins in inactive muscles following activity

11.3.5 The cool down component

In much the same way as exercise intensity must gradually increase during the warm up, so too must it gradually decline towards the end of the training session. This gradual reduction in intensity of the activities being performed is referred to as the **cool down** and should be of approximately the same intensity and duration as the warm up.

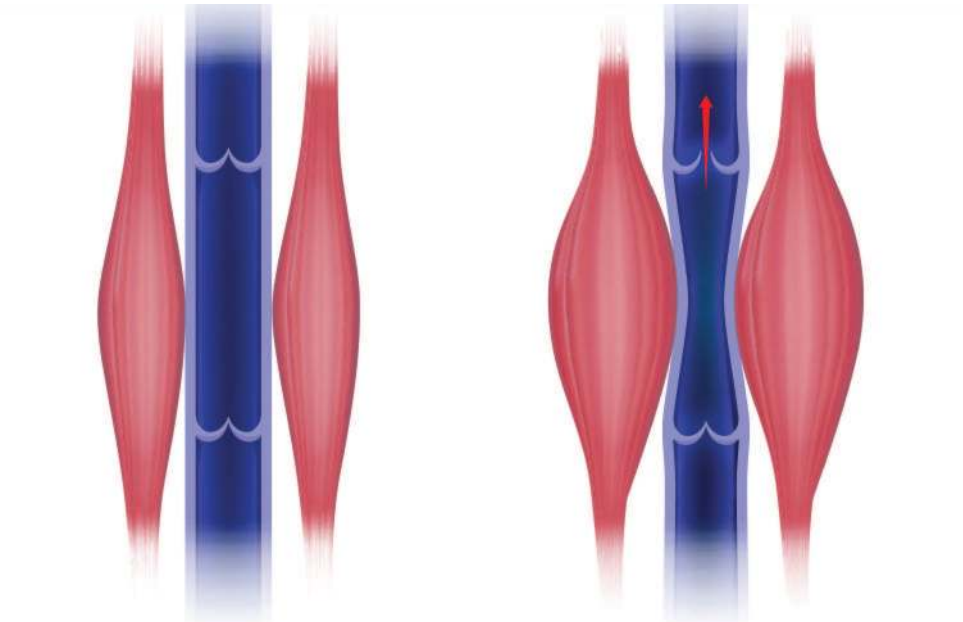
The types of activities performed in the cool down should replicate the activities performed in the conditioning component so that the appropriate muscle groups are recovered effectively. An example is a cyclist who, after completing a series of sprints around the velodrome, completes a number of additional laps at a gradually decreasing pace. The cool down should also incorporate a series of optimal static, proprioceptive neuromuscular facilitation (PNF) stretches and foam rolling of all the major muscles used in the skill development and conditioning components of the training session. The cool down is the first stage in an athlete's recovery process after training. It helps with:

- lowering heart rate
- removing lactate
- preventing venous pooling
- decreasing the effects of delayed onset muscle soreness (DOMS)
- maintaining joint range of movement
- mental relaxation.

The need for a cool down

The major physiological rationale for completing an active cool down is to prevent **venous pooling**, remove metabolic waste from the muscles and reduce the likelihood of delayed onset muscle soreness. After strenuous exercise, the heart continues to pump out blood forcefully and rapidly for some period of time. If an athlete ceases activity altogether at this point, their muscles are no longer contracting and helping to propel blood back to the heart (the so-called skeletal muscle pump effect, as shown in figure 11.10). As a result, blood may pool in the veins, especially in the lower limbs. This venous pooling can result in a decreased venous return to the heart. Consequently, less blood is re-oxygenated via the lungs, and less metabolic by-products (carbon dioxide and lactate) are removed from the muscle tissues. The main aim of the cool down is to bring the body back to resting levels in the most efficient way possible.

FIGURE 11.10 The skeletal muscle pump effect is when the muscle is relaxed and no longer helping pump blood back to the heart when an athlete ceases activity. This results in less metabolic by-products being removed from the muscle tissues, which can result in muscle fatigue.



The stretching component of a cool down

At the end of the cool down component of the training session, stretching should take place in order to improve the flexibility of the muscles and reduce any stiffness or soreness. An athlete will gain the most benefit from stretching when the muscles are still warm and the ligaments and joints are more elastic. The type of stretches undertaken at this stage are more static in nature. Table 11.4 shows some common types of stretches that can be used as part of a cool down.

TABLE 11.4 Different types of stretches completed in a cool down

Type	What it involves	Example
Static stretching	• Taking the joint through its full range of movement that can be comfortably tolerated and holding it for a minimum of 10 seconds • Relaxes muscles and maintains or increases the flexibility and range of movement of joints	

(continued)

TABLE 11.4 Different types of stretches completed in a cool down *(continued)*

Type	What it involves	Example
Passive stretching	• Using an external force to assist in achieving the stretch	
Proprioceptive neuromuscular facilitation (PNF)	• Fully lengthening the muscle and isometrically contracting against resistance for a certain time before stretching again • Repeated until a full stretch is achieved • Works on the theory of reciprocal inhibition: when an agonist muscle contracts, the antagonist muscle is inhibited, which causes it to relax and achieve its full range of movement	
Slow active stretching	• The contraction of opposing muscles to help relax the targeted muscle, to achieve its full range of movement • Generally considered low risk because it is controlled by internal rather than external forces	
Foam rolling	• A form of **myofascial release** that involves using a foam roller to apply pressure over a muscle to reduce muscle soreness and improve flexibility	

on Resources

Digital document Example training session (doc-21029)

myofascial release a massage technique that focuses on relieving pain in the thick connective tissue that support muscles (myofascial tissues)

EXAM TIP

Be able to explain the purpose of a cool down and the type of activities that should be undertaken during this phase.

doc-41971

PRACTICAL ACTIVITY Designing and implementing a training session

Goal

To design and implement a 60-minute training session for a sport/activity of your choice.

Instructions

Design and implement a training session that includes *an overall goal/purpose* and each of these components:

1. warm up
2. conditioning phase
3. cool down

Each component should include the:

- type of activity specific to the sport/activity and method of training
- timing of each activity and/or the number of repetitions required
- intensity at which each activity should be performed
- type and time of rest/recovery periods.

You may like to access the **Example training session** template in the digital documents section of the Resources panel, or you can create your own.

Primary data/Reflection

Analyse the effectiveness of your training session in achieving its overall goal/purpose.

You could do this by collecting the following data.

Physiological data

- Use heart rate monitors to assess the intensity of the session. Compare heart rates and/or rate of perceived exertion (**RPE**) during the session with the target heart rate required.
- Gather feedback from the participants in relation to how they felt during the session and how hard they worked (their RPE) using a scale from 6–20, where:
  9 = very light
  13 = somewhat hard
  17 = very hard
  18 = extremely strenuous

Psychological data

- Ask the participants how they enjoyed the training session (on a scale of 1–10). Were there any activities that they found challenging or too easy?
- Check the participants' post-session feelings. Do they feel a sense of accomplishment? Are they in a positive mood?

Sociological data

- Record the environmental conditions, such as temperature, weather, location (indoors, outdoors), etc.
- Record the time of day.

Questions

1. Outline the purpose of the warm up for the exercise training session that you designed.
2. Using the data you have collected, evaluate the effectiveness of your exercise training session.
3. Justify the design of your cool down.

RPE (rating of perceived exertion — Borg Scale) a subjective rating of how hard the athlete feels they are working. It is a numerical scale ranging from 6 to 20, with 6 being no feeling of exertion and 20 being extremely hard. A score of 13–14 is classified as moderate intensity, and 15–16 is classified as vigorous.

11.3 Activity

11.3 Quick quiz on | **11.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
3, 5	1, 2, 7	4, 8, 6, 9, 10

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TEST your understanding

1. **Discuss** how the warm up prepares the athlete physiologically.
2. **Discuss** how the warm up prepares the athlete psychologically.
3. **Outline** the three main phases of a warm up and **explain** the types of stretches that should be performed during the warm up component of training.
4. **Explain** when a warm up may be detrimental to performance.
5. **Outline** the two phases of the conditioning component of a training session.
6. **Explain** venous pooling. Why does it occur, and how does an active cool down help to prevent it from happening?

APPLY your understanding

7. **Provide** an example of a sport/activity in which an athlete may prioritise skill development over fitness conditioning.
8. **Describe** and **explain** a situation in which a coach would implement the skill development phase before the fitness conditioning phase.
9. **Describe** and **explain** a situation in which a coach would implement the fitness conditioning phase before the skill development phase.
10. **Explain** the purpose of incorporating stretching at the end of a training session.

11.3 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section A, Q.12;* © ACHPER

An effective exercise training session incorporates the following components in the correct order.

A. warm up, skill phase, stretching
B. warm up, conditioning phase, cool down
C. conditioning phase, skills phase, cool down
D. conditioning phase, skills stretching, cool down

Question 2 (1 mark)

Source: Adapted from *ACHPER 2017, Trial Exam Units 3 & 4, Section A, Q.13;* © ACHPER

An under-15 school basketball team was required to complete the following activities as part of their training session.

The correct order from the start of the training session to the conclusion of the training session for the activities should be:

A. warm up jog, static stretches, plyometrics, cool down jog, dynamic stretches.
B. warm up jog, dynamic stretches, plyometrics, cool down jog, static stretches.
C. warm up jog, static stretches, high-intensity circuit, cool down jog, dynamic stretches.
D. warm up jog, dynamic stretches, high-intensity circuit, static stretches, cool down jog.

Question 3 (7 marks)

Source: Adapted from *VCE 2021, Physical Education Exam*, *Section B, Q.2;* © VCAA

The Olympic cycling track sprint involves two riders racing against each other over three laps of the velodrome. In the early stages of the race, the riders are tactical in watching each other carefully and waiting for the other to make the first move. They can sometimes become stationary during this time. It is usually in the last lap that they accelerate and build to top speed in an attempt to win the race.

a. **Discuss** the benefits for an Olympic cycling sprinter of a warm up prior to competing in the track cycling sprint event. **(3 marks)**

b. **Outline** the purpose of the conditioning component of a training session for an Olympic track cyclist. **(2 marks)**

c. **State** two main reasons why you would recommend that an Olympic track cyclist undertake a cool down at the completion of the race. **(2 marks)**

Question 4 (4 marks)

Source: Adapted from *VCE 2020, Physical Education Exam*, *Section B, Q.2.c;* © VCAA

In the table below, design a training session for a cricket wicketkeeper. Include two exercises in the conditioning phase (one fitness conditioning activity and one skill development activity). You may use diagrams to explain the exercises.

Warm up	Conditioning phase	Cool down
	1.	
	2.	

Question 5 (5 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.6.d,e;* © VCAA

Michelle is a lacrosse player. Her pre-game warm up routine is shown in the table below.

Cardio component	walking at a moderate pace for two minutes
Stretching component	• three lunges • three leg swings on each leg • three torso twists in each direction • three arm swings in each direction • three neck circles in each direction • three squats
Sport-specific component	using a lacrosse stick to throw and catch from various distances with a teammate

a. **Identify** one purpose of a well-designed warm up. **(1 mark)**

b. **Critique** the effectiveness of Michelle's warm up routine. **(4 marks)**

More exam questions are available in your learnON title.

11.4 Strategies to monitor and record training data

Key knowledge	Key skill
• strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital tools and wearable technologies	• participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

11.4.1 Monitoring and recording strategies

A variety of monitoring and recording strategies are available for athletes to collect their **physiological**, **psychological** and **sociological training data**.

- Advances in wearable technologies and applications have created the opportunity for athletes to collect data electronically and monitor their training more effectively.
- Training diaries and digital tools are also very useful monitoring tools that an athlete and coach can use to increase the effectiveness of a training program. Monitoring training allows for a reconciliation between the aims of the program and what is actually being achieved.

physiological training data provides information about the body's physical functioning in response to training

psychological training data provides the athlete with an understanding of their mental readiness and mental capacity to train and perform. Includes recording the athlete's thoughts, feelings and cognitive characteristics that affect performance.

sociological training data provides context about the broader social, cultural and environmental factors that contribute to an athlete's performance

Monitoring training provides an understanding of how hard an athlete is working and how well they are coping physiologically, psychologically and sociologically with the training load (see figure 11.11). It is important that monitoring is used to inform, evaluate and modify training and not simply to collect data. The information gathered can allow the athlete to incorporate the concepts of peaking and tapering effectively into their training program.

Over recent decades, increased knowledge of physiology has had an impact on improving sports performance. This, combined with advancements in digital technologies, means that athletes are being heavily monitored, further improving performance. There are now an overwhelming number of digital monitoring systems to choose from. The choice of which to use is dependent on the information that the athlete and coach require. It is important that the information gathered is relevant to considering whether to maintain or modify a training program. A combination of both subjective and objective data should be used in order to understand the whole picture of the athlete.

FIGURE 11.11 Monitoring training allows the athlete to stay on track to reach their training goals.



Physiological responses may be influenced by both psychological and sociological factors. The data that is gathered should be informative, relevant and useful for monitoring the aspects specific to the sport and the athlete. Data that is easily interpreted and practical in its application is more likely to support ongoing monitoring.

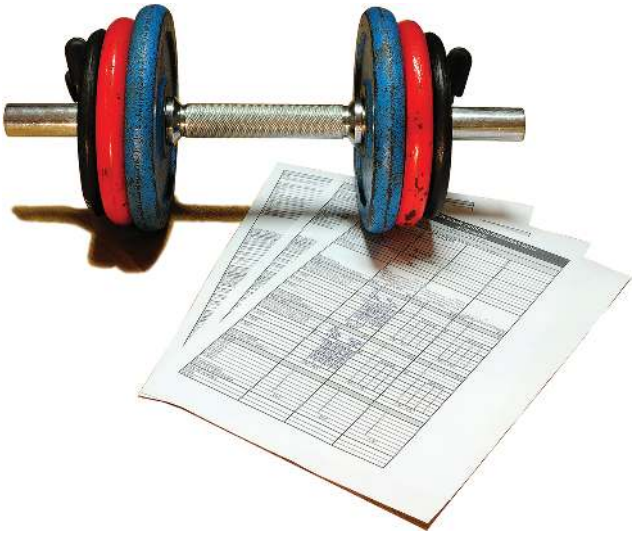
Coaches and athletes will often incorporate a variety of strategies to monitor training so that they can obtain a comprehensive understanding of the physiological, psychological and sociological influences. Training diaries, digital tools and wearable technologies provide a range of ways to monitor the effectiveness of a training

program and minimise injury and/or illness. The ultimate goal of a training program is to achieve the necessary chronic responses to improve an athlete's performance in a particular sport or activity. Monitoring training is essential for keeping the athlete on track to reach this goal.

11.4.2 Training diaries

A training diary (recorded online or in hardcopy) is an athlete's personal monitoring tool in which they can record both objective and subjective training information. An athlete can record objective data obtained from digital tools, apps and wearable technologies as well as subjective information such as emotional feelings, energy levels and environmental factors (see figure 11.12).

FIGURE 11.12 A wide range of physiological, psychological and sociological parameters can be recorded in a training diary.



There are many benefits to keeping an accurate training diary. It can be used to:

- gather information about an athlete's physiological, psychological and sociological influences (see table 11.5)
- increase motivation
- improve goal setting
- track progress over time
- identify any limitations to training
- provide feedback to the coach for any sessions the athlete has undertaken without their presence
- apply progressive overload correctly and prevent overtraining
- record dates for competitions.

Most importantly, a training diary helps the athlete to develop a greater self-knowledge about their training and development (see figure 11.13).

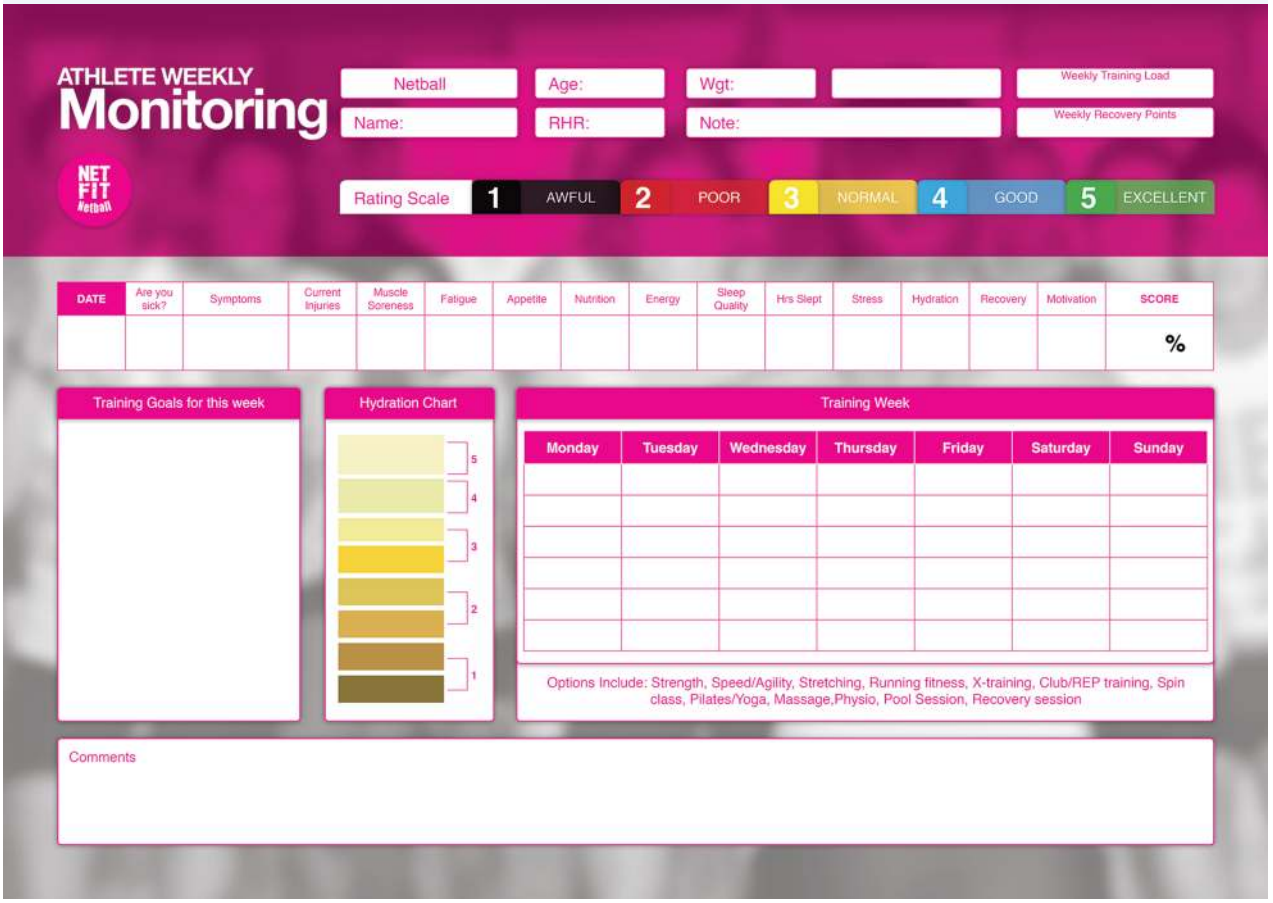
TABLE 11.5 Some of the specific physiological, psychological and sociological variables that can be recorded in a training diary.

Physiological	Psychological	Sociological
• Energy level (RPE) during training • Heart rate responses (resting, exercise and recovery) • Muscle soreness • Sleep patterns (quality and quantity) • Nutritional information • Breathing rate • Perspiration levels	• Emotional and motivational variables • Confidence levels • Arousal levels • Stress levels • Goal setting	• Temperature and weather conditions during the training session • Training time and day • Time of training session • Type of training session • Place of training (indoors, outdoors, type of surface, venue) • Training partners/teammates

EXAM TIP

Be able to identify at least three specific types of physiological, psychological and sociological data that can be recorded using a training diary.

FIGURE 11.13 Sample training diary template used by elite netballers



Source: Sarah Wall, http://netfitnetball.com.au/

11.4.3 Digital tools and wearable technologies

Sports science and analysis is a continually growing field and digital tools and wearable technologies are accessed by elite sports people and recreational athletes alike. Data transmission from increasingly sophisticated sensors provides elite athletes, coaches, recreational sportspeople and teams with real-time feedback and an increased ability to reach peak fitness levels. Whether it be from a smart watch, wristband, smart ring, belt, chest strap, smart shirt or headband, there are many parameters that digital tools and wearable technologies can monitor, measure and track (see figure 11.14).

FIGURE 11.14 There are a number of digital tools and wearable technologies that can be worn to collect data, including **(a)** activity trackers **(b)** sleep rings and **(c)** smart shirts.



Digital tools and wearable technology have come a long way since entering the fitness industry and Australia continues to lead the field in this particular area of sports science.

CASE STUDY

Catapult Sports example

The Australian Institute of Sport and the Cooperative Research Centre collaborated to develop a unique, evidence-based, highly accurate and accessible approach to athlete monitoring. Catapult Sports is a company that works with more than 3,800 elite sporting teams globally. Their technology accesses the Global Positioning System (GPS) and the Global Navigation Satellite System (GNSS) and uses **accelerometers**, **gyroscopes** and **magnetometers** to provide valuable inertial movement analysis (see figure 11.15). Each system collects the athlete's micro-movements and transfers the information into algorithms providing valuable metrics for athlete analysis. Athletes and/or coaches are able to make calculated decisions based on the following parameters that are provided using the Catapult system:

- movement patterns
- intensity
- velocity
- distance covered
- acceleration
- efforts of force from the body
- player loads.

A digital tracking system such as this is highly accurate, and valuable information is wirelessly transmitted in **real time** to the athlete or coach for immediate analysis and adjustment to training.

Teams across the AFL, AFLW and AFL Pathways use Catapult's technology to empower data-driven decisions regarding player performance improvement, injury prevention and return to play.

Take a look at the **Catapult wearable technology** weblinks to find out more about how their digital technology monitors, measures and tracks athlete information.

accelerometer an instrument for measuring the rate at which an athlete changes velocity

gyroscope a sensory device that explains the direction of gravity and determines the position of an athlete

magnetometer a device that measures the direction and strength of magnetic fields

real time means that data is processed straight away and is available virtually immediately as a source of feedback

FIGURE 11.15 Catapult wearable technology



on Resources

Weblinks Catapult
Catapult learning library
Catapult webinar library

There are many other GPS units that can provide data for the analysis of various physiological parameters in real time, which is vital for monitoring athlete training. Rapid advancements in the area of sports science and research will continue to create digital tools with increasing accuracy and functionality that can provide coaches and athletes with the best possible information for helping to manage training volume and load, with the aim of optimising performance.

Recreational sportspeople use a variety of very accessible general fitness digital tools to monitor, measure and track their progress in training. The popularity of these tools has grown significantly in recent times. There are many brands available on the consumer market, which all offer different functions and features. Most digital tools provide information on the number of steps, distance, calories burned and activity time. Some tools measure heart rate and allow a person to record sleep patterns and nutritional intake (see figure 11.16).

CASE STUDY

Wearable technology to measure sweat

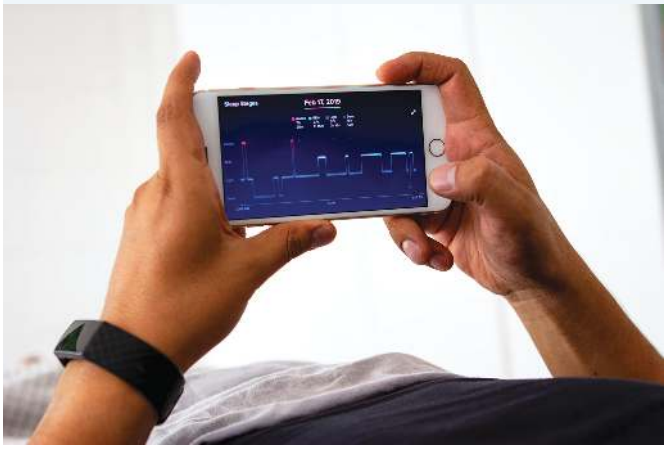
The University of California, Berkley developed wearable technology that analyses the chemicals in a person's sweat as they train and sends the information immediately to their smartphone. The metabolites (glucose and lactate) and electrolytes (sodium and potassium) measured in a person's sweat can help to determine muscular fatigue and hydration status.

Some companies have also tapped into the idea of 'smart clothes', where activity sensors are embedded into everyday clothing. Some compression garments have incorporated sensors to measure muscle vibrations and provide feedback on muscular fatigue. Biometric devices such as muscle oxygen monitors measure oxygen saturation levels and also provide insights into levels of muscular fatigue.

The most appropriate digital tool and wearable technology to select is dependent on what parameters a person wishes to track.

- Digital tools can be used to collect data on parameters such as number of steps, distance covered, calories expended, activity time and heart rate.
- Some offer the ability to record location via inbuilt GPS, which is beneficial for people who require more precise measurement of distances covered.
- Many digital tools provide coaching features that give actionable advice to the user.

FIGURE 11.16 Monitoring sleep patterns



Not all digital tools and wearable technologies are suitable for all sports, so it is important to select what is best to track the requirements of a person's chosen sport. Make sure that you take this into account if you are considering the use of a digital tool or wearable technology as primary data to measure, monitor and track your chosen physical activity. Many tools measure walking, running and cycling effectively but are not as effective at measuring activities such as Pilates, yoga and gym sessions. Furthermore, if swimming is the main choice of activity, it is important that the activity tracker is waterproof. Generally, the more costly the device, the more impressive its features; however, it is important to remember many features may not be necessary for the parameters that an individual wants to monitor.

Fitbit, Garmin, Polar and Apple are some of the common brands of digital tools available on the market, and each provides a range of different features to cater to the needs of recreational sportspeople, high-performance elite sportspeople and everyone in between. The rapid development and advancement of technology will continue to make more features or parameters accessible to a larger variety of users. The current standard features of high-performance digital activity trackers for elite sportspeople are likely to be the standard features for recreational sportspeople in the future. Greater sophistication in digital tracking technology will also result in a higher level of accuracy, greater ability to track more physiological, psychological and sociological parameters, and increased automation of recording.

on Resources

Weblinks IDRO Brussels: wearable lactate sensing
The future of footy: wearable technology
The digital athlete
Why the future of sports training could be wearable

Digital software applications (apps) software and platforms

Pairing and syncing the data from digital tools and wearable technologies with applications and various software platforms allows for enhanced, holistic monitoring of a person's training progress. The incremental feedback gathered from combining these sources increases the user's awareness of not only the physiological influences on their training but also the psychological and sociological influences.

Just like digital tools and wearable technologies, there are many and varied apps available that provide features valued by the recreational athlete and the elite sportsperson alike. Fitness apps include self-monitoring tracking tools that allow the user to log workouts and record physiological, psychological and sociological information similar to how they would in a training diary. Table 11.6 details some of the information that can be captured by fitness apps.

TABLE 11.6 Some of the benefits of using digital tools, wearable technologies and associated applications and software

Physiological factors	Psychological factors	Sociological factors
Step count	Motivation	Training time and day
Heart rate responses	Goal setting	Length of training session
Sleep patterns	Determination	Type of training session
Calorie expenditure	Increase self-efficacy	Social support groups
Temperature	Reminder notifications	Break down barriers, such as social isolation
Sweat analysis	Positive reinforcement	Education and increased self-awareness
Breathing rate	Increased resilience	Social interaction
Oxygen saturation levels	Mood tracking	Data sharing
Hydration levels	Mindfulness	Inclusivity
Muscle fatigue levels	Cognitive stimulation	

Some apps are multifunctional and allow the user to measure, monitor and track a number of different parameters. The companion apps for digital tools and wearable technologies are important as these provide the interface where the user reviews the data for analysis. Table 11.7 shows just some of the fitness apps available, categorised by the user need they seek to meet.

TABLE 11.7 Some apps that are specific to the needs of the user

Community — connect with others	Personalised tips, training and workout routines	Distance tracking	Sport-specific	Other
• Strava • Peloton • Zwift • Stridekick	• Sworkit • C25K (couch to 5K) • Nike Training Club • Workout Trainer	• MapMyRun • RunKeeper	• Pocket Yoga • StrongLifts • Caliber • Jetfit	• MyFitnessPal (nutrition) • Sleepbot (sleep)

on Resources

Interactivity Training program steps (int-6821)

Digital document Compare and contrast — digital tools and wearable technologies (doc-41972)

doc-41973

PRACTICAL ACTIVITY Interview

Goal

To understand how and why someone records, monitors and evaluates their training data.

Instructions

Interview, or conduct research about, an athlete who is currently undertaking a training program to find out how they are recording, monitoring and evaluating their training data. This may be an elite sportsperson or someone who is just aiming to improve their fitness.

Primary data/Reflection

After you have gathered the information from the interview, critique the effectiveness of their monitoring and provide any necessary recommendations for improvements. Examine if and how any of the data they have gathered has helped inform their training program design.

Questions

1. List the tools that the participant uses to record their data.
2. Outline the types of data that the participant recorded and provide examples of each.
3. Critique how effective the participant is at recording, monitoring and evaluating their training data.

EXAM TIP

Be able to identify at least three specific types of physiological, psychological and sociological data that can be recorded using digital tools and wearable technologies.

11.4 Activity

11.4 Quick quiz on

11.4 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3, 4, 5, 6, 7	8, 9	1, 9, 10

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TEST your understanding

1. **Explain** why coaches and athletes often access a variety of physiological, psychological and sociological strategies to monitor training.
2. **List** four benefits of maintaining an accurate training diary.
3. **Outline** two physiological, two psychological and two sociological factors that can be recorded in a training diary.
4. **Identify** the benefits of using digital tools and wearable technologies for elite sportspeople.
5. **Identify** the important factors that need to be taken into account when considering the most appropriate tools and wearable technologies to use.
6. **Outline** some of the information that can be measured, monitored and tracked with the use of apps.
7. **Describe** two physiological, two psychological and two sociological benefits of using digital tools, wearable technologies and associated applications and software.

APPLY your understanding

8. A training diary is a great tool to use to improve performance in any particular sport or activity. The parameters that are recorded and monitored using a training diary should be specific to the individual and the particular sport and/or activity they are training for.

a. **Design** an appropriate training diary template that would be most suitable to use during a six-week training program for an athlete of your choice. Make sure that you consider the relevant physiological, psychological and sociological factors that are important to include.
b. **Suggest** how the information that will be recorded in the training diary will inform the participant of any necessary modifications to their training program.

9. **Compare** and **contrast** at least four different digital tools and wearable technologies and **recommend** the most appropriate one to use during a six-week training program for a given case study. Use the **Compare and contrast — digital tools and wearable technologies** digital document, available in the Resources panel, to present your information.
10. Select an app or software program that would be suitable to use during a six-week training program for an athlete of your choice. You must **justify** your selection.

11.4 Exam questions

Question 1 (6 marks)

Source: Adapted from *VCE 2021, Physical Education Exam, Section B, Q.8;* © VCAA

Alex is a 20-year-old athlete at state level who has been playing tennis for 10 years. His coach has presented him with data that was collected from Alex's last practice match.

Data from Alex's last match

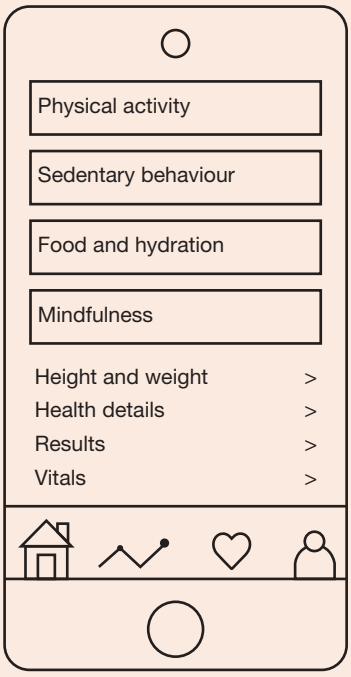
Measurements	Total
total metres covered in a match	1200 metres
total time of match	125 minutes
total time spent above 70% HR max	60 minutes
time spent above 85% HR max	20 minutes
time spent above 95% HR max	5 minutes

a. **Outline** why it is important for Alex's coach to record and monitor his training data. **(3 marks)**
b. **Suggest** a digital tool or wearable technology that may have been used to gather the data shown in the table. **Justify** your suggestion. **(2 marks)**
c. **Identify** the type of data that has been recorded in the table. **(1 mark)**

Question 2 (1 mark)

Source: Adapted from *VCE 2018, Units 3 & 4 Sample Questions, Section A, Q.9;* © VCAA

The diagram on the right represents a physical activity tracking app on a mobile phone.



Based on the diagram, which type of training data can the app record?

A. sociological and psychological data
B. physiological and sociological data
C. physiological and psychological data
D. physiological, psychological and sociological data

Question 3 (2 marks)

Source: Adapted from *VCE 2018, Physical Education Exam, Section B, Q.5;* © VCAA

Jalena is a 17-year-old student who wants to design a training program for her upcoming lacrosse season.

Jalena aims to participate in long interval training twice per week and circuit training three times per week over four weeks.

Recommend one strategy Jalena could use to monitor her training effectively. **(2 marks)**

Question 4 (3 marks)

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.6.a.i,ii* © VCAA

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. A snapshot of the program is shown below.

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
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 RPE — rate of perceived exertion	reps — repetitions mins — minutes	s — seconds

a. **Suggest** one way for Noah to monitor his training. **(1 mark)**

b. Using examples, **explain** why Noah should keep a record of his training. **(2 marks)**

Question 5 (5 marks)

Source: Adapted from *VCE 2018, Units 3 & 4 Sample Questions, Section B, Q.8;* © VCAA

The Australian Football League Women's (AFLW) Draft Combine is an event at which potential draftees display their athletic capacities and relevant Australian Rules football skills. Participants are required to undergo a series of medical, psychological, motor skill, athletic and fitness tests. The tests include the following:

- Yo-Yo intermittent recovery test
- a 2-kilometre time trial
- an agility test
- a 20-metre sprint
- a running vertical jump
- a standing vertical jump.

The AFLW Draft Combine requires players to keep detailed training records.

a. **Outline** the importance of maintaining both physiological, psychological and sociological training records. **(1 mark)**

b. **Identify** two physiological variables and two psychological variables that can be recorded in a training diary. **(4 marks)**

More exam questions are available in your learnON title.

11.5 Analysis and evaluation of training data

Key knowledge	Key skill
• strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital tools and wearable technologies	• participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

The systematic analysis and evaluation of the recorded data is a crucial step in providing beneficial and timely feedback to the athlete. By examining and evaluating the data, coaches and athletes can make informed decisions to enhance training effectiveness and work towards optimal performance levels. Interpreting the data and deciphering which **qualitative** and/or **quantitative** information is relevant and beneficial to the athlete is a vital aspect in the process of performance improvement.

FIGURE 11.17 A road cyclist enhances their performance using real-time and post-race data analysis and evaluation.



Real-time data analysis can provide the immediate feedback of a summary of performance metrics. However, additional time (post-match or training) analysis that uses a variety of physiological, psychological and sociological data allows for a more detailed evaluation. The data that is used post-match or training can come from data sources such as RPE, motivational readiness, the temperature and time of day, as well as metrics such as heart rate, blood lactate levels, work-to-rest ratios, speed and distance covered, collected via wearable technologies.

11.5.1 Qualitative and quantitative data analysis

Both qualitative and quantitative data obtained from training diaries, digital tools and/or wearable technologies need to be interpreted, dissected and scrutinised to obtain the most accurate and relevant information to enhance an athlete's performance levels. This information should be clearly presented in a way that is easy to understand, allowing coaches to quickly gain insights about any areas of the athlete's training program that may require attention.

qualitative subjective in nature; thoughts, opinions and feelings (e.g. RPE)

quantitative objective in nature; expressed in numerical terms (e.g. heart rate)

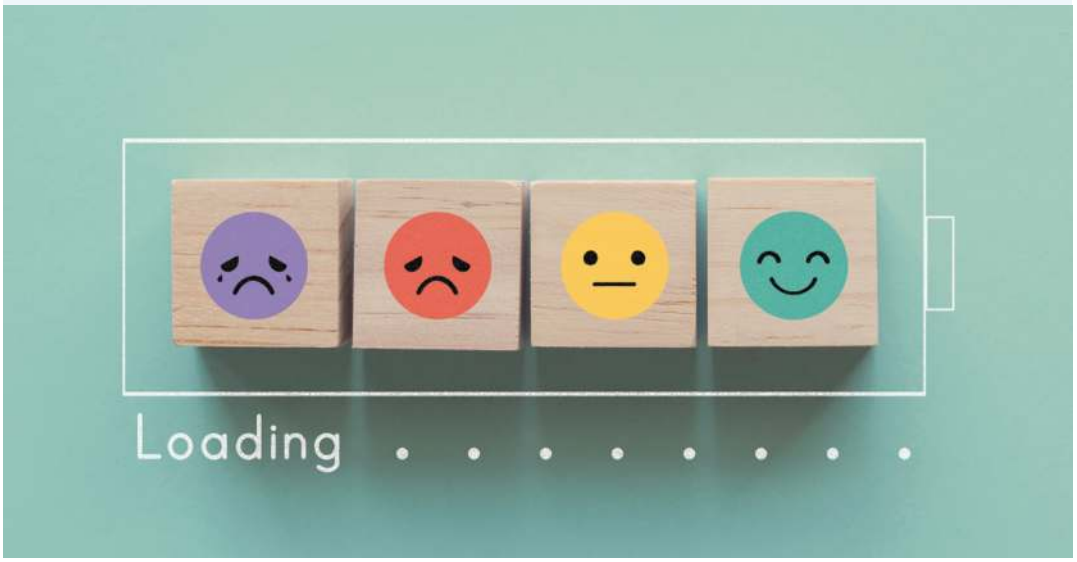
11.5.2 Physiological analysis and evaluation

Analysing the various data metrics related to an athlete's physiological responses to exercise assists the coach and athlete to understand the physical impact of the training program. Evaluating the physiological parameters helps to determine the effectiveness of the training program and to make any necessary adjustments to optimise performance. For example, analysing resting heart rate (RHR) from wearable technologies over time will inform the athlete of any cardiovascular improvements and help determine whether a change in training volume and/or intensity is needed. Monitoring an athlete's fatigue level feedback in a training diary helps to assess the effectiveness of the training program's recovery sessions and overall fatigue management.

11.5.3 Psychological analysis and evaluation

Psychological data obtained on the athlete's mental and emotional responses can be analysed to understand the impact that the training program is having on the athlete's mental health and wellbeing. A psychological analysis provides the coach and athlete with valuable information about motivation levels and mental capacity. For example, a training diary entry that indicates a change in the athlete's mood may require a training session to be adapted accordingly. The long-term analysis of an athlete's stress levels can indicate whether the training program is having a positive or negative effect on an athlete's emotional wellbeing.

FIGURE 11.18 The mental and emotional wellbeing on an athlete is important and can affect their training program.



11.5.4 Sociological analysis and evaluation

Analysing the sociological training data involves evaluating metrics about the broader social, cultural and environmental factors that may be impacting an athlete's training and performance. Evaluating the athlete's social networks can provide information about whether the athlete feels socially supported in achieving their goals. Understanding the available environmental data will give the coach some insights regarding the time of day and temperature at which the athlete trains at their best.

Analysing training data by systematically evaluating various physiological, psychological and sociological parameters offers a holistic approach by which the coach and athlete can assess the effectiveness of a training program.

EXAM TIP

Be able to evaluate physiological, psychological and sociological data to to determine if adaptations are necessary for an athlete's training program.

11.5 Activity

11.5 Quick quiz on | **11.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	2	4, 5, 6, 7

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TEST your understanding

1. **Outline** why a systematic analysis and evaluation of training data is crucial for the coach or athlete.
2. **Compare** and **contrast** the use of real-time data analysis and post-match or training data analysis.
3. **Identify** a type of qualitative data that can be analysed.
4. **Explain** why it is beneficial for a coach or athlete to analyse data from a variety sources.

APPLY your understanding

5. Provide one example of how a coach or athlete can use the information from physiological data analysis. **Explain** how it might influence the training program.
6. Provide one example of how a coach or athlete can use the information from psychological data analysis. **Explain** how it might influence the training program.
7. Provide one example of how a coach or athlete can use the information from sociological data analysis. **Explain** how it might influence the training program.

11.5 Exam questions

Question 1 (3 marks)

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.3;* © VCAA

In a study, elite-level male sprint and distance runners' blood lactate levels were assessed under different conditions. The runners had been training for three months and were in the middle of their competitive season.

The following data was collected.

Distance		Sprint runners	Distance runners
		Blood lactate (mmol/L)	Blood lactate (mmol/L)
400 m	baseline	1.3	1.3
	post-exercise	6.6	4.1
1600 m	baseline	1.4	1.5
	post-exercise	14.5	8.8

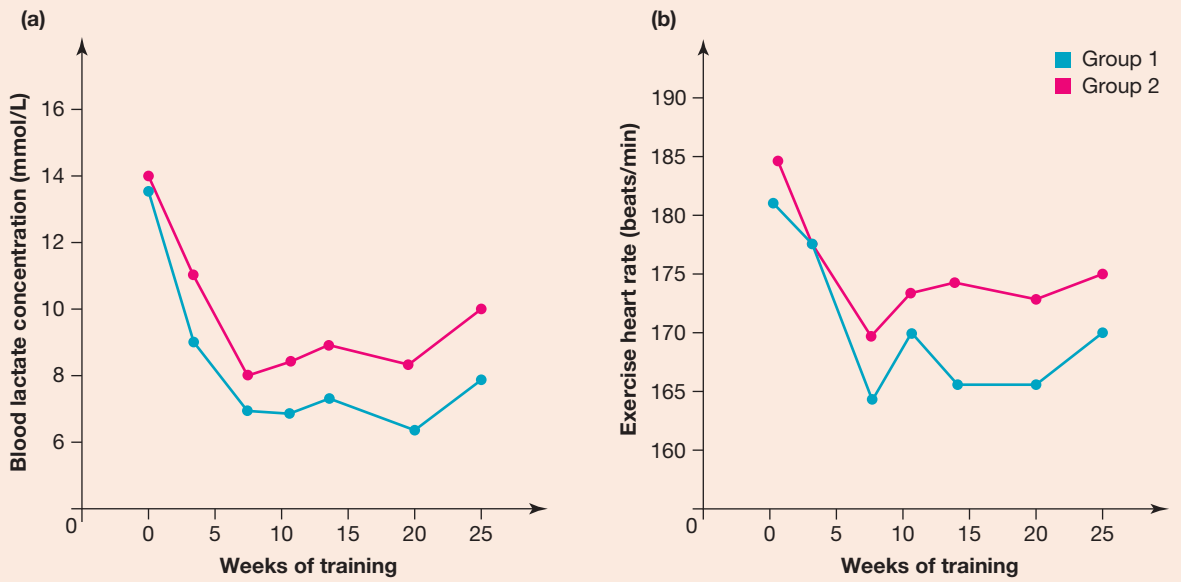
Data: TJ Canfield & KA Gabel, 'Blood lactate, heart rate, and rating of perceived exertion in collegiate sprint, middle distance, and long distance runners after 400 and 1600 meter runs', *International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering*, vol. 7, no. 8, 2013, p. 479

a. **Identify** the type of training data that was assessed and analysed. **(1 mark)**
b. Using examples, **describe** how an analysis of this training data might inform the coach or athletes about the runners' training programs. **(2 marks)**

Question 2 (4 marks)

Changes in swimmers' (a) blood lactate concentrations and (b) heart rates during a standardised 366-metre (400-yard) swim over 25 weeks of training was collected.

All swimmers began the program following the same training regimen: one session per day. From the beginning of the 5th week through the end of the 10th week, group 1 continued training once per day, whereas group 2 increased to training twice per day. After 6 weeks on the different regimens, both groups returned to their once-daily program.



Source: Reprinted by permission from WL Kenney, JH Wilmore & DL Costill, *Physiology of sport and exercise,* 5th ed., Human Kinetics, Champaign, IL, 2011.

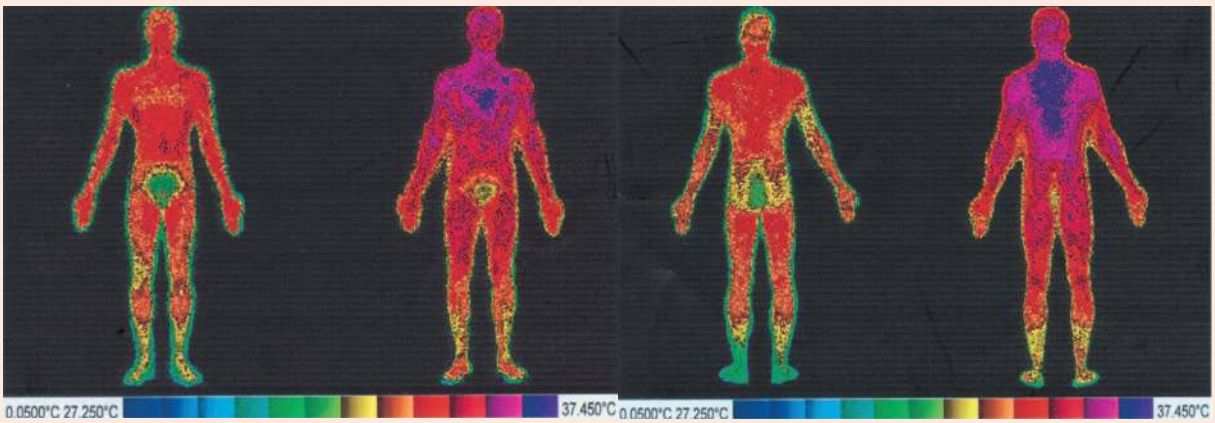
a. **Analyse** the blood lactate and exercise heart rate data to **identify** the frequency of training per day that was more effective. **(1 mark)**

b. i. Blood lactate and exercise heart rate are examples of physiological data. **Identify** an example of psychological data that would be beneficial for the swimmers and their coach to evaluate. **(1 mark)**

ii. **Explain** how this type of data could inform future training sessions. **(2 marks)**

Question 3 (4 marks)

Thermograms of the body showing the variations in radiant (infrared) heat leaving the (a) front and (b) rear surfaces of the body both before (left) and after (right) running outside at a temperature of 30 °C and 75 per cent humidity. The colour scale at the bottom of each photo provides the temperature variation for the changes in colour.



a. With reference to the physiological data provided in the photos, **discuss** a sociological parameter that a coach may need to take into consideration when the athlete is undertaking their training program. **(3 marks)**

b. **Identify** an alternative data tool that the coach could use to evaluate the effect of heat on the body. **(1 mark)**

More exam questions are available in your learnON title.

11.6 Key skills

Key skills

- participate in and reflect on training sessions by recording physiological, psychological and sociological data in a reflective folio
- participate in and conduct components of an exercise training session

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

11.6.1 Tell Me

To address these key skills, it is important to be able to:

- identify some of the physiological, psychological and sociological factors that can be recorded, and describe the benefits of maintaining this information
- design and demonstrate an effective training session that includes the warm up, conditioning phase and cool down components
- critique the effectiveness of a training session in which you have participated, based on your knowledge of the requirements of each component
- recognise how physiological, psychological and sociological factors can be beneficial in informing an athlete or coach about the effectiveness of a training program.

11.6.2 Show me

Practice question (10 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *ACHPER 2015, Trial Exam Units 3 & 4, Section B, Q.9;* © ACHPER

1 A Year 11 Physical Education class at ACHPER Secondary College intends to complete the Great Victorian Bike Ride. They have entered the five-day event, which covers a total of 318 km. During term 4, they intend to complete the following training program for the nine weeks leading up to the event. Training includes a mixture of lunchtime, after-school and weekend cycling training.

Week	Tuesday	Wednesday	Saturday	Sunday	TOTAL
1	20 km cycle	Spin class 30 mins	40 km cycle	30 km cycle	90 km cycle
2	20 km cycle	Spin class 30 mins	45 km cycle	30 km cycle	95 km cycle
3	25 km cycle	Spin class 30 mins	45 km cycle	30 km cycle	100 km cycle
4	25 km cycle	Spin class 35 mins	50 km cycle	30 km cycle	105 km cycle
5	25 km cycle	Spin class 35 mins	55 km cycle	30 km cycle	110 km cycle
6	25 km cycle	Spin class 35 mins	60 km cycle	30 km cycle	115 km cycle
7	25 km cycle	Spin class 40 mins	70 km cycle	30 km cycle	125 km cycle
8	25 km cycle	Spin class 40 mins	75 km cycle	30 km cycle	130 km cycle
9	20 km cycle	20 m SRT Test	30 km cycle	Rest	50 km cycle
10	Participate in Great Victorian Bike Ride				

a. **Explain** the importance for the Year 11 students of maintaining physiological, psychological and sociological data *records of training* in the *lead up* to the Great Victorian Bike Ride event. (5 marks)

b. Some of the Year 11 students were hesitant to perform a cool down after every training session. **Explain** the *purpose* of a cool down and **discuss** the *impact* of not completing one. (5 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Explain — provide detail to show the relationship between concepts
  Discuss — present a clear, considered and balanced argument
- **Key terminology** — *records of training*, *lead up*, *purpose*, *impact*
- **Key concepts** — physiological, psychological and sociological data, cool down
- **Marking scheme** — 10 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

a. Physiological training data provide information about the *body's physical functioning* in relation to training. Psychological training data provide the athlete with an understanding of their *mental readiness* and include *thoughts, feelings and cognitive characteristics that may affect training*. Sociological training data provide context about the *broader social, cultural and environmental factors* that contribute to an athlete's *training performance*. Monitoring training provides an *understanding of how hard an athlete is working*, paralleled with how well they *cope* physiologically, psychologically and sociologically *with the training load*. Monitoring these factors is important *to inform and evaluate a training program* so that it remains *effective in achieving the desired goals*.
Award 3 marks (1 mark each) for describing the kinds of physiological, psychological and sociological data that can be recorded.
Award 2 marks for linking how monitoring such factors can inform the athlete or coach about the effectiveness of a training program.

b. A cool down involves the Year 11 students completing a *low-intensity activity* at the *end of the conditioning component of the training session*. The cool down allows the *heart rate and blood flow to the muscles to remain elevated*, which assists in *preventing venous pooling, removing metabolic by-products* and gradually returning the body back to its *resting* physiological state. If the Year 11 students choose to cease their high-intensity conditioning component *without completing* a cool down, their muscles will no longer continue to contract and help to propel blood back to the heart (skeletal muscle pump effect). As a result, *blood may pool in their veins*, especially in the lower limbs. This *venous pooling* can result in a decreased venous return to the heart. Consequently, less blood is re-oxygenated via the lungs, and *less metabolic by-products (carbon dioxide and lactate) are removed from the muscle tissues*.
Award 1 mark for outlining what a cool down consists of.
Award 2 marks for describing the purpose of a cool down.
Award 2 marks for discussing the impact of not completing a cool down.

11.6.3 Let me do it

Question 1 (10 marks)

Below is an example of Lucy's 6-week training program.

Week	1	2	3	4	5	6
Sunday						Interval (long)
Monday	Continuous		Continuous	Fartlek	Continuous	
Tuesday	HIIT	Fartlek	HIIT		HIIT	HIIT
Wednesday				HIIT		Interval (long)
Thursday	Fartlek	Continuous	Interval (long)		Interval (long)	
Friday				Continuous		Continuous
Saturday	Interval (long)	HIIT	Fartlek	Interval (long)	Interval (long)	

a. Explain the importance of Lucy recording her physiological, psychological and sociological training data for the 6-week training program. **(5 marks)**

b. Lucy sometimes skipped the warm up and went straight into the conditioning phase of the training session. Explain the purpose of a warm up, including the important components, and discuss the impact of not completing one. **(5 marks)**

11.7 Review

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11.7.1 Summary

Designing a training program

- The design and implementation of a training program requires a step-by-step approach that incorporates information obtained from an activity analysis and fitness assessment, the appropriate application of training principles and the selection of relevant training methods.
- It is necessary to plan the length of the training program, ensuring that the proper periodisation of training is incorporated in the program. The number of specific training sessions and the content of each of these sessions then need to be determined and recorded via a training planner or matrix.
- The term *periodisation of training* refers to dividing a training program into smaller phases of training, with each phase focusing on a specific goal.
- Peaking and tapering are important considerations in the design of training programs. Peaking refers to the planning of training so that an athlete obtains their optimum state of readiness to perform at a particular predetermined time, such as a major event or competition. Tapering refers to a reduction in training loads, particularly the volume of training prior to a major event, to allow for complete recovery. The goal of peaking and tapering is to produce a fresh, rested, uninjured athlete who is ready to perform at their optimum level at a given time.
- The main goal of a training program is to prepare an athlete to perform at their best. Monitoring, recording and evaluating training program data is crucial to the overall success of the program.

Components of an exercise training session

- Each individual training session should consist of a warm up, a conditioning phase and a cool down.
- The warm up is designed to prepare the body both physiologically and psychologically for the conditioning phase of the training session. A gradual increase in the intensity level of physical activity is performed in order to increase heart rate, blood flow and ultimately the temperature of the muscles to be used. A warm up allows the body to transition from a resting state to meet the higher physiological demands of the conditioning phase of training.
- The conditioning component is the main focus of the training session and it may include a skill development phase and/or a fitness conditioning phase.
- The cool down transitions the body gradually from high-intensity exercise back to resting levels. It involves completing low-intensity exercise, allowing for the maintenance of blood flow and the prevention of venous pooling.
- At the end of the cool down component, stretching should take place in order to improve the flexibility of the muscles and reduce any stiffness or soreness. An athlete gains the most benefit from stretching when the muscles are still warm and the ligaments and joints are more elastic.

Strategies to monitor and record training data

- There are many strategies available to athletes and coaches in order to monitor and record their physiological, psychological and sociological training data so as to reach a peak level of performance. The ultimate goal of a training program is to achieve the necessary chronic responses to improve an athlete's performance in a particular sport or activity, and monitoring training is essential to keep the athlete on track to reach this goal.

- It is important that monitoring is used to inform and evaluate training and not simply as a method of collecting data. The information provided can allow the athlete to incorporate the concepts of peaking and tapering effectively into their training program.
- Training diaries, digital tools and wearable technologies are very useful monitoring tools that an athlete and coach can use in order to increase the effectiveness of a training program.
- A training diary is an athlete's personal monitoring tool in which they can record both objective and subjective training information. There are many physiological, psychological and sociological benefits to keeping a training diary.
- Sports science and analysis is a continually growing field and wearable technology and/or digital tools are accessed by elite sportspeople and recreational athletes alike and can monitor a wide range of parameters.
- There are many and varied applications (apps) and software platforms available that provide various features valued by both recreational athletes and elite sportspeople. The best ones are the easiest to use and permit the user to set personal training goals and monitor their physiological, psychological and sociological training data to keep them motivated and injury-free on the road to attaining their peak level of fitness and performance.

Analysis and evaluation of training data

- The systematic analysis and evaluation of the recorded data is a crucial step in providing beneficial and timely feedback to the athlete.
- Real-time data analysis can provide immediate feedback; however, additional time (post-match or training) analysis that uses a variety of physiological, psychological and sociological data enables a more detailed evaluation.
- Both qualitative and quantitative data from training diaries, digital tools and/or wearable technologies can be analysed and evaluated.
- Physiological data analysis and evaluation assists the coach and athlete to understand the physical impact of the training program.
- Psychological data analysis provides the coach and athlete with valuable information about motivation levels and mental capacity.
- Sociological data analysis and evaluation provides information about the broader social, cultural and environmental factors that may impact an athlete's training and performance.
- Systematically evaluating the various physiological, psychological and sociological parameters provides the coach and athlete with a holistic approach to assessing the effectiveness of a training program.

11.7.2 Key terms

accelerometer an instrument for measuring the rate at which an athlete changes velocity
competition phase (in-season phase) the phase of training in which the emphasis is on maintaining the fitness and skill level developed during the preparatory phase, and further developing and refining strategies, tactics and game plans
cool down low-intensity activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling, gradually returning the body to its resting physiological state
fitness conditioning phase the part of a training session that focuses on the development and/or maintenance of the specific fitness components, muscle groups and energy systems required for a particular sport or activity
gyroscope a sensory device that explains the direction of gravity and determines the position of an athlete
magnetometer a device that measures the direction and strength of magnetic fields
myofascial release a massage technique that focuses on relieving pain in the thick connective tissue that support muscles (myofascial tissues)
neuromuscular the connection between the nervous (neural) system and muscular system. Motor neurons transmit signals to muscular fibre/s, causing a muscle contraction.
overtraining often caused by an overload of training volume and/or intensity, limiting recovery. It is characterised by a decline in an athlete's performance and an increase in their susceptibility to injury/illness.

peaking refers to the planning of training so that an athlete reaches their optimum state of readiness to perform at a particular predetermined time
periodisation a systematic approach to training that involves dividing the training program into specific phases each with distinct goals, including the planned manipulation of training variables (volume, frequency and intensity)
physiological training data provides information about the body's physical functioning in response to training
preparatory phase (pre-season phase) the first phase of training within a yearly training program. The major objective of this phase of training is to provide a suitable fitness and skill base for the phases of training that follow.
psychological training data provides the athlete with an understanding of their mental readiness and mental capacity to train and perform. Includes recording the athlete's thoughts, feelings and cognitive characteristics that affect performance.
qualitative subjective in nature; thoughts, opinions and feelings (e.g. RPE)
quantitative objective in nature; expressed in numerical terms (e.g. heart rate)
real time means that data is processed straight away and is available virtually immediately as a source of feedback
RPE (rating of perceived exertion — Borg Scale) a subjective rating of how hard the athlete feels they are working. It is a numerical scale ranging from 6 to 20, with 6 being no feeling of exertion and 20 being extremely hard. A score of 13–14 is classified as moderate intensity, and 15–16 is classified as vigorous.
skill development phase includes activities designed to develop and/or practise skills, game plans, tactics and strategies
sociological training data provides context about the broader social, cultural and environmental factors that contribute to an athlete's performance
tapering a reduction in training that allows the athlete time for extra recovery and for their energy stores to be fully replenished
transition phase (off-season phase) designed to provide the athlete with a break from the physiological and psychological demands of competition and training. The aim in this phase is for an athlete to remain reasonably active through participation in recreational and low-intensity activities.
venous pooling an accumulation of blood in the veins in inactive muscles following activity
warm up activities and exercises undertaken at the beginning of a training session that are designed to prepare the body, both physiologically and psychologically, for the conditioning phase of the training session

11.7 Exam questions

11.7 Section A – Multiple choice questions

Question 1 (1 mark)

Consider the following training diary entry:

Date: Monday 12 November, 6 am – 7 am
Session: 20-min fartlek session around lake with Jodie. Weather was sunny but not too hot.
Weight prior: 70 kg
Weight after: 68.8 kg with 500 mL water during session

What type of data is missing?

A. Physiological
B. Psychological
C. Sociological
D. Quantitative

Question 2 (1 mark)

Which of the following statements is false?

A. Training diaries can help identify overtraining.
B. Training diaries can help track progressive overload.
C. Training diaries cannot record physiological data.
D. Training diaries can record physiological and psychological data.

Question 3 (1 mark)

What data is being shown on the activity tracker?



A. Distance
B. Respiration rate
C. Blood pressure
D. Heart rate

Question 4 (1 mark)

Which part of an activity training app is most likely to track sociological data?

A. The workout calendar
B. The diet plan
C. Plan your goals
D. Check your health

Question 5 (1 mark)

Which part of an activity training app is most likely to track psychological data?

A. The workout calendar
B. The diet plan
C. Plan your goals
D. Check your health

Question 6 (1 mark)

The environmental conditions of the training session are which type of data?

A. Physiological
B. Psychological
C. Sociological
D. Quantitative

Question 7 (1 mark)

Which of the following is not an example of psychological data that is likely to be recorded in a training diary?

A. Arousal levels
B. Goal setting
C. Stress levels
D. Sleep quantity

Question 8 (1 mark)

Source: Adapted from *VCE 2021, Physical Education Exam, Section A, Q.5;* © VCAA

While completing any training program, athletes record a range of training data, such as sleep patterns, stress scores, heart rate data and the 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

Question 9 (1 mark)

Source: *ACHPER 2023, Trial Exam Units 3 & 4, Section B, Q.1;* © ACHPER

The following data is taken from a digital app used to monitor training.



According to the image above, the digital app is capable of recording which type of information?

A. Physiological only
B. Physiological and psychological
C. Sociological and physiological
D. Sociological, physiological and psychological

Question 10 (1 mark)

Examples of psychological data recorded to monitor a training program include:

A. heart rate, breathing rate and perspiration levels.
B. stress levels, goal setting and confidence levels.
C. RPE, sleep patterns and training time
D. weather conditions, training partners and place of training.

More exam questions are available in your learnON title.

11.7 Section B – Short answer questions

Question 1 (4 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.6.c;* © ACHPER

An instructor at a local gymnasium conducted a High Intensity Interval Training (HITT) session in a 'Spin Cycle' class for a group of adults aged over 18.

In the cool down, participants undertook five minutes of stretching.

a. **Outline** a type of stretching that could be undertaken in the cool down, following this Spin Cycle class. **(2 marks)**

b. **Describe** or draw a suitable stretch which could be used for the quadriceps muscle group which utilises the type of stretching identified in **part a.** **(2 marks)**

Question 2 (7 marks)

Source: Adapted from *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.1;* © ACHPER

Julia and Gus both participated in a 5-kilometre fun run over the weekend.

Heart rates during 5-kilometre run and 3-minute recovery

	Resting HR	1 km HR	2 km HR	3 km HR	4 km HR	5 km HR	Recovery HR 1 min	Recovery HR 2 min	Recovery HR 3 min
Julia	45	88	118	119	118	119	105	83	58
Gus	65	113	135	158	159	158	140	129	108

a. **Identify** the type of data that was collected and **discuss** how this data could be used to monitor training. **(3 marks)**

b. **Outline** another type of training data that could be recorded and **explain** how this data may be used to evaluate their training programs. Provide an example to support your explanation. **(4 marks)**

Question 3 (2 marks)

Source: Adapted from *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.11;* © ACHPER

Boxing is a combat sport between two competitors. It is a combination of strength, speed, power and skill. A boxing match traditionally goes for 12 × 3-minute rounds, with a 1-minute interval between rounds.

Both competitors keep a detailed training diary. **Outline** two benefits of them doing this.

Continue to build your exam skills

Access the Unit 4 Area of Study 2 Review at the end of Topic 14. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

12 Training program principles

12.1 Overview

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LEARNING SEQUENCE

12.1 Overview
12.2 Specificity, intensity, type and individuality
12.3 Time/duration, frequency and variety
12.4 Progression, overtraining and tapering
12.5 Diminishing returns, detraining and maintenance
12.6 Key skills
12.7 Review

12.1.1 Introduction

In order for a training program to achieve the goal of enhancing and/or maintaining fitness components, its design requires the correct application of training principles. The training principles help to guide the coach and/or athlete to design and implement a training program for the relevant chronic adaptations of the cardiovascular, respiratory and muscular systems to occur. This chapter explores the important training principles of:

- specificity
- intensity
- type
- individuality
- time/duration
- frequency
- variety
- progression
- overtraining
- tapering
- diminishing returns
- detraining
- maintenance.

FIGURE 12.1 How the training principles are applied will depend upon the athlete and the activity they are training for.



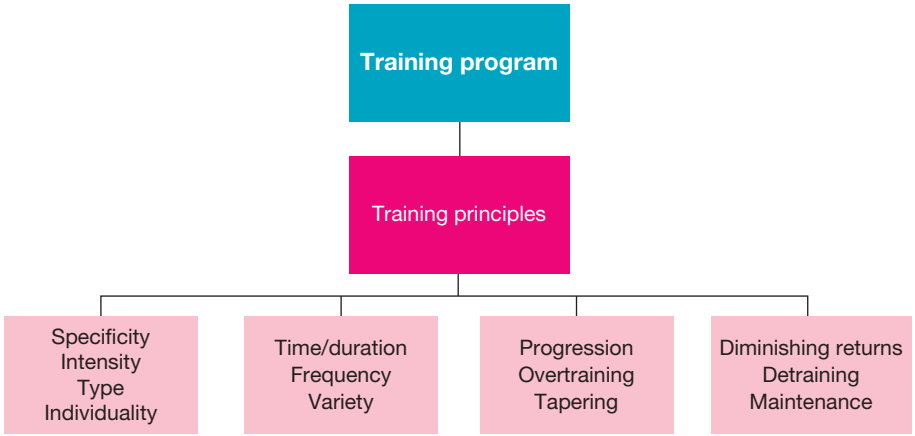
How the training principles are applied should be determined by the overall goal of the training program and the information provided from undertaking an activity analysis and assessment of fitness. The principles need to be applied appropriately to the selected training method/s.

12.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• training program principles including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining	• design a training program that demonstrates the correct application of training principles to enhance and/or maintain fitness components • evaluate and critique the effectiveness of different training programs	**12.2** **12.3** **12.4** **12.5**

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.1.3 Topic preview



12.2 Specificity, intensity, type and individuality

Key knowledge	Key skills
• training program principles including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining	• design a training program that demonstrates the correct application of training principles to enhance and/or maintain fitness components • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.2.1 Specificity

Of all the principles of training, **specificity** is the most important. Whether the aim of the training program is to improve general fitness or to become a better performer in a particular sport, it is essential that all training aspects are relevant to the overall purpose of the program.

specificity the process of replicating the characteristics of physical activity in training to ensure it benefits performance

The activity analysis provides information about the activity/sport and the fitness assessment provides information about the current state of fitness of the athlete. Both should be undertaken so that the principle of specificity can be applied effectively.

The important aspects that are identified in an activity analysis are the following:

- the predominant energy systems required
- the fitness components used
- the muscle groups used
- the skills performed
- the fatiguing factors.

It would be pointless for a tennis player who requires agility, short sprints, skills work and **resistance training** to follow the training schedule of a marathon runner who completes 200 kilometres of **continuous training** per week (see figure 12.2). Obviously, the aspects identified above have different applications in the two sports, and the training for one would not be specific to what is needed for successful performance in the other.

It is also important to select training methods (discussed in topic 13) that are specific to addressing the identified needs for optimum performance levels. If the athlete needs to focus on upper body strength, anaerobic power and the ATP–CP energy system, it would be counterproductive to choose continuous training that is specifically for aerobic improvement and lower body local muscular endurance.

FIGURE 12.2 It is essential that Alex De Minaur trains the specific energy systems, muscle groups and fitness components that are required for him to be competitive in tennis at the highest level.



EXAM TIP

The principle of specificity dictates the selection of training methods and how each of the principles will be applied.

For team sports such as netball, Australian Rules football, rugby and soccer, an activity analysis on each particular position and/or player would reveal quite different physiological characteristics that are required for optimal levels of performance. The energy system and fitness component requirements of a striker in soccer would be very different to those of the goalkeeper.

As discussed in topic 9, the completion of an activity analysis is a critical step when applying the principle of specificity to a training program.

If an activity analysis of an elite tennis player such as Alex De Minaur revealed that leg power and agility are two important fitness components (discussed in topic 8) needed for optimum levels of performance, then the principle of specificity would require the athlete to:

- test these fitness components by using tests such as the vertical jump test and the 5-0-5 agility test (refer to topic 10)
- design a training program that includes **circuit training** sessions that specifically work on muscular power and agility in the leg muscles

resistance training training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance

continuous training involves continuous activity that lasts a minimum of 20 minutes at the required intensity using the aerobic energy system. It is submaximal and requires an intensity of 70–85 per cent of maximum heart rate. Also known as long, slow distance training.

circuit training involves working at a variety of activity stations in sequence, training a number of fitness components at once

- select exercise stations that work specifically on leg power, such as squat jumps or drop jumps, and agility exercises such as speed and ladders
- ensure that the application of other training principles, such as type, intensity and time, are specific to the needs of the game of tennis and the individual athlete.

If the tennis player trains the specific energy systems, fitness components and muscle groups and also accounts for the fatiguing factors relevant to the game of tennis, they will achieve the chronic adaptations that allow them to perform at their optimum fitness in a game situation. However, a very important aspect of the tennis player's game is the execution of a high level of motor skill. It is essential that the tennis player also includes a specific skill component in each training session. Appropriately targeting the physiological requirements of the sport will enhance the likelihood of the athlete performing to the best of their ability. There are other influences such as psychological factors, nutritional intake and hydration status that may also ultimately affect the player's performance; these are discussed in topic 7.

EXAM TIP

Specificity relates to both the game or activity (activity analysis) and the needs of the athlete (fitness assessment).

SAID stands for specific adaptations to imposed demands
interval training consists of repeated periods of work followed by periods of rest or recovery

The **SAID** principle is a well-known acronym in the sports science field — it stands for Specific Adaptations to Imposed Demands. This means that the specific training that is undertaken will determine the type(s) of physiological adaptations that will occur. For example, weight/resistance training (see figure 12.3) specifically designed for strength improvements will result in an increase in motor unit recruitment, an increase in the rate and speed of neuromuscular firing, an increase in the size and number of myofibrils and an increase in the protein filaments actin and myosin as a result of the imposed demands placed on the muscles.

Alternatively, long **interval training** (see figure 12.4) will result in an increase in the number of myoglobin stores in the muscles, which will enhance oxygen extraction and delivery to the mitochondria for energy production and improved aerobic power. The chronic adaptations that occur are therefore defined by the specificity of the particular aspects of an athlete's training program.

FIGURE 12.3 There are specific adaptations to weights/resistance training designed to improve strength.



FIGURE 12.4 There are specific adaptations to long interval training designed to improve aerobic power.



By identifying the sport's requirements and the strengths and weaknesses of the athlete — through activity analysis and fitness assessment, respectively — and considering this information specifically in developing the training program, the athlete can be more certain about meeting the overall goals of the training program. The principle of specificity should guide the appropriate application of all other training principles.

12.2.2 Intensity

In terms of fitness gains, **intensity** is the most important training principle. In rudimentary terms, the following intensities are a guide to training each energy system:

- ATP–CP energy system — 95–100 per cent of maximum heart rate (MHR)
- anaerobic glycolysis energy system — 85–95 per cent of MHR
- aerobic energy system — 70–85 per cent of MHR.

Therefore, to improve the ATP–CP energy system by doing 50-metre sprints, the athlete needs to perform the sprints at 95–100 per cent intensity (maximum effort).

The intensity at which a person trains will determine the kinds of adaptations that will be achieved.

There are a variety of methods/variables used to measure the intensity of exercise:

- percentage of maximum heart rate (% MHR)
- rating of perceived exertion (RPE)
- percentage of VO_2 maximum (% VO_2 max)
- percentage of **heart rate reserve** (% HRR)
- **metabolic equivalents (METs)**
- blood lactate levels (mM)
- power output: wattage (W)
- percentage of repetition maximum (% RM).

intensity the exertion level or how hard the training is being performed. It is commonly measured as a percentage of maximum heart rate (MHR), which is determined by beats per minute (bpm).

heart rate reserve the difference between resting heart rate and maximum heart rate

metabolic equivalents (METs) a system for classifying exercise intensity. 1 MET is equal to resting levels.

training zone describes the intensity range that is required for specific adaptations to occur

Two widely used measurements of intensity are percentage of maximum heart rate (% MHR) and percentage of VO_2 maximum (% VO_2 max). However, to use VO_2 max, it is necessary to undertake a VO_2 max test (see topic 10) to determine the maximum reference point by which percentage exercise intensities can be defined. Since it is difficult to actually determine oxygen consumption while training, % MHR is used. Heart rate and oxygen consumption increase linearly with exercise intensity; therefore, using % MHR as a measurement of intensity is justified.

A simple and general calculation for determining MHR is:

$$220 - \text{age} = \text{MHR}$$

on Resources

Interactivity Heart rates during exercise (int-6823)

A commonly recognised way to categorise the adaptations that occur at different intensities is the division of **training zones** (see figure 12.5 and table 12.1).

FIGURE 12.5 The various generic training zones according to age and heart rate

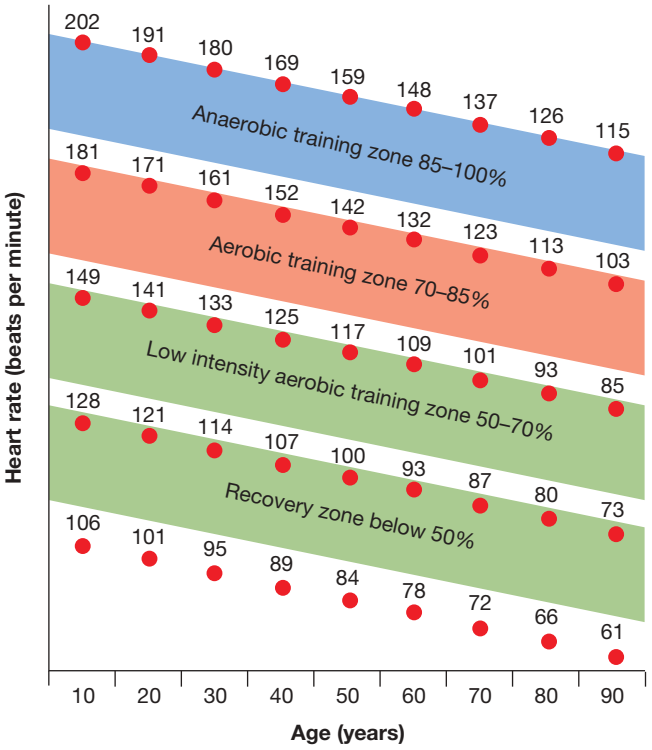


TABLE 12.1 The relationship between other variables and exercise intensity

Training zone	% MHR	% VO_2 max	RPE	% HRR	Blood lactate (mM)
T6	NA	NA	Maximal	NA	NA
T5	>92%	>86%	Very hard	>86%	>6.0
T4	90–92%	83–86%	Hard	83–86%	4.0–6.0
T3	85–90%	75–83%	Somewhat hard	75–83%	3.0–4.0
T2	70–85%	60–75%	Light	58–75%	2.0–3.0
T1	60–70%	36–60%	Very light	30–58%	<2.0

= Anaerobic training zone = Aerobic training zone = Low intensity aerobic zone/recovery zone

Source: Adapted from https://www.visualcoaching.com/

Metabolic equivalents

Metabolic equivalents (METs) categorise exercise intensities as:

Light	Moderate	Vigorous
<3.0 METs	3.0–6.0 METs	>6.0 METs

The limitation of using METs as a measure of exercise intensity is that they do not take into account individual fitness levels.

In general terms, a person's **lactate inflection point (LIP)** is thought to occur at an intensity of approximately 85 per cent MHR.

For the athlete whose data for a bicycle ergometer test is shown in figure 12.6, they had an MHR of 182 bpm and a relative VO_2 max of 61 mL/min/kg.

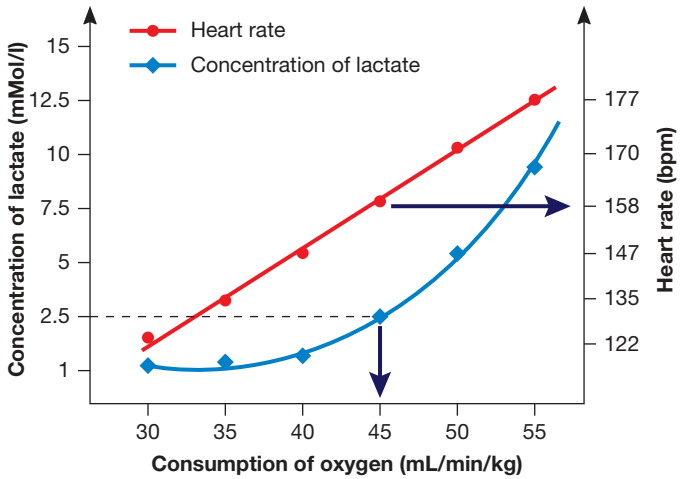
Blood lactate concentration will accumulate faster than it can be removed when the athlete's VO_2 max is 45 mL/min/kg; therefore, their LIP occurs at about 74 per cent of VO_2 max.

The heart rate at this point is 158 bpm; therefore, their LIP occurs at about 85 per cent of their MHR.

lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.

repetition maximum (RM) the maximum amount of weight that a person can lift in one muscular contraction

FIGURE 12.6 This graph represents the relationship between lactate concentration, heart rate and oxygen consumption for a successive bicycle ergometer test, with the exercise intensity starting at about 50–60 per cent of VO_2 max.



Wattage is a measure that is generally used to determine the power generated during cycling. A higher wattage value indicates that an athlete is working at a higher exercise intensity.

Weight/resistance training intensity is determined by the amount of weight lifted in a given set, which is measured as a percentage of an athlete's **repetition maximum** (% RM) (refer to topic 13).

Working at the correct intensity levels is critical to achieving the goals of a training program.

EXAM TIP

The principle of intensity determines the level of fitness gains. You must be able to demonstrate your understanding of intensity in relation to the goals of the program (e.g. anaerobic and aerobic training zones).

12.2.3 Type

The type of exercises, activities and/or training methods that are included in a training program will also determine the particular adaptations and performance gains achieved. It is important that the types of exercises, activities and/or methods selected are appropriate for achieving the overall training program goals. They should replicate the movement patterns, muscle groups/actions, energy systems and fitness components relevant to the particular sport or activity for which the person is training.

A marathon runner's training program would involve predominantly running-based training (see figure 12.7), whereas a triathlete's training program would require a combination and balance of swimming, running and

cycling (see figure 12.8). Both athletes would, however, need to select training methods that aim to improve their aerobic power and local muscular endurance.

FIGURE 12.7 Australian marathon record-holder Brett Robinson finishing the 2022 London marathon.



FIGURE 12.8 Aaron Royle competing in the men's cycle leg of the World Triathlon.



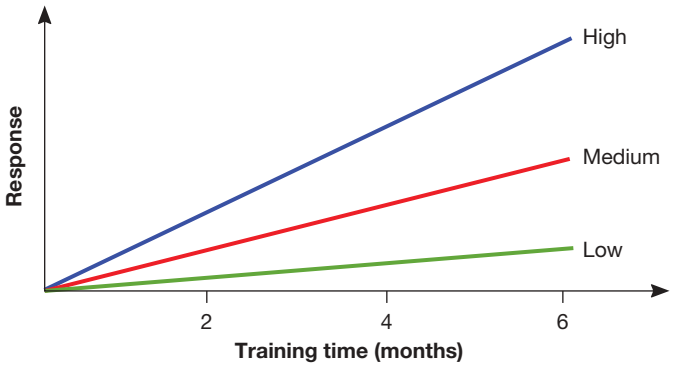
12.2.4 Individuality

No two individuals react in exactly the same way to a similar physical activity program. Regardless of the training programs being used, some people will achieve significant gains, while others will only improve slowly (see figure 12.9).

individuality a principle that suggests that individual responses to physical activity are highly varied

The principle of **individuality** is strongly influenced by heredity (genetic characteristics passed on from your parents and grandparents).

FIGURE 12.9 Individual responses to training vary widely.



Source: C Bouchard & T Rankinen, 'Individual differences in response to regular physical activity', *Medicine and Science in Sports and Exercise*, vol. 33, no. 6, 2001, pp. S446–S451

It is essential that a training program is designed to cater for the specific needs, goals and abilities of the individual.

EXAM TIP

Be able to explain why two athletes undertaking the same training program may respond differently.

doc-41974

PRACTICAL ACTIVITY Requirements of netball

Goal

To identify the requirements of different positions in the game of netball.

Instructions

Participate in a 20-minute game (2 × 10-minute halves) of netball as a class and consider the different requirements of each position.

Primary data/Reflection

Take notes on the general movement patterns, the types of skills and the intensity of a goalkeeper (GK) or goalshooter (GS) and a centre (C) player position.

Gather feedback from the players in each position in relation to how they felt during the game and how hard they worked (their RPE), using a scale from 1 to 10 where:

1 to 3 = very light

4 to 6 = somewhat hard

7 to 8 = very hard

9 to 10 = extremely strenuous

Alternatively, you may like to try each position yourself in each 10-minute half and provide your own personal reflection.

Questions

1. Using the data that you have collected, contrast the intensity levels that were experienced in each position and give reasons for the differences.
2. In relation to the principles of specificity, intensity, type and individuality, outline how the training program for a goalkeeper or goal shooter may differ to that for a centre player.

12.2 Activity

12.2 Quick quiz on

12.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 5, 6, 9, 10	8, 12	7, 11

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TEST your understanding

1. **Define** the principle of *specificity*.
2. **Outline** the important aspects of an activity analysis that specificity must address.
3. **Identify** the most common way to determine training intensity.
4. **Identify** another way to determine training intensity.
5. **State** the recommended heart rate training zone for aerobic training.

6. **State** the recommended heart rate training zone for recovery.
7. **Explain** the principle of *individuality*.

APPLY your understanding

8. **Discuss** why it is easier to use MHR as the means of assessing training intensity, rather than using maximum oxygen uptake.
9. **Determine** your aerobic training heart rate zone. **Identify** the aerobic training heart rate zone of an adult in your family.
10. **Describe** how you would correctly apply the specificity training principle to a training program of your choice.
11. **Explain** how you would correctly apply the principle of type to a training program of your choice.
12. **Compare** and **contrast** how you would apply the training principles of specificity, intensity, type and individuality to a training program for a road cyclist whose event is 50 kilometres and an Olympic triathlete who completes the following: 1500-metre swim, 40-kilometre ride and 10-kilometre run.

12.2 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.15;* © ACHPER

The level of response of acute physiological changes within the body systems, when participating in physical activity, is primarily dependent on the

A. duration of the activity.
B. type of activity.
C. intensity of the activity.
D. type of fuel used.

Question 2 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.4;* © ACHPER

The intensity (RPE) which should be applied to the training of the ATP–CP energy system is

A. 8–9.
B. 7–8.
C. 5–6.
D. 9–10.

Question 3 (1 mark)

Source: *VCE 2016, Physical Education Exam, Section A, Q.10;* © VCAA

The predominant energy system used during a training session depends on the

A. duration of the session.
B. intensity of the session.
C. athlete's training status.
D. frequency of the sessions.

Question 4 (2 marks)

Source: Adapted from *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.4.b;* © ACHPER

A Commonwealth Games athlete jumped 6.77 metres to win the long jump competition.

Describe your training session design by correctly applying the training principles of specificity and intensity.

Question 5 (3 marks)

Source: *VCE 2009, Physical Education Exam, Section B, Q.2.c;* © VCAA

Your 16-year-old friend wants to compete in a 10-km run in six months time. He has no previous running training but is fit and healthy and plays numerous sports such as hockey, basketball and tennis. As you are a VCE Physical Education student, he asks you for some training advice.

Identify the recommended running intensity, you believe would improve your friend's cardiorespiratory fitness.

More exam questions are available in your learnON title.

12.3 Time/duration, frequency and variety

Key knowledge	Key skills
• training program principles including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining	• design a training program that demonstrates the correct application of training principles to enhance and/or maintain fitness components • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.3.1 Time/duration

The **time/duration** principle is important to consider in combination with the principle of intensity. An athlete will not make fitness gains unless they are working at the required intensity for the required amount of time.

This is important for continuous aerobic training, for example, where improvement requires a minimum session of 20 minutes with the person operating at 70–85 per cent of their MHR. It is equally important if the desired outcome is improvement in the ATP–CP system. The work intervals within the training session should be short and at maximum intensity (see figure 12.10). The time/duration principle defines the work-to-rest ratio, which is important in determining the energy system contribution (see table 12.2).

FIGURE 12.10 It is important to time the length of each work interval in order to achieve the appropriate fitness adaptations.



The principle of time/duration also refers to the minimum length of time for a training program to result in improved fitness. This is dependent on the type of training methods undertaken and the intensity of training (see table 12.3). Improvements in aerobic training will occur in about six weeks, but a greater amount of improvement is generally seen in about 12 weeks of training. Anaerobic training improvements are quite noticeable after about 6–8 weeks of training.

The principle of time/duration applies to the length of each activity within a training session, the length of the training session itself and the length of the overall training program.

time/duration the length of a training session, the length of a work interval within a training session and/or the length of the overall training program

TABLE 12.2 Energy systems' work-to-rest ratios

Energy system	Work interval time	Work:rest ratio
ATP–CP system	3–10 seconds	1:5+
Anaerobic glycolysis system	10–60 seconds	1:3
Aerobic system	>30 seconds	1:1 1:0 2:1

TABLE 12.3 Suggested guidelines for applying the training principles to aerobic and anaerobic training programs

Training principle	Aerobic training	Anaerobic training
Duration	6 weeks minimum 12–16 weeks	6 weeks minimum 8 weeks
Frequency	3–7 times per week	3–5 times per week
Intensity	70–85 per cent MHR	85–100 per cent MHR

12.3.2 Frequency

Generally, the minimum number of training sessions per week for fitness gains to be possible is three (see table 12.3). It is also generally acknowledged that to at least maintain a level of fitness, two training sessions per week are required.

An important consideration with **frequency** is the recovery time given following an exercise session before a similar session is undertaken. Other factors include the nature of the activity, the fitness level of the individual and the recovery facilities available.

frequency the number of training sessions needed per week to ensure improvements are achieved in the desired fitness components and energy systems

Early in a training program, a positive training session may be followed by a poor or flat effort, usually because the untrained muscle has not recovered for the next exercise bout. Similarly, high-intensity and contact activities require longer recovery periods than are needed for submaximal aerobic-type activity. This rule applies through to elite-level competition. Therefore, the formula for gaining fitness is not to train as often as possible, but to find a balance between training frequency and recovery.

The minimum training frequency for improving aerobic fitness is three times per week, with up to five sessions being normal. Training can be even more frequent as the athlete's aerobic fitness increases, especially for elite long-distance athletes. Before his retirement, Simon Gerrans was one of Australia's most successful road cyclists. When he was competing, he generally trained two long days (four to five hours), three × three-hour rides with intervals and two easy days per week (see figure 12.11).

FIGURE 12.11 Road cyclist Simon Gerrans (right) of team Orica-GreenEdge narrowly wins stage 3 of the 2016 Tour Down Under.



The minimum frequency for improving anaerobic fitness, including strength and power, is also three sessions per week, with four being normal as the individual consolidates. The nature and intensity of this type of activity means that muscle recovery is an important factor, and this must be planned for as an integral aspect of the training program.

Just as you can have too few training sessions per week, you can also have too many.

12.3.3 Variety

It is important to consider the principle of **variety** when designing a training program. Training can become boring, and the athlete may lose motivation and drop out of the program if there is insufficient variety. Changes to training activities and drills stimulate and challenge participants, who are therefore more likely to train at optimal levels. But the use of variety must not diverge from the initial aims of the program.

variety providing different activities, formats and drills in training, while still addressing the aims of the training program. Its focus is to maintain the motivation levels of the performer and thereby optimise their fitness gains.

Some examples of implementing variety include the following:

- Continuous training could be held at different venues or courses. This variable would work regardless of whether the continuous training was for running, cycling or swimming.
- Continuous running or cycling training could incorporate carefully introduced hill work.
- Continuous training sessions for running could be occasionally replaced with continuous sessions of cycling or swimming.
- A program of resistance training could occasionally substitute free weights for machine weights.
- A resistance training session could vary the order of exercise stations.
- Coaches should always try to vary warm-ups, drills and other aspects of their training sessions to promote enjoyment and improve the focus of their athletes.

It is important that the specificity of the training program is maintained when applying the principle of variety.

EXAM TIP

You must be able to provide at least three examples of how you could include variety for each training method.

doc-41975

PRACTICAL ACTIVITY Time/duration

Goal

To be able to apply the principles of time/duration and variety in a circuit training session.

Instructions

Design a fixed-time circuit training session (refer to topic 13) for your class to participate in.

Primary data/Reflection

You may like to use the table below to design and record the training session or create your own. Take notes about how the participants are feeling when completing each activity.

Exercise	Intensity/ load	Work period time/duration	Rest period time/duration	W:R ratio	Sets	Notes and reflections
1						
2						
3						

4						
5						
6						
7						
8						

Questions

1. Outline the ways that you applied the principle of time/duration in your circuit training session. Provide examples.
2. Explain how you incorporated the principle of variety.
3. Describe how you would consider the principle of frequency when designing a training program.

12.3 Activity

12.3 Quick quiz on

12.3 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3, 4, 6	1, 7	5, 8

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TEST your understanding

1. **Describe** the three meanings of the principle of time/duration.
2. **State** the minimum time for which the heart rate should be in the required training zone for continuous training.
3. **State** what is generally recognised as the minimum number of weeks for a training program to show measurable aerobic fitness gains.
4. **Outline** how often you should train if you just want to maintain a certain level of fitness.
5. **Evaluate** whether there should be more recovery between aerobic or anaerobic training sessions.

APPLY your understanding

6. To show measurable fitness gains, the duration of a training program varies according to the targeted energy system. **Outline** the differences.
7. For the following sports, **suggest** ways in which variety could be introduced to training sessions: netball, swimming, tennis, basketball, water polo, cross-country running.
8. **Explain** why it is important to consider the principle of variety when designing a training program.

12.3 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.8;* © ACHPER

Scott is a 35-year-old male who has decided to enter a virtual 5 km fun run. His online personal trainer has given Scott the following continuous running program to follow for the 12 weeks, leading up to the event.

Week	Heart rate training zone (bpm)	Time (mins)	Weekly sessions
1–3	130–135	30	3
4–6	135–145	30	3
7–9	145–150	35	3
10–12	150–155	40	4

In the training program above,
A. specificity and frequency have been applied correctly.
B. frequency and progression have been applied correctly.
C. progression and intensity have been applied correctly.
D. tapering and variety have been applied correctly.

Question 2 (1 mark)

Source: *VCE 2011, Physical Education Exam, Section A, Q.3;* © VCAA

A 3-km runner wants to participate in the sport of cross-country running. He begins a training program running 5 km once a week at 70% of heart rate max. After four months, he notices little improvement in his race time.

Which is the most likely training principle that has **not** been implemented correctly into his program?
A. duration
B. intensity
C. frequency
D. specificity

Question 3 (2 marks)

Source: Adapted from *ACHPER 2021, Trial Exam units 3 & 4, Section B, Q.2.e;* © ACHPER

With reference to time/duration and variety, **outline** two benefits of the netballer performing an interval training session in preference to a continuous training session.

Question 4 (5 marks)

Source: *VCE 2020, Physical Education Exam, Section A, Q.7.c;* © VCAA

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 1 RM	85% of 1 RM		85% of 1 RM	85% of 1 RM		65% HR max
fixed reps = 6	maximum reps		fixed reps = 6	maximum reps		20 min
4 rotations	4 sets		4 rotations	4 sets		
40 s rest between each station	10 s rest between each set,		40 s rest between each station	10 s rest between each set,		
8 stations, all lower-body exercises	all lower-body exercises		8 stations, all lower-body exercises	all lower-body exercises		

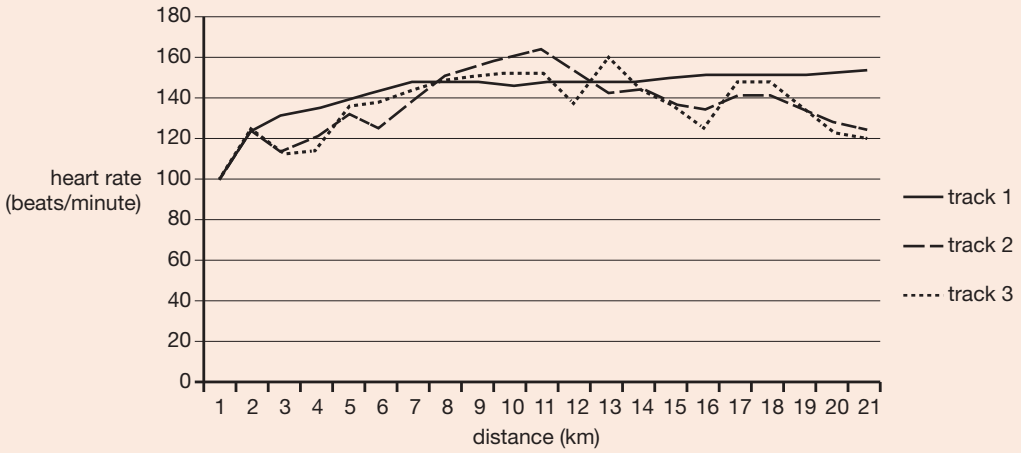
Key
reps — repetitions; RM — repetition maximum; s — seconds; min — minutes

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.

Question 5 (3 marks)

Source: *VCE 2013, Physical Education Exam, Section B, Q.14.b.i–ii;* © VCAA

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.



i. Which training principle is Alice able to apply by wearing a heart rate monitor while riding? **(1 mark)**

ii. **Explain** how Alice may use the heart rate data to structure her training sessions. **(2 marks)**

More exam questions are available in your learnON title.

12.4 Progression, overtraining and tapering

Key knowledge	Key skills
• training program principles including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining	• design a training program that demonstrates the correct application of training principles to enhance and/or maintain fitness components • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.4.1 Progression (progressive overload)

Progression is the systematic application of overload (progressive overload) in order to achieve the adaptations required to improve performance. Progression forms the basis of improvement and the development of chronic adaptations.

There can be no improvement in personal fitness levels without progressively increasing or overloading the existing training levels. The new levels of physical activity must exceed the level to which the individual is already accustomed. Any overload of physical activity can take into consideration the FITT principle (**F**requency, **I**ntensity, **T**ime, **T**ype of exercise).

The human body responds to stress caused by physical work. Consequently, it adapts to cope with this stress or increased workload. Otherwise, there is a plateau in performance levels.

EXAM TIP

Make sure that you can critique or design a training program with the correct application of progression (progressive overload). A general rule is to only change one aspect at a time and by no greater than 10 per cent.

Progressive overload relies on four factors:

1. The existing workload is appropriate to the level of the individual's fitness.
2. The amount of overload is sufficient to cause adaptation and improvement without causing the individual to feel unable to complete the session. Small incremental increases to the training load are safer and more sustainable.
3. The overload maintains the original aims of training.
4. There is appropriate application of recovery (tapering) periods. This should lessen the chances of physical fatigue or joint and muscle soreness.

The variables of training that are available to be manipulated for progressive overload could be:

- **volume** (increase number of repetitions, the time/duration of the exercises or the overall session, or reduce recovery periods)
- intensity (increase weights/resistance % RM, training heart rate or the difficulty of the type of exercise)
- frequency (increase how often the training is performed per week).

volume the amount of work performed during a specific period

The chosen variable must be manipulated for overload in a way that is consistent with the aim of the program. For example, an athlete aiming to improve their ATP–CP energy system by completing 5 × 70-metre running sprints could introduce overload by these methods:

- increase the number of repetitions of the 70-metre sprints
- move from a 95 per cent effort sprint to a 100 per cent effort sprint
- increase the distance sprinted, ensuring that the ATP–CP energy system remains the targeted energy system.

This last point is crucial. If in this case the time of each sprint becomes longer and the effort moves from focusing on the ATP–CP system to focusing on the anaerobic glycolysis system, the overload will not continue to meet the aim of the training program. An example of how progressive overload can be applied can be seen in table 12.4.

TABLE 12.4 Examples of how progressive overload can be applied

Overloading volume: weight/resistance (endurance) training

Week 1		Week 2		Week 3	
Squat	2 sets of 12 reps @45 kg	Squat	3 sets of 10 reps @45 kg	Squat	3 sets of 12 reps @45 kg
Bench press	3 sets of 10 reps @40 kg	Bench press	3 sets of 12 reps @40 kg	Bench press	3 sets of 14 reps @40 kg
• Either increasing the repetition or sets					

Overloading intensity: intermediate interval training

Week 1	Week 2	Week 3
Work: 2 sets of 8 reps x 30 s @85% MHR	Work: 2 sets of 8 reps x 30 s @90% MHR	Work: 2 sets of 8 reps x 30 s @95% MHR
Rest: 90 s	Rest: 90 s	Rest: 90 s
• Increasing the % MHR		

Overloading frequency: continuous training

Week 1	Week 2	Week 3
40 min jog @75% MHR × 2 per week	30 min jog @75% MHR × 3 per week	35 min jog @75% MHR × 3 per week
• Increasing the frequency by reducing the work time (gradual increase -10%)		

The next topic, which discusses training methods, further examines the more specific manipulation of variables for applying progressive overload. Progressive overload should be planned, but its application must be flexible. It may need to be applied after the first session if the prescription for the initial training bout is too low, or it may take several sessions. Progressive overload is particular to each individual, and rigid application to all participants will not maximise training benefits (see figure 12.12).

FIGURE 12.12 Triple Paralympic canoeing gold medallist and co-captain of the Australian Paralympic Team (Paris 2024), Curtis McGrath, progressively overloads his training to achieve his peak performance level.



It is vital that the application of progressive overload is gradual and systematic, allowing for appropriate adaptations to occur and to avoid overtraining. It is generally accepted that a variable is increased by 2–10 per cent. It is best to only increase one variable at a time and to progress slowly but steady. It is generally considered best to overload the volume before overloading the intensity, as this continues to permit adequate recovery and reduces fatigue.

EXAM TIP

Be able to critique and design a training program based on the correct application of the principles.

EXAM TIP

You can remember the five important training principles using the acronym SIDOF:

Specificity

Intensity

Duration/time

Overload (progression)

Frequency

12.4.2 Overtraining

Overtraining occurs when there is a long-term decline in performance and physical functioning. The ability of the body to continue to adapt to the training load is compromised when overtraining symptoms occur. Research suggests that there are both psychological and physiological causes of overtraining. Everyone will experience some level of fatigue following intense bouts of training; however, overtraining is characterised by a decline in performance that cannot be remedied by a few days' rest.

While overtraining usually occurs when the amount and quality of recovery time is insufficient to allow full recovery from the stresses of training, there can be a number of other causes. These include:

- excessive training volume; for example, several training sessions every day of the week
- inappropriate increases in the frequency, duration and/or intensity of training; in other words, too much overload
- training when suffering from illness
- excessive increases in training loads following periods of enforced lay-off due to injury or illness
- excessive competition scheduling with maximum demands and frequent disturbance of daily routines
- poor nutritional state, especially inadequate carbohydrate, vitamin and mineral intake
- external stressors such as work and study demands, family responsibilities or difficulties in personal relationships.

It is important for adolescents who are physically active to be aware of the dangers of overtraining a growing body.

The signs and symptoms of overtraining are listed in table 12.5, and it is likely that they will vary according to the type of training undertaken.

TABLE 12.5 Symptoms of overtraining

Physiological symptoms	Psychological symptoms	Miscellaneous symptoms
• Persistent feelings of fatigue • Chronic muscle soreness • Increased or decreased morning resting heart rate (beyond normal variation) • Increased heart rate during submaximal exercise at a given workload (beyond normal values) • Earlier onset of fatigue during exercise bouts • Decreased performance during strength and power testing • Decreased coordination and disturbances in rhythm of movement	• Decreased concentration span • Decreased motivation levels • Increased irritability and anger • Depression • Increased anxiety levels • Increased fear of competition • Increased sensitivity to emotional stress • Increasing tendency to give up and believe that the challenge is too difficult • Increased susceptibility to demoralising influences before and during competition	• More frequent illnesses • Loss of appetite • Increase in overuse injuries • Insomnia • Lack of enjoyment of training and competition

The key to avoiding overtraining is prevention. Well-planned training programs that include adequate rest and recovery periods are essential, as are gradual increases in training loads. The **periodisation** of training in which the training load varies in cycles with built-in mandatory rest phases is also a key factor in the avoidance of overtraining. Appropriate recovery methods are important in ensuring that athletes gain maximum effectiveness from recovery sessions and rest periods. Tracking devices, such as training diaries, digital tools and wearable technologies (outlined in topic 11), can be used by athletes to monitor their training stress and other training variables (see figure 12.13).

periodisation a systematic approach to training that involves dividing the training program into specific phases each with distinct goals, including the planned manipulation of training variables (volume, frequency and intensity)

Other recommendations for the prevention of overtraining include avoiding monotonous training by including some variety within the training program and also maintaining adequate nutrition. Vigorous exercise during the incubation period of a viral illness (e.g. the flu) may increase the duration and severity of that illness. Athletes who feel as if they are developing a cold should rest or reduce their training schedule for a few days.

If overtraining has occurred, the cure is relatively straightforward — reduce training loads and increase rest periods. A period of complete rest may be recommended. The longer the period of overtraining, the longer the period of time needed for recovery tends to be.

FIGURE 12.13 Digital tools and wearable technologies are useful in tracking training and in preventing overtraining.



EXAM TIP

Be able to recognise the symptoms of overtraining so you can identify whether an athlete is experiencing it. Know how to adjust a training program to prevent overtraining.

12.4.3 Tapering

A short-term reduction in training load is broadly known as **tapering**. This promotes both physiological and psychological recovery and allows for energy stores to be fully replenished. Tapering involves systematically reducing the training load with the aim of decreasing cumulative fatigue without compromising any training adaptations, while also optimising performance. To achieve these aims:

- the volume (quantity) of training should be reduced
- the intensity (quality) of training should remain at the same level
- the frequency (how often) of training could remain the same or be slightly reduced.

While most athletes and coaches agree that tapering is a good thing, there are wide differences in opinion as to how tapering periods should be constructed. These debates revolve around:

- the length of the tapering period
- the extent to which training volume and frequency should be reduced
- the rate at which these variables should be reduced.

These variables are adapted according to the needs of the athlete and the sport or activity for which they are training (see figure 12.14). There are a variety of strategies for including a taper in a training program (see table 12.6). The training load that precedes the taper should determine the strategy that is implemented. Understanding the interactions between training volume, intensity and frequency is crucial in determining the requirements of the taper period. How much to taper depends on the volume, intensity, frequency and duration of the current training program.

FIGURE 12.14 Tapering for a rock climber will be different from tapering for a water polo player.



TABLE 12.6 Manipulating variables for tapering

Variable	How?
Training volume	Decrease as determined by the preceding training level and actual duration of the taper (approximately 30–60 per cent reduction).
Training intensity	Maintain at current level or slightly increase.
Training frequency	Maintain at current level or decrease only slightly (keep at no less than 80 per cent of the original level) for elite athletes and moderately (keep at no less than 50 per cent) for less-trained athletes.

Note: Research suggests that the duration of a taper should be individualised due to the differences in people's physiological and psychological adaptations to training load reductions. More experienced athletes may require a longer taper, while less-experienced athletes may require a shorter taper.

Traditionally, athletes taper prior to a competition to achieve peak performance levels. However, tapering is also an important principle to consider as part of an athlete's regular training program. A successful training program incorporates a period of work and rest; without appropriate rest, the body cannot adapt to the training demands. When designing a training program, the coach or athlete must consider the rest days (tapering periods) just as carefully as the training days. The timing of regular tapering periods during a training program depends on the athlete's intensity and volume of the athlete's training. Failing to taper as part of a training program can result in the athlete training at below optimal levels due to feeling tired and fatigued from a previous training session.

Some coaches can be apprehensive about allowing their athletes to undertake a period of tapering; they worry that it will cause a reduction in their aerobic conditioning. However, research reveals that although a considerable amount of training is required to achieve significant improvements in aerobic capacity when starting a training program, much less training is required to maintain these improvements, and reducing the load with appropriate tapering should not cause any detraining. Every individual athlete will respond differently to tapering; however, most athletes will improve or at least maintain their current level of performance.

Benefits of tapering

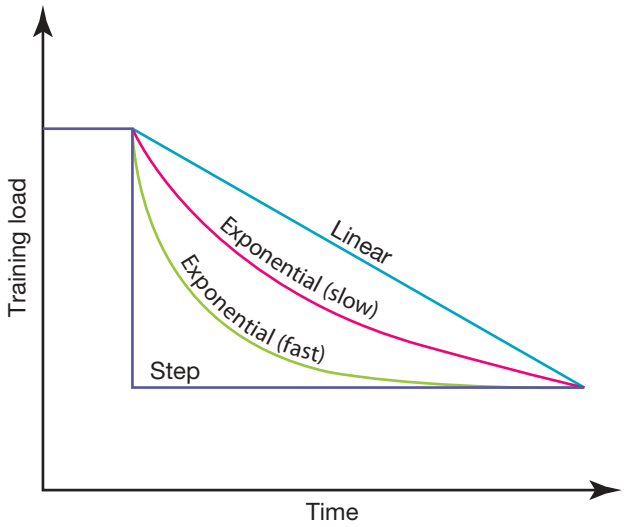
Some of the benefits of tapering include:

- allows for replenishment of fuel substrates such as glycogen
- provides an opportunity for psychological refreshment
- heightens enzyme activity
- increases red blood cell volume
- expands blood plasma
- improves neuromuscular coordination
- allows for the repair of muscle micro-trauma.

Types of tapering

Tapering can be designed in many ways, depending on the needs of the athlete (see figure 12.15). The reduction in training volume can be either progressive or non-progressive, and the rate of reduction will also vary (see table 12.7).

FIGURE 12.15 Representation of the different types of tapers



Source: Adapted from I Mujika & S Padilla, 'Scientific bases for precompetition tapering strategies', *Medicine* & *Science in Sports* & *Exercise*, vol. 35, no. 7, 2003, p. 1185

TABLE 12.7 Types of tapering that can be used depending on the needs of the athlete

Reduction type	Reduction rate	Description
Progressive	Linear	Gradual, linear reduction in proportion to the original load
	Slow exponential decay	Slow reduction in volume over time
	Fast exponential decay	Faster reduction in volume over time
Non-progressive	Step	A sudden reduction in training load, followed by a plateau

The application of tapering is both a science and an art as it should be individualised to meet the needs of each specific athlete's training. As discussed in topic 11, an athlete's progress should be frequently monitored and evaluated. This will assist the coach or athlete to assess when and how tapering should be included into their training program. An effectively implemented taper can result in considerable increases in performance; for an Olympic athlete, it may mean the difference between a gold or bronze medal.

on Resources

Weblinks Tapering and Peaking for Performance | How to Peak When it Counts
Sample tapering schedule for a marathon

doc-41976

PRACTICAL ACTIVITY Progressive overloading

Goal

To understand the importance of progressively overloading a training program by participating in a simulated experience.

Instructions

Complete an appropriate warm-up and then perform the following group of exercises for 3 sets as outlined below, measuring your heart rate after completing each exercise for each set.

Exercises
Jumping jacks
Push-ups
Abdominal crunches
Fast feet sprinting on the spot
Bodyweight squats
Triceps dips

Set 1	Set 2	Set 3
20 seconds each exercise/ 40 seconds rest	30 seconds each exercise/ 40 seconds rest	40 seconds each exercise/ 40 seconds rest

Primary data/Reflection

Record your rate of perceived exertion (RPE) for each set of exercises

Set 1 RPE	
Set 2 RPE	
Set 3 RPE	

Exercise	Set 1 heart rate	Set 2 heart rate	Set 3 heart rate
Jumping jacks			
Push-ups			
Abdominal crunches			
Fast feet sprinting on the spot			
Bodyweight squats			
Triceps dips			

Write a short reflection on how you felt at the completion of each set.

Questions

1. Imagine that the sets are weeks in a training program, the exercises represent a full training session, and the increased percentage volume prescribed for each set was applied to each week. Discuss the implications of this by referring to the data.
2. Explain how progression (progressive overload) should be applied.
3. Discuss the importance of tapering.

12.4 Activity

12.4 Quick quiz on | **12.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 6, 8, 9	10, 13	5, 7, 11, 12

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TEST your understanding

1. **Define** *progressive overload*.
2. **Outline** why it is important that overload is applied progressively.
3. **Name** the four factors on which overload relies.
4. **Identify** the variables with which training programs can be overloaded.
5. **Explain** the concept of overtraining.
6. **List** some of the signs and symptoms of overtraining.
7. **Explain** the concept of tapering.
8. **Outline** the variables that can be manipulated when tapering.
9. **List** four benefits of tapering.

APPLY your understanding

10. In the following training scenarios, **suggest** ways in which an athlete could introduce overload.
    a. An 800-metre elite runner: one set of 6 × 300-metre intervals run at 75 per cent MHR with 1-minute walk recoveries between efforts
    b. A 10 000-metre runner: three sessions per week of 15-kilometre runs around her local suburban streets
    c. A pole vaulter: five sessions per week of two sets of 10 × 20-metre track sprints at 98 per cent MHR with 60 seconds of rest recovery between efforts and 10 minutes of walk recovery between sets.
11. **Examine** the graph below and **explain** the progress of each of the six subjects in their application of progressive overload.



Consider:

a. the appropriateness of the initial training load
b. adjustments made to the training load
c. no change to the training load
d. implications of a training load that is too easy or too hard.

12. **Explain** the factors that you would incorporate into your training program design that would prevent the likelihood of overtraining occurring.
13. **Discuss** the four different types of tapering and provide examples of how each of them may be applied.

12.4 Exam questions

Question 1 (3 marks)

Source: Adapted from *VCE 2023, Physical Education Exam, Section B, Q.9.b,f;* © VCAA

Emily is a well-trained recreational runner who is training to complete the 10-kilometre run at the Melbourne Marathon Festival. She hopes to complete the run in 35 minutes. To prepare for the run, she has completed a 12-week training program. Below is an example of a typical training session that Emily would complete. Running around the athletics track for 6 × 4-minute repetitions with 2 minutes' rest between repetitions at 75–85% HR max.

a. **Provide one** example of how Emily could apply progression to her training session. **(1 mark)**
b. **Explain** how Emily could prevent overtraining. **(2 marks)**

Question 2 (2 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.6;* © VCAA

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
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	

Using data from the training program, **justify** whether progression has been correctly applied in Noah's training program.

Question 3 (3 marks)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.7.b,c;* © ACHPER

Throughout August, during weeks 21–25 of her training program, Zara is training every day completing between 8–20 kilometres in each session. In her training diary, Zara's entries show she is struggling to run at the same intensity she had in prior weeks. Her sister Sarah says she is being lazy and she should train more. Conversely Laura, a work colleague of Zara's, suggests she should reduce her training.

a. Whose advice should Zara take? Circle the correct answer. **(1 mark)**

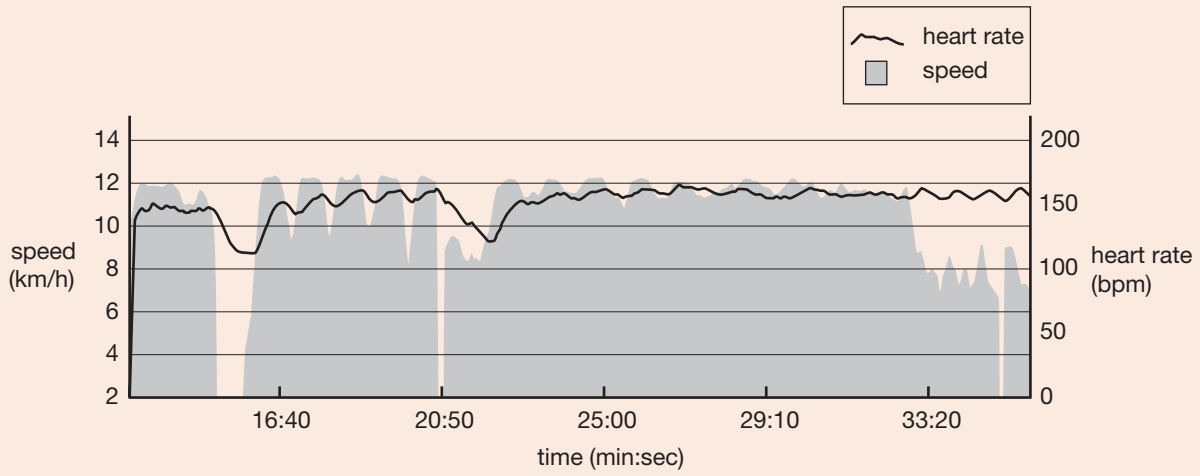
Sarah Laura

b. With reference to training principles, **describe** what might be causing Zara's loss of form. **(2 marks)**

Question 4 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section B, Q.11.d;* © VCAA

Personal fitness trackers have become popular as exercise prompts for individuals aiming to monitor adherence to Australia's Physical Activity and Sedentary Behaviour Guidelines. 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.



Suggest a suitable overload for this run session.

Question 5 (1 mark)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section B, Q.7;* © ACHPER

Each January many of Australia's elite distance runners spend three weeks at a summer training camp at Falls Creek in the Australian Alpine region. Falls Creek is situated at approximately 1 600 m above sea level.

Below is one week of training that a 5 000 m runner undertook. His personal best for this event is 14 minutes 10.22 seconds.

	Morning Session	Afternoon Session
Monday	– Easy 8 km run @ 70% Heart Rate Maximum (HR max)	– 12 km run @80% HR max
Tuesday	– Easy 8 km run @ 70% HR max	– 10 minute warm up @ 70% HR max – 2 × 3 × 1 000 m in 3 minutes @ 88% HR max with 3 minutes recovery between each repetition – 10 minute cool-down @ 60% HR max
Wednesday	– Rest	– 16 km run @ 80% HRM
Thursday	– Easy 8 km run @ 70% HR max	– 8 km run with random bursts of speed over varying distances @ 75–90% HR max
Friday	– Easy 12 km run @ 70% HR max	– Rest
Saturday	– 10 minute warm-up @ 70% HR max – 2 × 6 × 600 m 88% HR max in 90 seconds with 90 second recovery between each repetition – 10 minute cool-down @ 60% HR max	– Easy 5 km run @ 70% HR max
Sunday	– Easy 20 km run @ 70% HR max	– Rest

Apply correct overload to the Saturday morning session.

Sets	Repetitions	Distance	% HR max	Recovery
2	6	600	88% HR max	90 seconds

More exam questions are available in your learnON title.

12.5 Diminishing returns, detraining and maintenance

Key knowledge	Key skills
• training program principles including frequency, intensity, time/duration, type, progression, specificity, individuality, diminishing returns, variety, maintenance, tapering, overtraining and detraining	• evaluate and critique the effectiveness of different training programs • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.5.1 Diminishing returns

Fitness gains and improvements in performance occur most rapidly during the early stages of undertaking a training program, and smaller margins of improvement occur as a person nears their optimal level of fitness and performance.

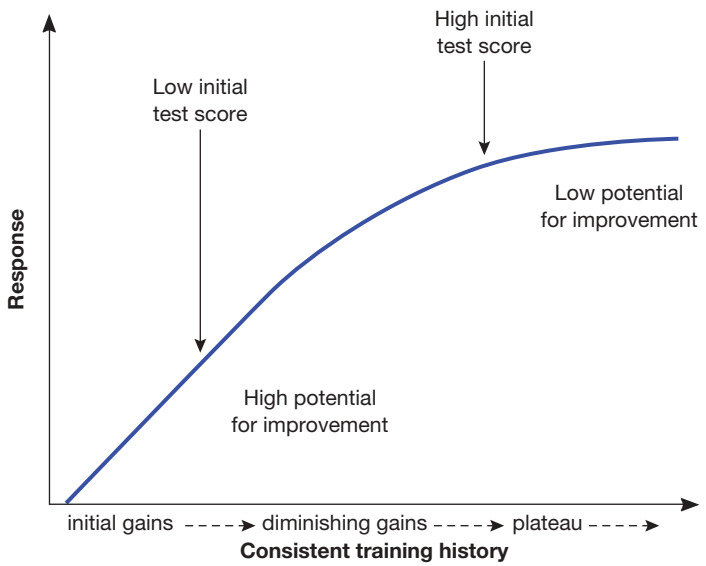
As an individual's fitness level increases, the rate of improvement lessens, thus creating **diminishing returns**. Someone who is unfit can make a large improvement in the first few weeks of a training program, while someone who is already fit can make only progressive, small gains despite training at a high level. An unfit older adolescent or adult sprinter who initially takes 18 seconds to sprint 100 metres may rapidly reduce their time to 14 seconds, but improvement from this point will take longer and be measured in tenths or hundredths of a second.

diminishing returns a principle that states that as a performer becomes more competent in their skill performance and progresses to the later stages of learning, there is a gradual reduction in the rate of improvement in skill performance in response to practice

The application of overload must be kept in perspective as an individual reaches peak levels of fitness. When the athlete's improvement begins to plateau, large or increasing amounts of overload may lead to injury or fatigue and loss of fitness.

The principle of diminishing returns suggests the rate of fitness gains diminishes over time as individuals approach their ultimate genetic potential (see figure 12.16). Simply stated, as fitness improves, continued levels of improvement cannot be expected. The fitter individuals are, the less likely they are to improve further.

FIGURE 12.16 Recent training history determines an individual's future responsiveness to physical training.



Although diminishing returns is inevitable when an athlete approaches their peak potential, they can mitigate the impact by:

- periodising the training program
- applying progressive overload
- including adequate rest and recovery
- incorporating a variety exercises and/or training methods.

It is important for athletes to understand the principle of diminishing returns so that they don't continue to overload when they experience a performance plateau and risk overtraining. They also need to make sure that they continued to incorporate adequate recovery.

12.5.2 Detraining

When training stops or is reduced, the reversal of fitness gains occurs much more quickly than the gains were achieved. The extent of performance loss is dependent upon the length of the **detraining** and the type of activity. Generally, aerobic endurance gains are lost quickly, in the first two to four weeks, while muscular strength degeneration tends to be much slower. Research has found that aerobic capacity declines between 4 and 20 per cent during the initial eight weeks of detraining (see figure 12.17) and the degree of **reversibility** tends to be greater in highly trained aerobic athletes.

detraining a period of time when training is ceased or there is a reduction in training load beyond what is required for fitness to be maintained

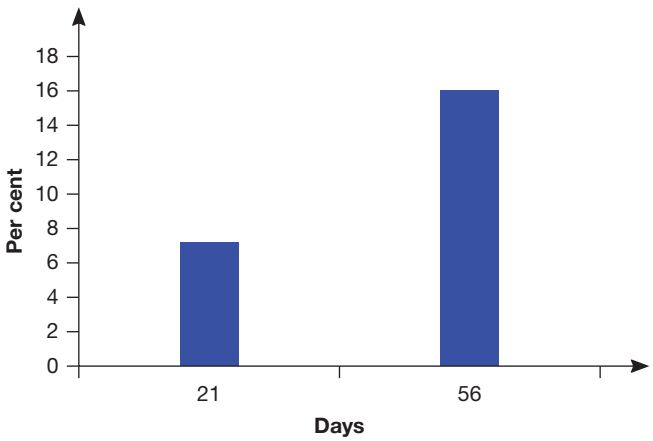
reversibility the fitness and/or performance loss after a period of detraining

The extent of decline in strength and power during a period of detraining is dependent upon training experience, the length of training time prior to detraining and specific muscle groups. Izquierdo and colleagues (2007) found a decrease of 6 per cent in squat strength and a decrease of 9 per cent in bench press strength following a four-week detraining period in athletes who had undertaken a 16-week resistance training program.

This principle suggests that the intensity and frequency of physical activity are critical determinants of both fitness maintenance and improvement. All the hard work put in over weeks of training to make measurable fitness gains can be easily reversed in just a couple of weeks.

It is important for athletes to be aware of the implications of detraining so that they can make informed decisions about their training program design. An injury or illness may force an athlete to decrease their training for a period of time. However, they may be able to continue to train at lower intensities or include resistance training. When ready, they should gradually return to pre-injury training levels by progressively overloading.

FIGURE 12.17 Loss of aerobic capacity is dependent on the duration of the detraining period.



EXAM TIP

Make sure you can explain the difference between diminishing returns and detraining. Remember, they have different causes.

12.5.3 Maintenance

Acquired fitness levels can be **maintenance** by carefully altering the FITT principle (Frequency, Intensity, Time, Type of exercise).

maintenance a principle that suggests that once a required level of fitness has been achieved, the level of effort to maintain that level of fitness is not as great as was required to achieve it

By maintaining the intensity of training and decreasing the volume or frequency of training, the athlete should maintain their fitness level. How much the training load is reduced will be different from one person to the next.

Generally, moving from a minimum of three quality training sessions per week to two should support the maintenance of an attained level of fitness.

The training intensity is vital for maintaining fitness and performance. The principle of detraining supports the saying 'use it or lose it'. Therefore, a strategic approach to training is necessary to maintain current fitness levels.

Athletes may choose to apply the principle of maintenance when their focus is on sustaining their current level of fitness, such as when they are transitioning from one season to another or when they have reached their peak performance levels and want to prevent overtraining.

EXAM TIP

A general rule for the maintenance principle is that intensity is maintained and the volume or frequency is reduced. Remember that a minimum of two sessions per week is required for maintenance.

12.5 Activity

12.5 Quick quiz on | **12.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4	6, 7, 8	3, 5

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TEST your understanding

1. **Outline** what other training principle is important to consider when a training program begins to show signs of diminishing returns.
2. **List** some strategies that a coach or athlete may use to mitigate the effects of diminishing returns.
3. **Explain** what *detraining* is.
4. **Identify** which of the FITT factors must stay the same if maintenance of training gains is desired.

APPLY your understanding

5. **Explain** the differences in the speed of reversibility of fitness gains from detraining between aerobic and anaerobic training programs.
6. **Discuss** how a training program can be adapted to delay detraining.
7. For the following training scenario, **suggest** ways to adjust the FITT factors to allow this athlete to achieve maintenance.

A pole vaulter: five sessions per week of two sets of 10 × 20-metre track sprints at 98 per cent MHR with 60 seconds of rest recovery between efforts and 10 minutes of walk recovery between sets.

8. **Discuss** how a trainer or coach prepares for the effects of the principle of diminishing returns in a training program.

12.5 Exam questions

Question 1 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section A, Q.8;* © VCAA

An untrained individual increases their aerobic capacity by 25% in the first three months of training. However, a further increase of only 15% is reported in the next nine months.

This is an example of

A. diminishing returns.
B. overtraining.
C. detraining.
D. duration.

Question 2 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section B, Q.2.a;* © VCAA

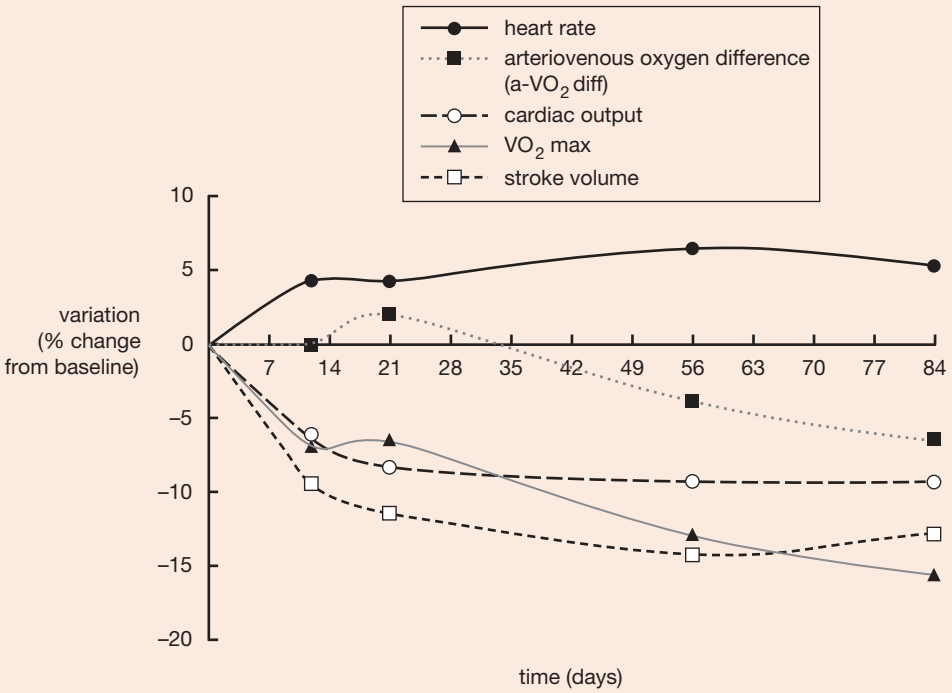
Samantha is a road cyclist who competes in races that can be up to 200 km long and take five hours to complete. Samantha suffered a knee injury and was unable to train for eight weeks.

State the training principle that would explain any changes to chronic adaptations resulting from Samantha being unable to train.

Question 3 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section B, Q.4.b;* © VCAA

The graph below shows the physiological changes the human body goes through after training has stopped for a period of time.



Source: L Bosquet & I Mujika 2012, 'Detraining', in I Mujika (ed.), *Endurance training: Science and practice*, Figure 10.1, p. 102

State the training principle shown in the graph above.

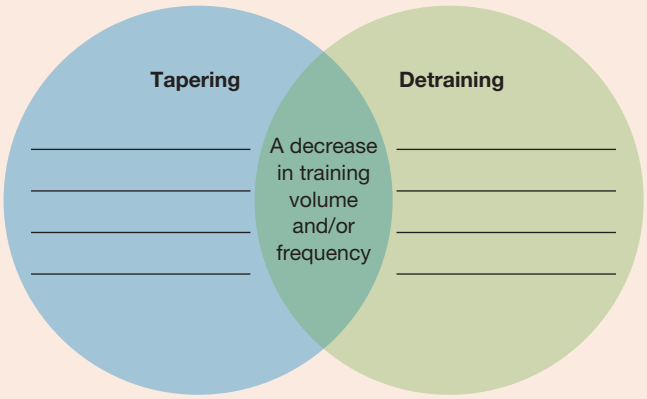
Question 4 (4 marks)

Source: *VCE 2006, Physical Education Sample Exam, Section B, Q.10.e;* © VCAA

Identify two physiological symptoms of overtraining and **two psychological** symptoms of overtraining.

Question 5 (2 marks)

Tapering and detraining may be demonstrated with a training program. Complete the Venn diagram below to **compare** and **contrast** tapering and detraining.



More exam questions are available in your learnON title.

12.6 Key skills

Key skills

- design a training program that demonstrates the correct application of training principles to enhance and/or maintain fitness components
- evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

12.6.1 Tell me

To address these key skills, it is important to:

- know how to correctly apply each of the training principles to each type of training method
- be able to evaluate and critique the principles of a training program
- know how to use different monitoring strategies to assess the effectiveness of the application of training program principles.

12.6.2 Show me

Practice question (4 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: *VCE 2022, Physical Education Exam, Section A, Q.4.c;* © VCAA

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, 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 1 RM)	Repetitions	Sets	Speed of contraction	Rest time
weighted squats	50% of 1 RM	3 reps	5 sets	as fast as possible	3 min rest between sets
dead lift	40% of 1 RM	6 reps	3 sets	as fast as possible	2 min rest between sets
kettle bell swings	30% of 1 RM	12 reps	3 sets	as fast as possible	1 min rest between sets

Note: 'reps' stands for 'repetitions'.

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. (4 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Discuss — present a clear, considered and balanced argument
  Recommend — put forward a suitable option
- **Key terminology** — *muscular power*, *rest day*, *errors*
- **Key concepts** — training program, training principles, conditioning phase
- **Marking scheme** — 4 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

The following training principles are used correctly in the volleyballer's training program to improve their *muscular power*.

Intensity — the *fast contraction speed* mimics the *explosive requirements* of *muscular power* and the load ranges given are suitable for *muscular power* in all three exercises.

Time — the three-minute *rest period* for weighted squats is suitable to *replenish energy*, as required for *muscular power movements*.

Specificity — the exercises selected *mimic* the movement patterns that would be required for *powerful jumps* in volleyball.

A possible **recommendation** is to *increase the rest time* for the dead lift and kettlebell swings to 3 minutes to ensure adequate recovery.

Award 1 mark for identifying intensity as one of the correctly applied training principles and stating how it improves muscular power.

Award 1 mark for identifying time as one of the correctly applied training principles and stating why it is required for muscular power movements.

Award 1 mark for identifying specificity as one of the correctly applied training principles and relating it to movement patterns.

Award 1 mark for making one recommendation to fix errors in the conditioning phase.

12.6.3 Let me do it

Question 1 (5 marks)

Source: Adapted from *VCE 2021, Physical Education Exam, Section A, Q.10.b;* © VCAA

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 per cent HR max is immediately followed by a burst of higher-intensity running for 90 seconds at an intensity of 90 per cent 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 fartlek training method in improving the AFLW midfield player's aerobic power. **Provide examples** from the session outlined in the table to support your response.

12.7 Review

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12.7.1 Summary

Specificity, intensity, type and individuality

- Specificity: training should replicate the requirements of the activity or sport and be relevant to the goals of the athlete.
- Intensity: a measure of how hard the athlete is working or the level of effort exerted during a training session.
- Individuality: catering for the specific needs, goals and abilities of the individual athlete, as the rate and amount of improvement varies from one individual to the next.

Time/duration, frequency and variety

- Time/duration: applies to the length of each activity within a training session, the length of the training session itself and the length of the overall training program.
- Frequency: the number of sessions trained per week with appropriate periods of rest.
- Variety: including a range of different activities, changing the order of exercises and changing the venue can all improve player motivation.

Progression, overtraining and tapering

- Progressive overload: the gradual increase of training levels (volume, intensity or frequency) so the body can adapt to higher levels of stress.
- Overtraining: a long-term decline in performance and physical functioning. The ability of the body to continue to adapt to the training load is compromised when overtraining symptoms occur.
- Tapering: a short-term reduction in training load to promote both physiological and psychological recovery.

Diminishing returns, detraining and maintenance

- Diminishing returns: the rate and amount of improvement reduces as fitness levels increase.
- Detraining: the loss of fitness increases as the period of time without training becomes greater.
- Maintenance: current levels of fitness can be maintained with less frequent training sessions (minimum of two per week) than are required to improve fitness, provided intensity levels remain the same.

12.7.2 Key terms

circuit training involves working at a variety of activity stations in sequence, training a number of fitness components at once
continuous training involves continuous activity that lasts a minimum of 20 minutes at the required intensity using the aerobic energy system. It is submaximal and requires an intensity of 70–85 per cent of maximum heart rate. Also known as long, slow distance training.
detraining a period of time when training is ceased or there is a reduction in training load beyond what is required for fitness to be maintained
diminishing returns a principle that states that as a performer becomes more competent in their skill performance and progresses to the later stages of learning, there is a gradual reduction in the rate of improvement in skill performance in response to practice

frequency the number of training sessions needed per week to ensure improvements are achieved in the desired fitness components and energy systems
heart rate reserve the difference between resting heart rate and maximum heart rate
individuality a principle that suggests that individual responses to physical activity are highly varied
intensity the exertion level or how hard the training is being performed. It is commonly measured as a percentage of maximum heart rate (MHR), which is determined by beats per minute (bpm).
interval training consists of repeated periods of work followed by periods of rest or recovery
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.
maintenance a principle that suggests that once a required level of fitness has been achieved, the level of effort to maintain that level of fitness is not as great as was required to achieve it
metabolic equivalents (METs) a system for classifying exercise intensity. 1 MET is equal to resting levels.
periodisation a systematic approach to training that involves dividing the training program into specific phases each with distinct goals, including the planned manipulation of training variables (volume, frequency and intensity)
repetition maximum (RM) the maximum amount of weight that a person can lift in one muscular contraction
resistance training training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance
reversibility the fitness and/or performance loss after a period of detraining
SAID stands for specific adaptations to imposed demands
specificity the process of replicating the characteristics of physical activity in training to ensure it benefits performance
time/duration the length of a training session, the length of a work interval within a training session and/or the length of the overall training program
training zone describes the intensity range that is required for specific adaptations to occur
variety providing different activities, formats and drills in training, while still addressing the aims of the training program. Its focus is to maintain the motivation levels of the performer and thereby optimise their fitness gains.
volume the amount of work performed during a specific period

12.7 Exam questions

12.7 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section A, Q.10;* © ACHPER

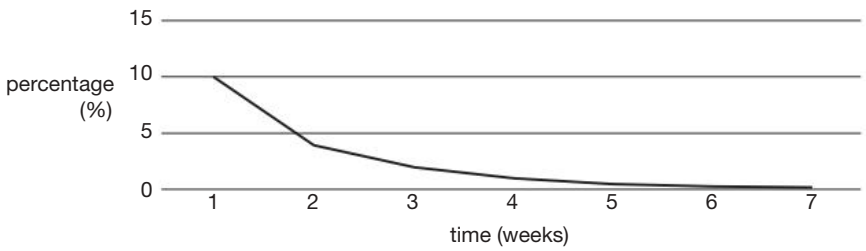
Physiological symptoms of overtraining may include

A. decreased concentration, coordination, and sensitivity to emotional stress.
B. decreased coordination, strength performance in power testing and increased morning resting heart rate.
C. increased chronic muscle soreness and irritability.
D. insomnia and decreased motivation levels.

Question 2 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.4;* © VCAA

The graph below shows the percentage of improvement on an agility test over seven weeks.



Which training principle is shown in the graph above?

A. progression
B. reversibility
C. diminishing returns
D. individuality

Question 3 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.4;* © VCAA

Following an athlete's competitive phase, they will be prescribed a training program by their fitness coaches. This training program is likely to contain less volume than the training program the athlete follows during their competitive phase, but it is of similar intensity.

Which one of the following training principles best relates to the information above?

A. diminishing returns
B. maintenance
C. individuality
D. variety

Question 4 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.11;* © VCAA

'The rate of fitness gains will decrease as an athlete gets closer to their genetic potential.'

Which training principle does this statement refer to?

A. detraining
B. progression
C. overtraining
D. diminishing returns

Question 5 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.5;* © VCAA

To maintain aerobic power, an athlete should train

A. once a week.
B. twice a week.
C. below 60% of their maximum heart rate.
D. above 85% of their maximum heart rate.

Question 6 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.10;* © VCAA

The estimated maximum heart rate of a 50-year-old athlete would be

A. 150 bpm.
B. 170 bpm.
C. 190 bpm.
D. 220 bpm.

Question 7 (1 mark)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section A, Q.9;* © ACHPER

Progressing an interval training session, while maintaining specificity, is best achieved by

A. increasing the number of sets or repetitions.
B. decreasing the rest between repetitions.
C. increasing the work time of each interval.
D. increasing the intensity of the work intervals.

Question 8 (1 mark)

Source: *ACHPER 2014, Trial Exam Units 3 & 4, Section A, Q.6;* © ACHPER

Georgina has been a member of the school's cross-country team, which has been training three times per week, for the past four months. During a physical education class, Georgina reached level 7.2 in the 20-metre shuttle run test while her friend, Paige reached level 6.1. Paige has never been involved in running and was invited to participate in cross-country training. Three months later, they both did a post-test where Georgina reached 7.5, but she was surprised that Paige reached 7.8 after only three months of training.

The training principle that best explains this situation is

A. reversibility.
B. detraining.
C. diminishing returns.
D. progression.

Question 9 (1 mark)

A chronic lack of motivation towards a training program could be attributed to the principle of:

A. detraining.
B. overtraining.
C. variety.
D. maintenance.

Question 10 (1 mark)

Which of the following best describes the FITT principle for maintaining acquired fitness levels?

A. Frequency, Intensity, Time, Type of exercise
B. Flexibility, Intensity, Type of exercise, Technique
C. Frequency, Intensity, Time, Training equipment
D. Frequency, Intermittent, Type of exercise, Target heart rate

12.7 Section B – Short answer questions

Question 1 (4 marks)

Source: Adapted from *ACHPER 2018, Trial Exam Units 3 & 4, Section B, Q.4;* © ACHPER

The data in the table below was collected from an activity analysis of a Year 12 student playing in an interschool basketball match which lasted for 40 minutes.

Work : rest data Work = sprint and stride Rest = jog, walk and standing still		**Movement patterns**	
Total work time	16 minutes 10 seconds	Forward movement	522 metres
Total rest time	23 minutes 50 seconds	Backward movement	112 metres
Longest work	43 seconds	Shuffle sideways	153 metres
Shortest work	1 seconds	Change of direction	222 times
Longest rest	3 minutes		
Shortest rest	2 seconds		
Movement intensity		**Skills**	
Sprint — maximal intensity	8 minutes 44 seconds	Overhead passes	35
Stride	4 minutes 15 seconds	Chest passes	12
Jog	12 minutes 20 seconds	Shoulder passes	38
Walk	5 minutes 40 seconds	Rebounds	23
Standing still	9 minutes	Lay ups	5
		Shots in key	9
		Shots outside key	5

a. **Identify** the training principle most dependent on the accurate collection of data from an activity analysis. **(1 mark)**

b. Using that data, **explain** how you would use this training principle when developing a training program. **(3 marks)**

Question 2 (6 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.7;* © ACHPER

Kaiwyn is a 20-year-old female who has decided to enter a 10 km fun run in six months' time. She has sourced various continuous running training programs from the internet. Kaiwyn also completes a 3 km time trial approximately every six weeks to measure her improvement. Her training is uninterrupted for the entirety of the program.

Kaiwyn's training program

Week	Heart rate training zone (bpm)	Session length	Sessions per week
1–3	140–145	30 minutes	3
4–6	145–150	30 minutes	3
7–9	150–155	35 minutes	3
10–12	155–160	40 minutes	4
13–15	160–165	40 minutes	4
16–18	160–165	45 minutes	4
19–21	165–170	50 minutes	5
22–24	165–170	55 minutes	6

Kaiwyn's 3 km time trial results

Immediately before commencing training program	15 minutes
After 6 weeks training	14 minutes
After 12 weeks training	13 min 30 sec
After 18 weeks training	13 min 15 sec
After 24 weeks training	13 min 45 sec

a. Referring to the training program information, **outline** two training principles which have been correctly applied in this training program. **(2 marks)**

b. Kaiwyn is disappointed with her time trial results after 18 weeks of training and believes increasing her training load should lead to greater improvements. She is even more disappointed with her time trial results after 24 weeks of training. She now complains of always feeling fatigued and continual muscle soreness.

With reference to the data provided, **discuss** two training principles which could explain Kaiwyn's results for these two retests. **(4 marks)**

Question 3 (3 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.1.b,c;* © VCAA

The 'Couch to 5K®' training app is designed to get sedentary people running 5 km over a nine-week training program.

Week 7 of the program

Workout 1	Workout 2	Workout 3
Brisk five-minute warm-up walk, then jog 4 km or jog for 25 minutes	Brisk five-minute warm-up walk, then jog 4 km or jog for 25 minutes	Brisk five-minute warm-up walk, then jog 4 km or jog for 25 minutes

a. Other than duration, **identify one** training principle shown in Week 7 of the program. **(1 mark)**

b. A coach advises Jordan that if he runs for 25 minutes every time he runs, he could overload his training program.
Explain how Jordan could overload his training program without any increase in run time per session. **(2 marks)**

Question 4 (4 marks)

Source: *ACHPER 2017, Trial Exam Units 3 & 4, Section B, Q.3.a;* © ACHPER

Georgette and Leah decide to enter the Sussan Women's 10 km fun run. Below is a typical week of then training program leading into the fun run.

One week typical training program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Jog 60 minutes	Swim 60 minutes	Strength training with a Personal Trainer (PT)	Jog 60 minutes	Cycle 60 minutes	Strength training with a PT	Jog 60 minutes

Using examples, **list** and **describe** two training principles evident in this training program.

Question 5 (6 marks)

Source: *ACHPER 2015, Trial Exam Units 3 & 4, Section B, Q.9.a;* © ACHPER

A year 11 Physical Education class at ACHPER Secondary College intends to complete the Great Victorian Bike Ride in 2015. They have entered the five day event which covers a total of 318 km.

Dining term 4, they intend to complete the following training program for the nine weeks leading up to the event. Training includes a mixture of lunchtime, afterschool and weekend cycling training.

Week	Tuesday	Wednesday	Saturday	Sunday	TOTAL
1	20 km cycle	Spin class 30 mins	40 km cycle	30 km cycle	90 km cycle
2	20 km cycle	Spin class 30 mins	45 km cycle	30 km cycle	95 km cycle
3	25 km cycle	Spin class 30 mins	45 km cycle	30 km cycle	100 km cycle
4	25 km cycle	Spin class 35 mins	50 km cycle	30 km cycle	105 km cycle
5	25 km cycle	Spin class 35 mins	55 kin cycle	30 km cycle	110 km cycle
6	25 km cycle	Spin class 35 mins	60 km cycle	30 km cycle	115 km cycle
7	25 km cycle	Spin class 40 mins	70 km cycle	30 km cycle	125 km cycle
8	25 km cycle	Spin class 40 mins	75 km cycle	30 km cycle	130 km cycle
9	20 km cycle	20 m SRT Test	30 km cycle	Rest	50 km cycle
10	Participate in Great Victorian Bike Ride				

Identify **three** training principles that have been applied correctly in the above program.

Use examples from the training program to support your answer.

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13 Training program methods

13.1 Overview

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LEARNING SEQUENCE

13.1 Overview
13.2 Continuous, fartlek and interval training
13.3 Weight/resistance and plyometrics training
13.4 Circuit training
13.5 Flexibility training
13.6 Key skills
13.7 Review

13.1.1 Introduction

Training methods are designed to achieve the specific chronic adaptations of the cardiovascular, respiratory and muscular systems that improve fitness and enhance performance for the chosen sport or activity. There are seven different training methods from which to select when designing a training program:

- continuous
- interval (short, intermediate, long and high-intensity)
- fartlek
- circuit
- weight/resistance (strength, power, endurance and hypertrophy)
- flexibility
- plyometrics.

FIGURE 13.1 The game of Sepak Takraw requires high levels of power and flexibility. These athletes would incorporate plyometrics and flexibility training into their training programs.



Each method is unique in how it enhances and/or maintains specific fitness components. A coach or athlete needs to be familiar with each type of training method to select and apply the most appropriate method/s to suit the needs of the athlete. The principle of specificity dictates which training method/s will be most appropriate, with the selection based on the data and fitness assessment analysis.

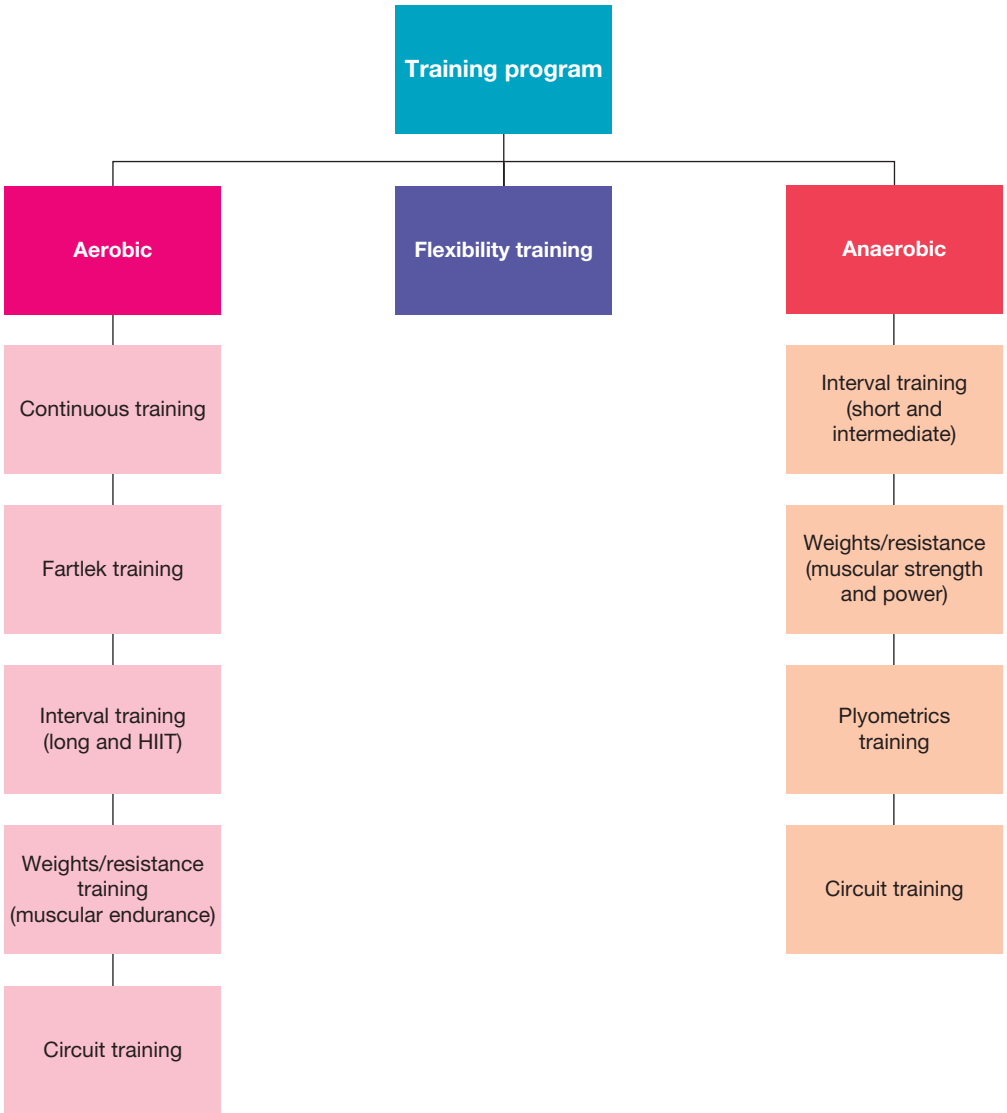
Aerobic training methods aim to enhance the aerobic energy system and the ability of the cardiovascular, respiratory and muscular systems to take up, transport and use oxygen more efficiently. Anaerobic training methods aim to enhance the aerobic energy systems' ability to produce power, strength and speed. An athlete may incorporate a variety of training methods as part of their training program.

13.1.2 Key knowledge and Key skills

Key knowledge	Key skills	Subtopic
• training methods including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics	• design a training program that demonstrates the correct application of training methods to enhance and/or maintain fitness components • analyse training data to identify and prescribe appropriate modifications to a training program • evaluate and critique the effectiveness of different training programs	**13.2** **13.3** **13.4** **13.5**

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13.1.3 Topic preview



13.2 Continuous, fartlek and interval training

Key knowledge	Key skills
• training methods, including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics	• design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components • analyse training data to identify and prescribe appropriate modifications to a training program • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

13.2.1 Continuous training

Continuous training leads to an improvement in aerobic power and local muscular endurance, and improves the **lactate inflection point (LIP)**. It is identified as the final exercise intensity or oxygen uptake value at which blood lactate concentration is relatively stable during a maximal aerobic test. It represents the maximal intensity an athlete can work at where blood lactate is in steady state. As a result of undertaking a continuous training method, athletes will be able to reach an aerobic steady state faster, accumulate lactate and H^+ ions more slowly and recover more quickly.

This type of training can be adapted to any activity that requires the use of the aerobic energy system as the main provider of ATP. It is not restricted to running; continuous training can also be applied to swimming, cycling, cross-country skiing and kayaking, for example:

- a 5-kilometre run
- a 500-metre swim
- a 20-kilometre bike ride
- a 5-kilometre cross-country skiing trip
- a 2-kilometre rowing session.

Continuous training is also sometimes used in team sports as a pre-season training method to establish a sound aerobic base from which athletes can improve their other fitness components, in the off-season for the purpose of maintaining their aerobic power and for recovery runs.

continuous training involves continuous activity that lasts a minimum of 20 minutes at the required intensity using the aerobic energy system. It is submaximal and requires an intensity of 70–85 per cent of maximum heart rate. Also known as long, slow distance training.

lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.

To gain the most out of continuous training, follow the **FITT** formula:

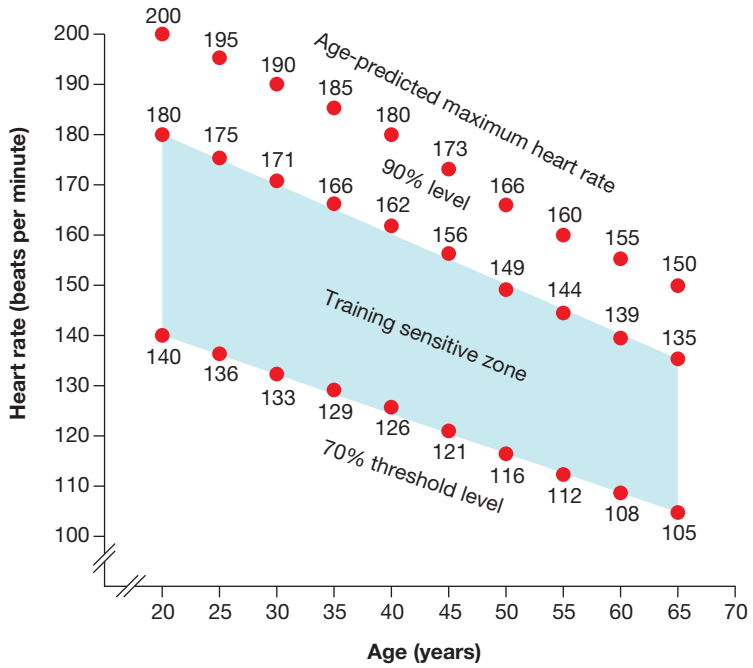
F	**Frequency**	(at least three sessions per week for aerobic improvement)
I	**Intensity**	(in the aerobic training zone between 70–85 per cent of maximum heart rate (MHR) as indicated in figure 13.2)
T	**Time**	(minimum of 20 minutes continuous activity is required)
T	**Type**	(whole-body activities that use large, major muscle groups, such as walking, running, cycling, rowing, swimming and aerobics).

All aspects of the FITT formula should be used.

Long, slow distance training is generally the most common and safest type of training adopted by recreational athletes to achieve health-related benefits.

Continuous training can also include high-intensity endurance training, performed at intensities of 85–95 per cent MHR. The purpose of high-intensity endurance training is to improve the athlete's lactate inflection point.

FIGURE 13.2 Target training zone for aerobic fitness improvement



13.2.2 Fartlek training

Fartlek training is a variation of continuous training that involves changes of intensity throughout the training sessions. These changes of intensity can be simply an increase in pace or running up a hill, which increases the contribution of the anaerobic glycolysis energy system to help produce the increased amount of ATP needed for the increased intensity. This stimulates the interplay between the aerobic and anaerobic energy systems used in individual sports (such as in sprinting, to gain a better position within the field of runners) and in team games (when involved in a sprint to the ball, followed by jogging to a new position on the field).

fartlek training a type of training that works both the aerobic and anaerobic energy systems by interspersing continuous low/medium-intensity efforts with high-intensity efforts

Fartlek training is continuous activity completed within the aerobic training zone (70–85% MHR) that alternates bursts of speed with moderate intensity activity.

The bursts of speed are completed at an intensity at the higher aspect of the aerobic training zone, close to the LIP (80–85% MHR), and the moderate intensity periods are completed at the lower aspect of the aerobic training zone (70–75% MHR). There are no 'rest' periods in fartlek training, and like in continuous training, the duration of the session should be at least 20 minutes to achieve aerobic adaptations.

Fartlek is mainly used by runners, but it is a highly adaptable type of training that can be applied to various forms of aerobic activity (see figure 13.3). It is equally useful for swimming, cycling, rowing, skiing and basically any sport, including team sports, where aerobic energy with bursts of anaerobic energy is important. Fartlek training can easily be designed to meet the specific needs of an activity.

FIGURE 13.3 Elite triathletes use various forms of fartlek training to optimise their tactical surges during races.



Ways to overload using fartlek training include:

- increasing the frequency of the high intensity efforts
- increasing the duration of the high intensity efforts
- increasing the overall distance covered
- including more hills and variety in terrain
- shortening the time to cover the same distance.

13.2.3 Interval training

Interval training consists of repeated periods of work followed by periods of rest or recovery.

interval training consists of repeated periods of work followed by periods of rest or recovery

Interval training is a versatile training method that can be tailored to the specific energy system needs. It requires careful planning, and several variables must be considered when planning both the initial exercise bout and the application of progressive overload (see table 13.1).

TABLE 13.1 Planning interval training

Variable	Description	Examples
Work interval distance	The distance of the work	60 metres
Work interval time	The time in which the work must be completed	8 seconds
Rest interval time	The time between work intervals	40 seconds
Rest interval type	The nature of the rest between work intervals (active or passive)	Walk
Work intensity	How hard the work is to be done (usually a percentage of the maximum heart rate)	90 per cent
Number of repetitions	The number of work periods in a sequence	6
Number of sets	The number of repetition sequences	3
Training frequency	The number of training sessions per week	3

Interval training and work-to-rest ratio

In planning interval training, a knowledge of the work-to-rest (W:R) ratio is important because this determines the setting of the variables. The work-to-rest ratio is established by analysing and breaking an activity into work and rest components. It indicates how much work is completed in an activity in proportion to how much rest is available.

An important fact to establish is what is classified as work and what is classified as rest.

Although work-to-rest ratios cannot be used in isolation to determine energy system usage, the following examples show the general relationship:

- A work-to-rest ratio of 1:5 and greater indicates that the ATP–CP energy system is the main contributor.
- A ratio of 1:3 suggests the anaerobic glycolysis energy system is the main contributor.
- A ratio of 1:1 indicates that the aerobic energy system is the main contributor.

Once the work-to-rest ratio is established for an activity, it can be replicated in the interval training program design (the principle of specificity). Examples of interval training for the three energy systems are outlined in table 13.2.

With sports science's understanding of the contribution of the energy systems to athletic performance, we now acknowledge that interval training can facilitate the development of all three energy systems, depending upon how the variables are manipulated.

TABLE 13.2 Interval training guidelines

	Short interval training	Intermediate interval training	Long interval training
Energy system	ATP–CP	Anaerobic glycolysis	Aerobic
Work interval time	3–10 seconds	10–60 seconds	60 seconds – 5 minutes
Work intensity	≥95% MHR (Maximal)	85–90% MHR	80–85% MHR (at or just below LIP)
Number of repetitions	6–15	6–10	2–4
Number of sets	3	2	2
Rest interval time	15–50 seconds	30–180 seconds	30 seconds – 5 minutes
Rest interval type	Passive	Passive	Active or passive
W:R ratio	1:5	1:3	1:1, 1:0, 2:1
Training frequency (per week)	3	3	4–5

Applying progressive overload to interval training

The training examples shown in table 13.2 could be overloaded by manipulating the following variables:

- work interval distance
- work interval time
- rest interval time
- rest interval type
- number of repetitions
- number of sets.

However, it is also important to maintain the original aim of training. Table 13.3 summarises the impact of variable manipulation when applying progressive overload with the aim of improving the capacity of the ATP–CP energy system.

TABLE 13.3 The impact of variable manipulation

Variable	Current training	Manipulation to cause overload	Impact
Work interval distance	100 metres	Longer	Increasing the distance too much may cause a reliance on the anaerobic glycolysis energy system as the major contributor.
Work interval time	15 seconds	Longer	Increasing the work time may increase the contribution of the anaerobic glycolysis energy system.
Rest interval time	75 seconds	Shorter	A work-to-rest ratio of less than 1:5 will result in less ATP resynthesis and a greater reliance on the anaerobic glycolysis system during the work periods.
Rest interval type	Rest	Slow jog	An active recovery is appropriate as long as the intensity of jogging remains low.
Number of repetitions	8	Increase	Appropriate, although too many repetitions may lead to gradual depletion of adenosine triphosphate and a greater reliance on the anaerobic glycolysis system.
Number of sets	2	Increase	May overload the training session too much.

Many team sport coaches adopt interval training as the most effective means of conditioning athletes. For example, Australian Rules football teams long ago moved away from an emphasis on continuous training to interval work because the work-to-rest relationship closely resembles that of the game situation.

High-intensity interval training (HIIT)

Long interval training has traditionally been the type of interval training adopted to improve aerobic power; however, **high-intensity interval training (HIIT)** is a very time-efficient training method to elicit chronic aerobic adaptations. HIIT involves repeated work intervals with sessions that are relatively brief in duration, performed at a high level of intensity close to VO_2 maximum. A single work interval may be a few seconds to several minutes in duration, separated by a short period of passive rest or low-intensity active recovery (refer to table 13.4).

high-intensity interval training (HIIT) involves repeated work intervals that are relatively brief in duration, performed at a high level of intensity close to VO_2 maximum, followed by less intense recovery/rest intervals

HITT training sessions can be designed in various ways to achieve aerobic adaptations; however, the Victorian Curriculum Authority suggests that the following principles of training are generally accepted for optimal improvements to occur.

Intensity

- Reach and sustain an intensity close to VO_2 max (90–100% MHR) per repetition.
- The accumulated duration of time spent at the intensity close to VO_2 max should not exceed several minutes across the training session.

Time

- The work time per repetition should be between 30 seconds and 4 minutes. A shorter work period may require more repetitions than a longer work period.
- The duration of a HIIT session may be less time than the accepted 20 minutes of other aerobic training methods due to the impact of the higher intensity.

Recovery

- The recovery periods can be either passive or active in nature. However, an active recovery should be performed at a low intensity of approximately 60% MHR.
- The type of recovery will determine the work periods. An individual may need to complete more repetitions if using a passive recovery than if they are using an active recovery, as an active recovery will allow the individual to reach close to their VO_2 max more quickly during each work period. The accumulation of the time spent close to VO_2 max is important.
- A work-to-rest ratio of between 1:1 and 2:1 is appropriate.

Research indicates that for athletes who already have a high level of aerobic capacity, further improvements are best obtained through HIIT. When compared with other volume-based aerobic training methods, HIIT induces similar chronic physiological adaptations with a lower time commitment.

FIGURE 13.4 HIIT training session on cycle ergometer



TABLE 13.4 Victorian Assessment Authority examples of accepted HIIT session protocols

	Frequency	Intensity	Type	Repetitions	Work period	Recovery period	Recovery type and intensity	Work-to-recovery ratio
Overview of accepted ranges	3 × week	• 90–100% VO_2 max • 90–100% HR max	Repetitive activity such as cycling or running	4–12	30 seconds – 4 minutes	30 seconds – 4 minutes	Passive (rest) or active recovery (~50% VO_2 max or 60% HR max)	1:1 or 2:1
Example 1 (Shorter work periods)	3 × week	• 90–100% VO_2 max • 90–100% HR max	Cycling or running	10	45 seconds	45 seconds	Passive (rest) or active recovery (~50% VO_2 max or 60% HR max)	1:1
Example 2 (Longer work periods)	3 × week	• 90–100% VO_2 max • 90–100% HR max	Cycling or running	4	2 minutes	60 seconds	Passive (rest) or active recovery (~50% VO_2 max or 60% HR max)	2:1
Example 3 (Active recovery)	3 × week	• 90–100% VO_2 max • 90–100% HR max	Cycling or running	10	30 seconds	30 seconds	Active recovery (~50% VO_2 max or 60% HR max)	1:1
Example 4 (Passive recovery)	3 × week	• 90–100% VO_2 max • 90–100% HR max	Cycling or running	12	30 seconds	30 seconds	Passive (rest)	1:1

HIIT has been found to be a very time-efficient training method that enables skeletal muscle adaptations similar to those achieved by other forms of endurance training. In as little as two weeks, including six sessions of HIIT of a total of only 12–15 minutes of maximum-intensity work per session can produce:

- increased skeletal muscle oxidative capacity in mitochondrial mass
- increased muscle buffering capacity
- increased resting muscle glycogen storage
- increased lactate tolerance
- a decreased rate of glycogen use
- decreased lactate production within the muscular system.

HIIT is also an effective training method that induces cardiovascular adaptations similar to other forms of aerobic training. This includes:

- increased stroke volume, maximal cardiac output, blood volume, capillarisation and arteriovenous oxygen difference (a-VO_2 diff)
- decreased resting and submaximal heart rates within the cardiovascular system.

These chronic adaptations (discussed in more detail in topic 14) result in an increased maximum oxygen consumption (VO_2 max) and an improved performance in aerobic type activities.

on Resources

Weblinks
- Fit in 6 minutes a week
- The benefits of high intensity training
- Runners treadmill HIIT workout
- Why should cyclists do HIIT?

doc-41977

PRACTICAL ACTIVITY Training methods and aerobic power

Goal

To be able to compare the continuous, long interval, fartlek and HIIT training methods for developing aerobic power.

Instructions

Divide the class into four groups and assign each group a training method to design and participate in.

- Group 1: Continuous training
- Group 2: Long interval training
- Group 3: Fartlek training
- Group 4: HIIT

Alternatively, if time permits, all students can participate in each training method (i.e. two methods each day, over two days).

Primary data/Reflection

- Gather feedback from the students in each group in relation to how they felt during the session and how hard they worked (their rate of perceived exertion (RPE)) using a scale from 1 to 10, where:
  1 to 3 = very light
  4 to 6 = somewhat hard
  7 to 8 = very hard
  9 to 10 = extremely strenuous
- You may also like to record the heart rate data of some of the participants undertaking each training method at similar intervals throughout the session.

	Continuous	Long interval	Fartlek	HIIT
Resting heart rate				
Exercise heart rate 1				
Exercise heart rate 2				
Exercise heart rate 3				
Exercise heart rate 4				
Exercise heart rate 5				
Recovery heart rate 1				
Recovery heart rate 1				
Recovery heart rate 1				

You may also like to graph the heart rate data.

- Use a training diary template to record any relevant physiological and psychological data.

Questions

1. Refer to the data to compare each of the aerobic training methods (continuous, long interval, fartlek and HIIT).
2. Using examples from the training method designs, explain how intensity and duration principles were implemented.
3. Outline how you could progressively overload each of these methods of training.
4. Explain how you would design a fartlek session to make it relevant to basketball.

EXAM TIP

Be able to compare and contrast continuous, fartlek and HIIT training for developing aerobic adaptations. Be able to justify when continuous, fartlek and HIIT training are best adopted.

13.2 Activity

13.2 Quick quiz on

13.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 5	6	2, 7, 8, 9

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TEST your understanding

1. **Define** the *continuous training* method.
2. **Explain** why continuous training is often the method of training used for improving aerobic power in recreational athletes.
3. **Outline** the best ways to manipulate the FITT principle to promote effective continuous training.
4. **Define** *interval training*.
5. **Outline** the recommendations in the variables associated with short, intermediate and long interval training.
6. **Reflect** on why it is beneficial to adopt HIIT as a method of improving aerobic power.

APPLY your understanding

7. a. **Describe** a scenario where continuous training would be the most appropriate method to include in a training program. Give reasons for your response.
   b. **Explain** why an endurance runner may incorporate Fartlek training into their training program planning.
8. a. Choose a particular case study and **design** an appropriate interval (short, intermediate, long or high-intensity) training program using the following variables:
   - work interval time
   - work intensity
   - number of reps
   - number of sets
   - rest/recovery time
   - work-to-rest ratio
   - frequency per week.

   b. **Justify** the selection of each of the variables for your training program design.
9. **Explain** some ways in which you could incorporate variety into continuous and interval training program design.

13.2 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section A, Q.9;* © ACHPER

Select the most appropriate training methods to improve a novice Year 7 student wanting to compete in the interschool 3 km cross country run.

A. swiss ball and muscular power
B. aerobic capacity and anaerobic capacity
C. fartlek and continuous
D. continuous and flexibility

Question 2 (5 marks)

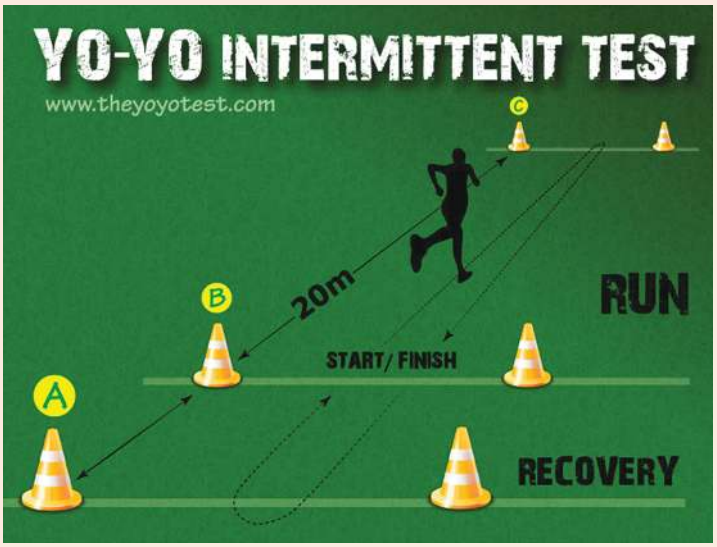
Source: *VCE 2022, Physical Education Exam, Section B, Q.6;* © VCAA

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: MS 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

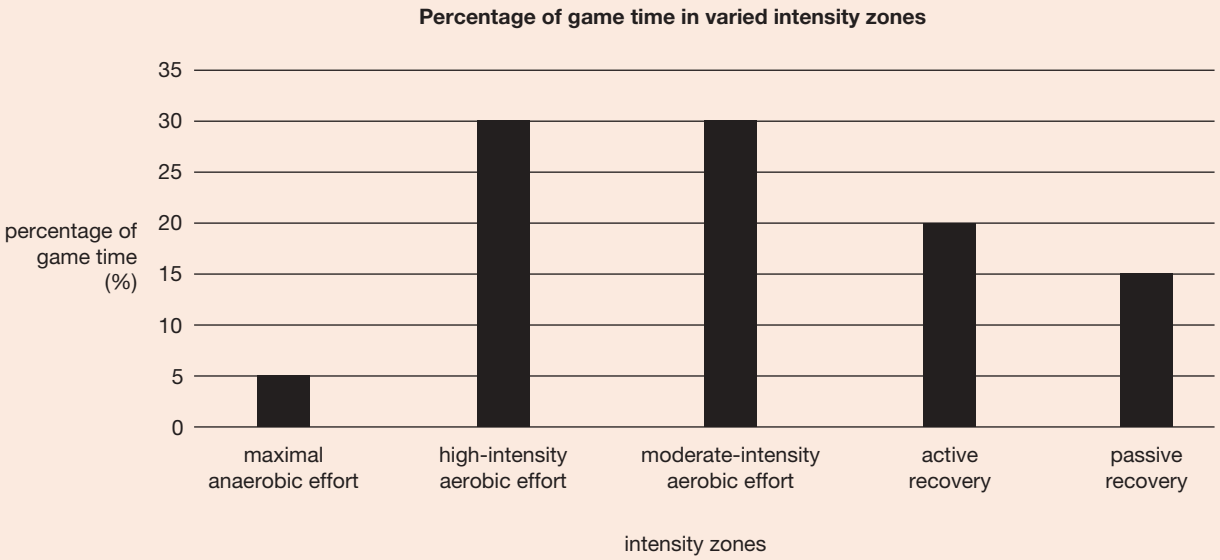
a. **Name** and **define** the fitness component that is assessed in the Yo-Yo intermittent recovery test. **(2 marks)**
b. One of the handball players scored 8.8 on the Yo-Yo intermittent recovery test. This was the lowest score for the team.
  i. **State** the minimum number of days per week this handball player will have to train to improve the fitness component identified in part a. **(1 mark)**
  ii. **List** two training methods this handball player could use to improve the fitness component identified in part a. **(2 marks)**

Question 3 (4 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.10;* © VCAA

During a soccer match, soccer referees cover significant ground to be able to best adjudicate the game. Following a soccer game in 33 °C heat, soccer referees undertake a rehydration protocol of 1.5 L of rehydration fluid per 1 kg of body weight lost.

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.

Question 4 (7 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.8.c–e;* © VCAA

a. The 100 m elite sprinters decided to complete a short interval training program. **Justify** the selection of this training method for 100 m elite sprinters. **(2 marks)**

b. **Design** a short interval training session for the elite sprinters using the following table. **(4 marks)**

Repetition time	Work-to-rest ratio	Intensity	Type of recovery

c. On the table below, **identify** with an **X** the days you would recommend the 100 m sprinters complete their short interval training program to improve their speed. **(1 mark)**

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday

Question 5 (5 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.2;* © VCAA

Samantha is a road cyclist who competes in races that can be up to 200 km long and take five hours to complete. Samantha suffered a knee injury and was unable to train for eight weeks.

Using the table below, **design** the conditioning phase of a high-intensity interval training (HIIT) session that Samantha could use to improve her cycling performance following her injury.

Type of training	Frequency per week	Intensity	Work period (time)	Recovery period (time)	Repetitions
cycling					

More exam questions are available in your learnON title.

13.3 Weight/resistance and plyometrics training

Key knowledge	Key skills
• training methods, including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics	• design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components • analyse training data to identify and prescribe appropriate modifications to a training program • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

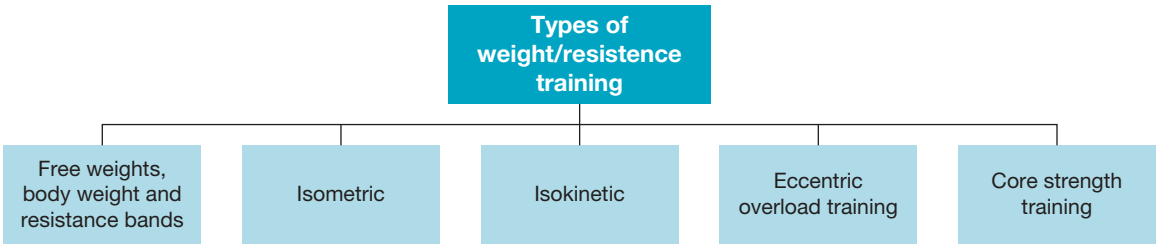
13.3.1 Weight/Resistance training

There are different ways to apply **weight/resistance training**:

- free weights, body weight and resistance bands
- isometric (static muscle contraction)
- isokinetic (variable resistance provided by a machine)
- eccentric overload training (flywheel and versapulley)
- core strength training (Pilates and gym ball).

weight/resistance training
training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance

Types of weight/resistance training



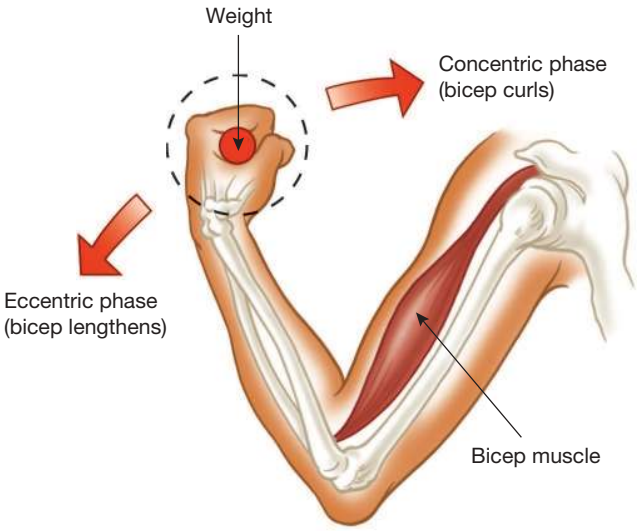
Free weights

The use of free weights is a traditional form of resistance training. Barbells, dumbbells and kettlebells, or resistance machines that use weight stacks for adjusting resistance are commonly incorporated into a weight/resistance-training program.

This type of training is dynamic and generally involves lifting a set weight through the range of motion of the joint. The muscle length and joint angle change through two distinct phases that can be completed independently of each other (see figure 13.5). These phases are:

- *the concentric phase*, where the muscle contracts against the force of gravity
- *the eccentric phase*, where the muscle lengthens under tension with the force of gravity.

FIGURE 13.5 Concentric and eccentric phases of the bicep curl



The criticism of this method has been that the maximum weight that can be used in free weights is that which can be lifted at the weakest points (the start and finish) of the range of motion. Muscle is not being trained by an appropriate resistance in the mid-section of the lift (approximately 115 degrees), which is the strongest point of the contraction. For example, when lifting the weight in a bicep curl, at the start of the exercise, the weight of the dumbbell must be overcome. Initially, the involved muscles contract isometrically in order to produce enough tension to begin to overcome the load of the dumbbell. As soon as the force produced by the muscle is greater than the resistance, the muscle contracts concentrically, and causes acceleration of the bicep curl exercise.

Body weight and resistance bands

Body weight resistance training uses the individual's own body weight as the resistance. No or minimal equipment is required. Examples of body weight exercises include abdominal curls, squats and push-ups. Resistance band training (see figure 13.6) uses elastic bands of various tension levels. Movements can incorporate multiple directions and be adapted easily for different exercises.

FIGURE 13.6 Resistance band training can be done anywhere, allows for movements to be changed and the resistance can be easily increased or decreased.



Isometric

Isometric resistance training involves holding the muscle in one position while it contracts against the resistance. Tension in the muscle increases, but the muscle stays the same length. Examples include pushing against a wall, performing a handstand and holding a crucifix (or iron cross) position on the Roman rings (see figure 13.7). This method is effective in increasing strength but only in the static position held, so it has minimal use in dynamic activities. If the arm, for example, is flexed at 90 degrees against an isometric resistance (see figure 13.8a), strength would improve for that position. Adjusting the flex to 120 degrees (see figure 13.8b) would produce an isometric strength gain for that position only.

FIGURE 13.7 The crucifix or iron cross is a men's gymnastics skill on the Roman rings.

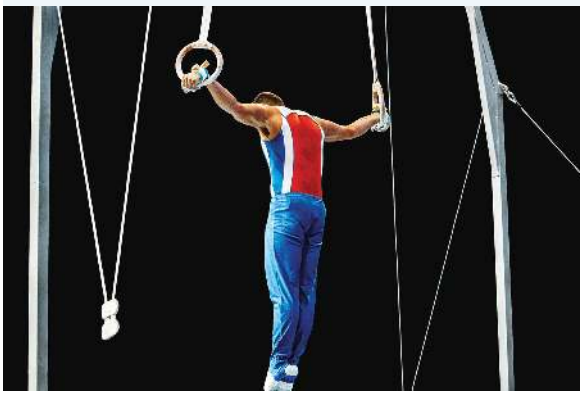
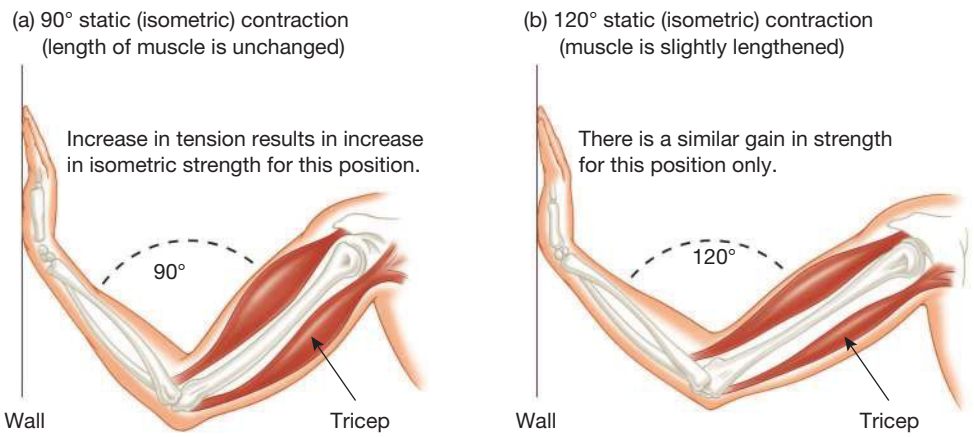


FIGURE 13.8 The impact of isometric training on muscular strength for the tricep is limited to the angle of joint flexion.



You may be surprised at how often the sport you play requires some form of isometric strength. Whether it is gripping a racquet, ball or opponent, or just holding a particular body position, these movements all require isometric strength. Specific sporting examples for which isometric strength is required and this form of training would be beneficial include:

- Olympic wrestling
- rugby scrums
- Australian Rules football tackling
- rock-climbing
- sports that require grip and strength to hold equipment.

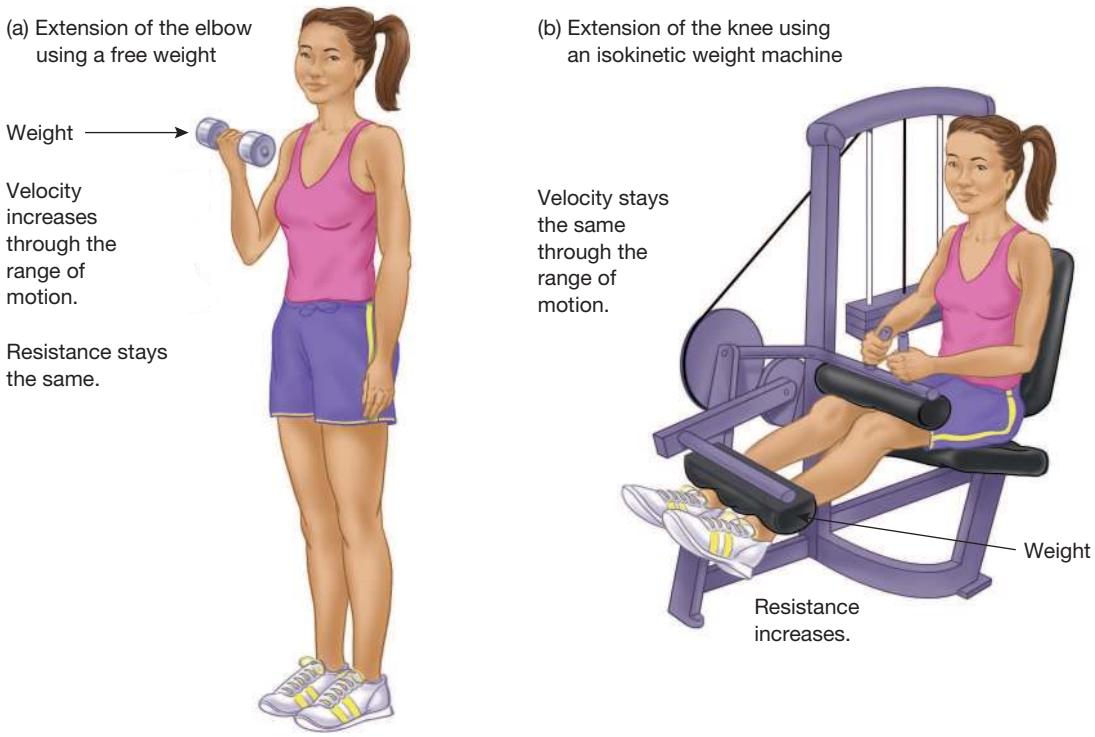
isometric a contraction in which the muscle length remains the same as it contracts under tension

Isokinetic

Isokinetic resistance training is undertaken using specialist machines, such as a Cybex, Kincom, Biodex or Hydragym, which can adjust the resistance as the body part moves through the range of motion (see figure 13.9). This allows the maximal amount of resistance to be provided through all joint angles.

Research shows that improvements in strength using isokinetic resistance training occur only at or below the velocity at which the resistance allows the joint to move. More advanced machines have adjustable resistance to allow higher velocity movements that result in greater benefits.

FIGURE 13.9 The difference between using free weights and specialist isokinetic machines for resistance training



Eccentric overload

Eccentric overload training is a form of dynamic resistance training that emphasises the eccentric phase of the muscle contraction. A resistance program that includes an emphasis on both eccentric and concentric contraction phases will maximise the gains in muscular strength and size. Flywheel and versapulley technology allow for an eccentric contraction overload as they work on the basis of inertia opposing the force exerted by the muscle rather than simply gravity (see figure 13.10).

Your muscles are generally stronger in the eccentric phase of contraction than in the concentric phase of contraction. In standard loading resistance training, the maximal load that can be lifted is limited by the concentric phase of contraction, and the eccentric phase of contraction is therefore underloaded. Eccentric overload training leads to greater neuromuscular and strength adaptations compared with standard loading.

FIGURE 13.10 Eccentric training with inertia opposing the contraction



eccentric a contraction in which the muscle lengthens as it contracts

Core strength training

The aim of core strength (or stability) training is to effectively use the trunk musculature and to control the position of the lower back (or lumbar spine) during sport or recreation-based movements. The major abdominal and hip area muscles are central in the active support of the lumbar spine. The teamwork of these muscles stabilises the lumbar spine and acts directly to resist all the forces acting on the lumbar spine. The strength and coordination of these muscles is significant in creating a safe, successful and enjoyable movement. Improving the muscular strength of the postural muscles will reduce the risk of injury and improve performance. The strength of the core muscles becomes very important when fatigue sets in and form needs to be maintained in order to execute skills well. Core strength exercises should target the abdominals, gluteals and lumbar extensors.

As with all fitness training, the training procedure for core strength must be specific to the task required. The deep-trunk muscles act as stabilisers and provide isometric strength of varying degrees during all movements. Some common core strength exercises are the plank, bridge and superman (see figure 13.11). Pilates, yoga and gym ball training all have a focus on strengthening core stability (see figure 13.12).

FIGURE 13.11 Core stability exercises can be performed with no or minimal equipment.



Plank



Side plank



Bridge



Superman

Core strength training should be undertaken 2–3 times per week and include rest days to allow muscle recovery. As core strength develops, the load can be gradually increased by increasing the number of repetitions, number of sets, difficulty of each exercise or frequency of training.

Core stability has become recognised as an important part of modern fitness training philosophies. It is used by almost all elite sporting teams and individuals to increase total body stability during competition.

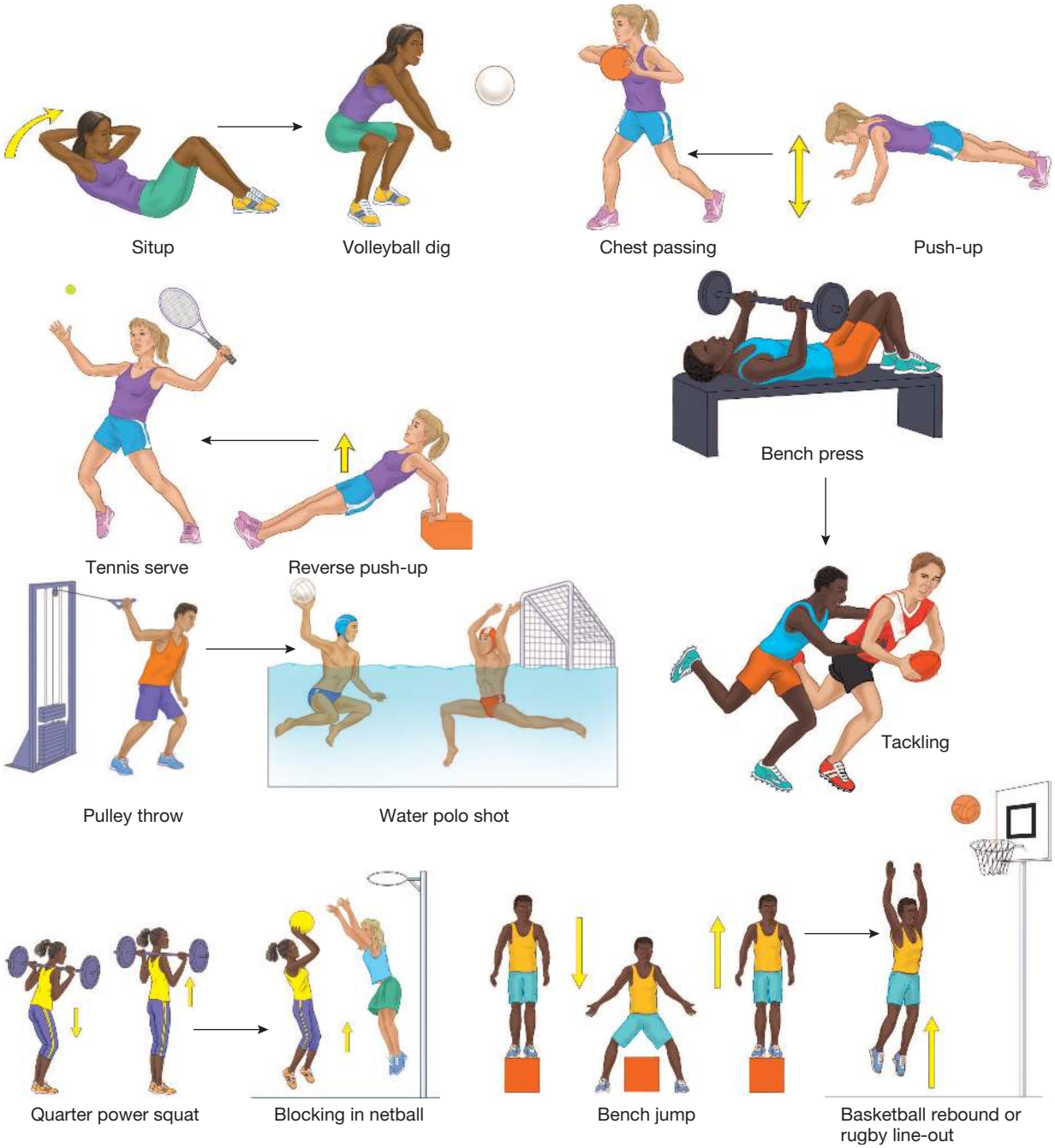
FIGURE 13.12 Core strength training with the assistance of a gym ball



Specificity in weight/resistance training

One of the main reasons that weight/resistance training is central to just about all sports training is that its movements can be designed to mimic most sporting actions (see figure 13.13). This means that the muscles used in a movement, the energy systems employed in that movement, the angles of joint movement used and the force required for the movement can generally be replicated in a weight/resistance-training exercise.

FIGURE 13.13 The selection of weight/resistance-training exercises should be based on the specific actions required for the sport or activity being trained for.



Some examples of this specificity are:

- bicep curls for handballs in Australian Rules football
- flies for tackling
- bench presses for netball or basketball chest passes
- quarter squats for basketball rebounds, long jump take-offs, sprint starts
- calf raises for running
- tricep extensions for throwing
- sitting leg extensions for kicking in Australian Rules football
- various pulley resistance exercises for hockey long hits, groin strengthening work for specific throwing movements to avoid osteitis pubis.

on Resources

eLesson Resistance training basics (eles-0509)

Weight/resistance-training terminology

The language of weight/resistance training is important, both for understanding this type of training and for applying it to your own training. Definitions for the variables used in weight/resistance training are provided in table 13.5.

TABLE 13.5 Definitions of variables in weight/resistance training

Variable	Definition
Repetition	A single effort or performance of an exercise
Repetition maximum (1 RM)	The heaviest load that can be successfully completed in one contraction
Set range	The number of exercise repetitions performed in a sequence without rest
Resistance or load	The weight that must be moved in the exercise or effort
Tempo/contraction speed	The velocity at which a muscle contracts

Weight/resistance-training principles

The principles of training that are most important in weight/resistance training are as follows:

Principles	Description
Specificity	Targeting the relevant muscle groups is the first consideration of any weight/resistance-training program.
Overload	The variables (as defined in table 13.5) are gradually overloaded. There are no set rules as to which variable is more appropriate to overload because research on this topic remains inconclusive. However, it is important to remember that overloading too little is much safer than overloading too much.
Frequency	The frequency of training should be 1–3 times per week, depending on other training methods being used, recovery strategies and level of desired performance.
Duration	The duration of the program should be a minimum of six weeks to obtain significant gains.
Order	The exercises within the weight/resistance program should be ordered in a way that does not use the same muscle or muscle group twice in a row. Cycling of muscle or muscle groups is required to avoid excessive stress on the muscles and allow recovery.
Purpose	When devising a weight/resistance-training program, first decide on the aim of your program. Is it to develop muscular strength, muscular power or muscular endurance?

Only one fitness component can be developed at a time. They should also be developed in the following order:

1. muscular endurance
2. muscle size
3. strength
4. power.

In order to develop a strength or power weights program, weight training should be carried out in phases. This means that endurance must be developed in the muscle before you progress to the next phase.

There has been much discussion and difference of opinion on the most appropriate number of sets, weights and repetitions to maximise strength, power or local muscular endurance. Traditionally, high weights and low repetitions equated to strength training, while higher repetitions and lower weights equated to muscular endurance training. There is also no doubt that a program designed for strength will indirectly help to improve muscular endurance and power, and vice versa.

Table 13.6 outlines the recommended variables guidelines for improving local muscular endurance, strength and power.

TABLE 13.6 Weight/resistance-training variables guidelines

	Muscular strength	Muscular power	Local muscular endurance
Frequency	3–4/week	2–4/week	3–4/week
Intensity (Load) — Repetition Max (RM)	80–100% 1 RM	30–70% 1 RM	40–60% 1 RM
Repetition range	1–6	3–10	15–25
Set range	3–6	3–6	3–6
Tempo/contraction speed	slow	as fast as possible	moderate
Rest	2–3 minutes	2–3 minutes	1 minute

Note: A beginner athlete who has done little resistance training should start at the lower end of the prescribed range, whereas a more highly trained athlete might need to start their program towards the upper end of the prescribed range.

The differentiating factors between the types of resistance training can be summarised as follows.

- Muscular strength — high load (% 1 RM) and low volume (reps)
- Muscular power — moderate load (% 1 RM) with fast contraction speed
- Local muscular endurance — low load (% RM) and high volume (reps).

on Resources

Interactivity Resistance training variables (int-xxxx)

Guidelines for safe weight/resistance training

When developing a weight/resistance-training program, it is necessary to consider the following general guidelines.

BASIC GUIDELINES FOR WEIGHT TRAINING

- Always properly warm up and cool down the muscles that are used in each resistance training session.
- Make sure that you concentrate on performing each exercise using correct body posture and complete each range of movement smoothly so as to avoid injury and prevent the development of bad habits.
- Stay in control of the movement and work at a good tempo.
- It is best to start a program with lower weights and higher repetitions.
- Think about your breathing technique. Exhale as you work against the resistance and inhale as you are releasing the resistance.
- Try to work different muscle groups with sequential exercises.
- Gradually increase the load by between 2 per cent and 10 per cent when you can comfortably perform the current workload over two consecutive training sessions. This helps to avoid overtraining. Remember that you should be able to do all the repetitions using good form and the muscles should feel tired by the last two repetitions.

- Train the larger muscle groups first, progressively working towards training the smaller muscle groups in one session, and ensure exercises targeting core strength are completed towards the end of the session.
- Ensure adequate rest and recovery of the muscles between training sessions. Strength training causes tiny tears in muscle tissue, which is important for achieving anabolic adaptations during recovery. Your muscles should have at least 48 hours to recover between each strength training session.
- Use a spotter for free weight activities such as squats and bench presses.

13.3.2 Plyometrics training

Plyometrics is an excellent way for conditioned athletes to increase and develop their force production, velocity and power output.

It is also known as depth jumping or rebounding, in which an eccentric contraction is immediately followed by a concentric contraction.

The eccentric stretching of the muscle prior to the rapid concentric contraction allows for a more forceful contraction, recruiting more motor units than if no pre-stretch occurred. During the eccentric phase, **potential energy** is stored in the elasticity of the muscle and then released at the start of the concentric phase of contraction.

Think of an elastic band: the elastic proteins of a muscle fibre act in a similar manner as an elastic band when it is stretched and released. There are three phases of plyometrics:

FIGURE 13.14 This athlete is combining higher-level impact plyometric jumps followed by lower-level impact plyometric jumps as defined by the height of the hurdles.



1. The eccentric pre-stretch phase	during this phase, the muscles are stretched rapidly, which activates the **stretch reflex** causing a powerful concentric contraction to protect the muscle from overstretching.
2. The amortisation phase	the very short phase between the eccentric and concentric contraction.
3. The concentric shortening phase	during this phase, the muscles contract forcefully with assistance from the stored potential energy (elastic energy) gained from the eccentric and amortisation phases.

Plyometric actions occur in many sporting activities. Leg muscles in each running stride are actually performing plyometrics as each leg lands on the running surface.

A baseball player must first swing the bat back, stretching the muscle, before contracting the muscle to hit the ball. If the player stops in the back swing or simply swings at the ball without a back swing, they either lose power or do not even generate it.

Because plyometric exercises can create so much muscular power, there is understandable concern about their safety and appropriateness. They place considerable pressures on both the body and joints and are not recommended for persons of poor or average fitness abilities. Table 13.7 outlines the different stress levels and recovery times for various plyometric exercises.

plyometrics involves the use of the stretch-shortening muscle cycle to produce powerful and explosive movements

potential energy the capacity of the muscle to do work based on its position. This happens in the eccentric phase of contraction. The greater the stretch, the greater the capacity of the concentric muscle contraction.

stretch reflex occurs when an impulse is immediately sent to the spinal cord for a muscle to contract when it is stretched, to prevent overstretching

An athlete's number of training years is important. Those with little foundation training should start with low-stress or low-impact activities, which have low demand on the nervous system and low motor complexity.

TABLE 13.7 The impact of varying intensity plyometric training programs

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; one day required	Tuck jump or other similar activity in place of jumps
3 = moderate stress	One to two days required	Stair jumps or other similar short jumps
4 = high stress	Recovery slow; two days required	Hops or bounds for distance or other similar long jumps
5 = very high stress	Recovery very slow; three days required Highest nervous system demand	Depth jumps or other similar shock-type jumps

Source: V Gambetta, 'Plyometrics: myths and misconceptions', *Sport Coach*, Summer, 1998, p. 7

Plyometric training recommendations

1. An adequate warm up must be performed, consisting of general aerobic activities progressively increasing in intensity and including dynamic flexibility.
2. The development of a good strength base should precede plyometric training.
3. Begin with low to moderate level plyometric exercises and progress to higher levels when sufficient strength and power have been developed (see figure 13.15).
4. Plyometric exercises should be performed in a controlled manner using good postural technique.
5. Footwear that has good ankle and foot support is recommended.
6. Plyometric exercises should be undertaken on shock-absorbing surfaces.
7. Plyometric exercises should be undertaken early in a training session so that the exercises are not being performed when the person is fatigued.
8. There should be at least 48 hours recovery between each plyometric session and a maximum of two sessions per week for beginners. (For variables guidelines, see table 13.8.)

Low-impact vs high-impact plyometric exercises

Examples of low-stress or low-impact plyometric drills are:

- skipping with and without a rope
- doing low hops, steps and jumps
- throwing light objects such as cricket balls and frisbees
- throwing a light (2.5 kilogram) medicine ball
- jumping 360 degrees.

The height for low-impact exercises is 25 centimetres or less, and the beginner should start with repetitions of 10 × 1–5 sets. The appropriate rest and recovery time between sets is 3 minutes.

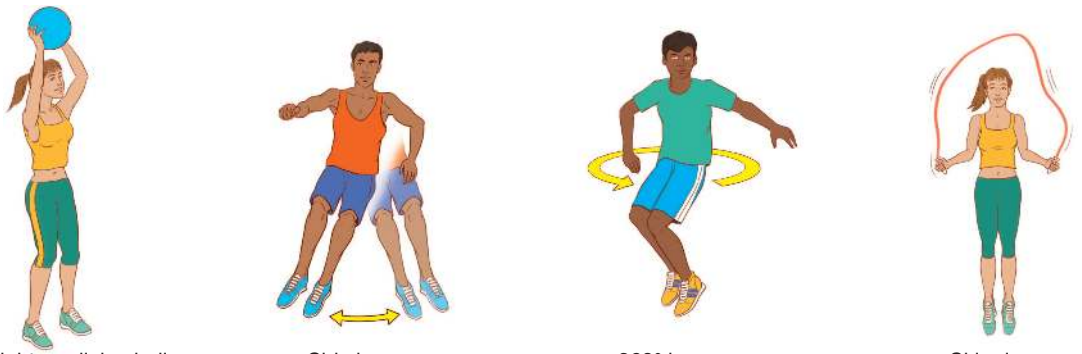
Examples of high-stress or high-impact plyometric drills are:

- bounding with alternate legs
- bounding with both legs
- speed hopping on a single leg
- doing clap push-ups
- jumping over, on and from benches that are 35 centimetres high
- triple jumping
- throwing a heavy medicine ball (above 4 kilograms).

The height for high-impact exercises is 35 centimetres and above, and the athlete should perform repetitions of 10–20 × 1–5 sets. The appropriate rest and recovery time between sets is 10 minutes.

FIGURE 13.15 Plyometric exercises

(a) Low-impact plyometric drills



Light medicine ball throw and catch

Side jumps

360° jumps

Skipping



Single leg low hops



Side steps



Squat jumps



Box jumps

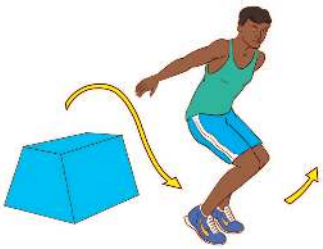
(b) High-impact plyometric drills



Alternate leg bounding



Double leg tuck jumps



Reactive/depth jumps



Speed hops

on Resources

Interactivity Plyometric exercises (int-6825)

TABLE 13.8 Plyometrics training variables guidelines

Variable	Recommendations
Intensity — amount of ground reaction force and rate of force development (RFD)	Start with low impact exercises (≤25 cm height) and progress to high impact exercises (≥35 cm height) when sufficient strength and power have been developed (increase by 10 per cent)
Volume (number of ground contacts per session)	Beginner: 60 ground contacts Intermediate: 80–100 ground contacts Advanced: 120+ ground contacts
Type of exercise	Bilateral before progressing to unilateral
Repetitions	Beginner: low impact, 10 Advanced: high impact, 10–20
Sets	Beginner: low impact, 1–5 Advanced: high impact, 1–5
Rest/recovery between sets	Beginner: low impact, 1–4 minutes between sets Advanced: high impact, 4–10 minutes between sets
Frequency of training	1–2 days per week
Recovery between training sessions	High intensity session: 48–72 hours Low intensity session: 24 hours
Duration of training program	7–12 weeks

doc-41978

PRACTICAL ACTIVITY Weight/Resistance training and specificity

Goal

To be able to consider the principle of specificity when designing a weight/resistance-training session.

Instructions

1. Design a resistance training session that is appropriate for a particular sport or activity and guide your class group through the session.
2. Make sure that your session includes the appropriate variables that are required to train strength, power or endurance and that you target your session at a level that is suitable for all participants.

Primary data/Reflection

	Exercise 1	Exercise 2	Exercise 3	Exercise 4	Exercise 5	Exercise 6
Intensity (Load) - Repetition Max (RM)						
Repetition range						
Set range						
Rest						
Tempo/ contraction speed						
Frequency						

- Use a training diary template and/or interview the participants to record any relevant physiological and psychological data for the session.

Questions

1. With reference to the sport of your choice, justify the type of weight/resistance-training program you selected.
2. Discuss the reason for the choice of exercises you included in the design of the session.
3. Compare and contrast your selected weight/resistance-training session design with another type of weight/resistance-training program design.
4. Evaluate the effectiveness of the session based on the participants' physiological and psychological feedback.

doc-41979

PRACTICAL ACTIVITY Plyometrics and specificity

Goal

To be able to consider the principle of specificity when designing a safe and effective plyometrics training session.

Instructions

1. Design a safe and effective plyometric training session for a sport of your choice, for your class to undertake.
2. Your training session template needs to include an appropriate warm up, four plyometric exercises that are suitable for your class group (2 upper body and 2 lower body) and an adequate cool down.

Primary data/Reflection

	Exercise diagram/explanation	Intensity (low, medium, high)	Volume/reps	Sets	Rest between sets
Exercise 1 (upper body)					
Exercise 2 (upper body)					
Exercise 3 (lower body)					
Exercise 4 (lower body)					

- Interview the participants to record any relevant physiological and psychological feedback from the session.

Questions

1. Outline how you designed a safe plyometric session.
2. Provide a justification for your selection of plyometric activities.
3. Using the data from the participants' physiological and psychological feedback, discuss the effectiveness of the plyometric session.

13.3 Activity

13.3 Quick quiz on | **13.3 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4	2, 9, 11, 13	5, 6, 7, 8, 10, 12

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TEST your understanding

1. **Define** *resistance training*.
2. **Summarise** the difference between strength, power and endurance types of weight/resistance training.
3. **Describe** isometric resistance training.
4. **Provide** three recommendations suitable for an individual who is just starting a weight/resistance-training program.
5. **Explain** the stretch reflex and how it applies to plyometrics training.

APPLY your understanding

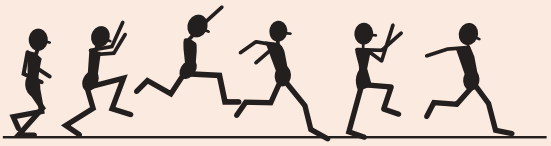
6. **List** some specific sporting examples of movements that would benefit from isometric resistance training. **Justify** your choices.
7. **Explain** the value of isokinetic resistance training machines.

8. **Explain** why core stability training is important.
9. **Discuss** the benefit of incorporating eccentric overload training into a resistance program.
10. With reference to a sport or activity of your choice, **explain** whether you would select to train for strength, power or endurance. Justify your selection with examples.
11. **Discuss** the importance of three plyometrics training recommendations.
12. **Identify** and **justify** five plyometrics training exercises for a sport of your choice.
13. **Compare** and **contrast** plyometrics training for beginner and advanced level athletes.

13.3 Exam questions

Question1 (5 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.2.b–d;* © VCAA

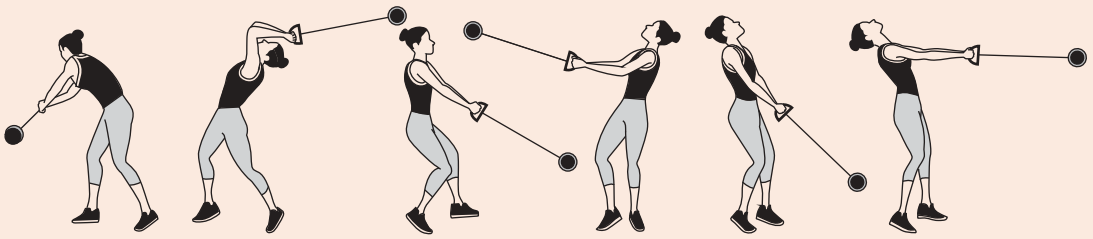


single leg hops

a. Other than strength, **state** one fitness component this type of training will develop. **(1 mark)**
b. **Describe** the stretch-shortening cycle that occurs in this type of training. **(2 marks)**
c. **List two** safety considerations an athlete or a coach may need to keep in mind before undertaking this type of training. **(2 marks)**

Question 2 (5 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.2;* © VCAA



The diagram above shows the sequence for a hammer throw. Flexibility is an important fitness component in hammer throwing.

a. Plyometrics is often used as a training method for the hammer throw.
   i. In the table below, **design** a plyometrics training session for the hammer throw. Include two exercises in the conditioning phase. You may use diagrams to **explain** the exercises. **(4 marks)**

Warm-up	Conditioning phase	Cool-down
	1.	
	2.	

   ii. **Give one example** of how progression could be applied to the conditioning phase of the plyometrics training session designed in **part a.i**. **(1 mark)**

Question 3 (1 mark)

Source: *ACHPER 2014, Trial Exam Units 3 & 4, Section B, Q.5;* © ACHPER

Research has proven that resistance training is an effective training method to use in order to increase muscular strength. **Complete** the table below to show an appropriate overload for a leg press exercise in a resistance training program for an elite athlete.

Exercise	Repetition Maximum (RM)	Number of repetitions	Number of sets	Duration of rest
Leg press	80% RM	5	6	2 minutes
Overload			6	

Question 4 (2 marks)

Source: *ACHPER 2014, Trial Exam Units 3 & 4, Section A, Q.14.b;* © ACHPER

Plyometric training can improve muscular power and is a suitable training method for volleyball. The senior girls' volleyball team at a local secondary college has made it to the state finals and the coach wants to prescribe plyometric training for the team.

Outline two guidelines for plyometric training that a coach should follow.

Question 5 (4 marks)

Source: *ACHPER 2010, Trial Exam Units 3 & 4, Section B, Q.9;* © ACHPER

The following program is being performed by a beginner trying to improve the muscular power of their legs.

Exercise	1 RM max (kgs)	Weight to lift	Sets	Reps	Rest	Speed of contraction
Squat	50	15–30	3	4	1 min	As fast as possible
Leg press	50	25	6	4	2 mins	As fast as possible
Bent knee deadlifts	30	9–18	3	6	3 mins	As fast as possible
Leg extension	25	20	2	8	2 mins	As fast as possible
Leg curl	25	15	2	6	2 mins	As fast as possible

a. **Outline** two errors in the above program. **(2 marks)**
b. For each error identified in **part a**, **suggest** a modification that will enable the exercise to meet the intended aim of the program. **(2 marks)**

More exam questions are available in your learnON title.

13.4 Circuit training

Key knowledge	Key skills
• training methods, including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics	• design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components • analyse training data to identify and prescribe appropriate modifications to a training program • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

13.4.1 Circuit training

Training methods include **circuit training**. Circuit training can have 5–15 stations that focus on specific components of fitness from the selected activity. An athlete can plan to train any of the fitness components in a circuit training session. Circuit training is a very versatile training method as it can be planned with minimal use of equipment, be performed indoors or outdoors and target a variety of aspects that are relevant to the activity or sport for which a person is training.

circuit training involves working at a variety of activity stations in sequence, training a number of fitness components at once

In circuit training the athlete completes one set of exercises and then moves on to the next. When the athlete has completed each exercise station once, they have completed one lap of the circuit.

Exercise stations should be arranged so that body parts are cycled or distributed. One body part should not be repeated twice in a row. For example, a leg station such as step-ups could be followed by sit-ups. This allows for specific muscle group recovery to take place.

Circuits also allow for specific skill drills to be included as exercise stations. In this way, both the physical and skill requirements of the sport are being specifically trained at the one time. For example, a field-hockey player could include push passes against a rebound wall or to a teammate as an exercise station.

The circuit can also be designed to focus on general aerobic fitness. This type of training allows a large number of participants to work in a confined area with minimal equipment, so it is inexpensive and efficient. Each training session should be designed to reflect the energy systems, muscle groups, fitness components and fatiguing factors of the game or activity.

13.4.2 Types of circuit training

Fixed time

- Each person completes as many repetitions of an exercise as they can at each station in an allocated time (30–60 seconds) (see figure 13.16).
- Work-to-rest (W:R) ratios are designed in relation to the requirements of the activity or sport.
- Easy to administer to large groups as everyone moves from station to station at the same time.

FIGURE 13.16 An example of a fixed time circuit where each person completes as many repetitions of an exercise as possible in an allocated time



Fixed load

- Each person completes a predetermined number of repetitions at each station.
- Individual strengths and weaknesses are not taken into account.
- Each person will complete each station at a different time, which is impractical for large groups.

Individual load

- Each person will have undertaken a pre-test to determine the maximum number of repetitions that can be performed in 60 seconds at each station and then work at a percentage of these repetitions.
- Each person will be completing different repetitions, so it is likely that some wait time will be experienced between stations.
- Individualised to each person's strengths and weaknesses.

Overload implementation

Overload implementation in circuit training can be done by:

- increasing the repetitions
- increasing the number of circuits
- increasing the weights
- changing the length and nature of the recovery periods.

For fixed-interval circuits, the athlete could also lengthen the work period.

An example of an individual circuit record sheet working at 50 per cent of 1-minute repetitions is shown in table 13.9.

TABLE 13.9 Example of an individual circuit record sheet

Stations	Score for 1 minute	Half score	Time and date	Time and date	Time and date
Skipping	50	25			
Sit-ups	60	30			
Push-ups	50	25			
Agility run	06	03			
Basketball throw	20	10			
Step-ups	50	25			
Medicine ball throw	20	10			
Ladder climb	06	03			
Shuttle run	10	05			
Initial time (three circuits)		21 minutes			
Target time		14 minutes			

There are any number of potential circuit training exercises that can be used in a particular training session; however, the principle of specificity means that the exercises selected should train particular aspects required in the sport or activity that the person is training for.

doc-41980

PRACTICAL ACTIVITY Classification of skills

Goal

To be able to apply the principles of time/duration and variety to a circuit training session.

Instructions

Design a fixed-time circuit training session for a sport of your choice for your class to participate in.

Primary data/Reflection

You may like to use the template below to design and record the training session or create your own. Take notes about how the participants are feeling when completing each activity.

Exercise	Intensity/ load	Work period time/duration	Rest period time/duration	W:R ratio	Sets	Notes and reflections
1						
2						
3						
4						
5						
6						
7						
8						

Questions

1. List the advantages and disadvantages of a fixed-time circuit training program.
2. Outline how you might apply progressive overload to the circuit training session that you designed.
3. Compare a fixed time and fixed load circuit training design.
4. Justify the application of time/duration to your circuit training session design.

13.4 Activity

13.4 Quick quiz on | **13.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 5	4	2, 6, 7

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TEST your understanding

1. **Define** *circuit training*.
2. **Explain** a major benefit of circuit training.
3. **Name** the three types of circuit training.

APPLY your understanding

4. **Discuss** which of the five main principles of training is most important when designing a circuit training program. Why?
5. **List** five exercises that would be appropriate to include in a circuit training session designed for each of these sports:
   a. netball
   b. soccer
   c. Australian Rules football
   d. water polo
   e. rowing
   f. volleyball.
6. **Justify** your selection of exercises in question 5.
7. **Explain** how you could progressively overload a circuit training program.

13.4 Exam questions

Question 1 (1 mark)

The type of circuit training that requires all participants to complete the same pre-determined number of repetitions at each station is:

a. individual load circuit.
b. fixed load circuit.
c. fixed time circuit.
d. free for all circuit.

Question 2 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.5;* © VCAA

Jalena is a 17-year-old student who wants to design a training program for her upcoming lacrosse season.

Muscular endurance of both the upper and lower body is important in lacrosse.

Jalena's circuit training includes undertaking the following activities for two minutes each, with 30 seconds' rest in-between:

- skipping
- high knees
- side steps
- star jumps
- push-ups
- depth jumps
- leg swings
- sit-ups
- dips
- plank

Evaluate the effectiveness of this circuit training to improve muscular endurance for lacrosse.

Question 3 (2 marks)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.7.c;* © ACHPER

Describe or **draw and annotate** an exercise which could be included in a circuit training session which specifically targets muscular endurance of the abdominals and upper body.

Muscle group	Circuit training exercise
Abdominals	
Upper body	

Question 4 (2 marks)

In a Year 12 Physical Education class fitness session, participants are expected to complete the following series of exercises in the conditioning phase of the training session. They do 30 seconds work followed by 20 seconds rest.

- push-ups
- squats
- sit-ups
- skipping
- kettle bell swings
- calf raises
- step ups

a. **Identify** the type of training demonstrated in the training session above. **(1 mark)**

b. **Outline** how you could apply progressive overload to this program. **(1 mark)**

Question 5 (2 marks)

Discuss two benefits of a cross-country skier participating in an individual load circuit.

More exam questions are available in your learnON title.

13.5 Flexibility training

Key knowledge	Key skills
• training methods, including continuous, interval (short, intermediate, long and HIIT), fartlek, circuit, weight/resistance, flexibility and plyometrics	• design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components • analyse training data to identify and prescribe appropriate modifications to a training program • evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

13.5.1 Flexibility

Flexibility is specific to each joint; an individual can be highly flexible in some joints and not so flexible in others. A very flexible person has a full range of motion for a given joint. Flexibility training is about improving the range of motion in the joints that are important for maximum performance in the activity being trained for.

For gains in flexibility, an athlete needs to undertake a stretching program three or four times per week for a minimum of three weeks. If they stop training, their flexibility reverses at about the rate of improvement. There is insufficient evidence from research about the role of stretching in preventing injury. However, stretching does improve flexibility, posture and body awareness (**proprioception**), and it also helps to relieve stress.

FIGURE 13.17 Post-exercise stretching has proven benefits in developing flexibility.



The ideal timing to include stretching aimed at improvement is after any training or exercise session. Many studies have proven that the benefits of post-exercise stretching (see figure 13.17) outweigh those of pre-exercise stretching in terms of developing flexibility.

Before any flexibility training, the participant should undertake a thorough and general aerobic warm up to increase blood temperature and circulation and thus minimise injury and maximise the potential to improve performance. It is good practice to include flexibility training at the end of every training session; however, flexibility training can also be the main focus of a session or program.

13.5.2 Methods of stretching

There are a variety of recognised methods of stretching that may be incorporated into a training program. These include:

- static (passive of isometric)
- slow active
- proprioceptive neuromuscular facilitation (PNF)
- dynamic
- ballistic
- myofascial release.

flexibility the range of movement around a joint

proprioception the body's ability to sense its location, movements and actions

Static (or passive) stretching

Static stretching is the safest and easiest method to practise. It involves a thorough, adequate and total body warm up, followed by gradual stretching of the muscle groups across a joint to the full range of motion and holding in the final position, or point of mild discomfort for 15–30 seconds (see figure 13.18). This is also the most effective stretching method in a cool down following the most exhaustive part of an exercise bout.

static stretches involve holding the end point of a stretch for up to 30 seconds

FIGURE 13.18 Some commonly used static (passive) stretches



Slow active stretching

Slow active stretching involves slowly moving the joints through the range of motion, relaxing the agonist and repeating the stretch. This type of stretching is common in aerobics classes and is considered low risk because it is controlled by internal rather than external forces.

Proprioceptive neuromuscular facilitation (PNF) stretching

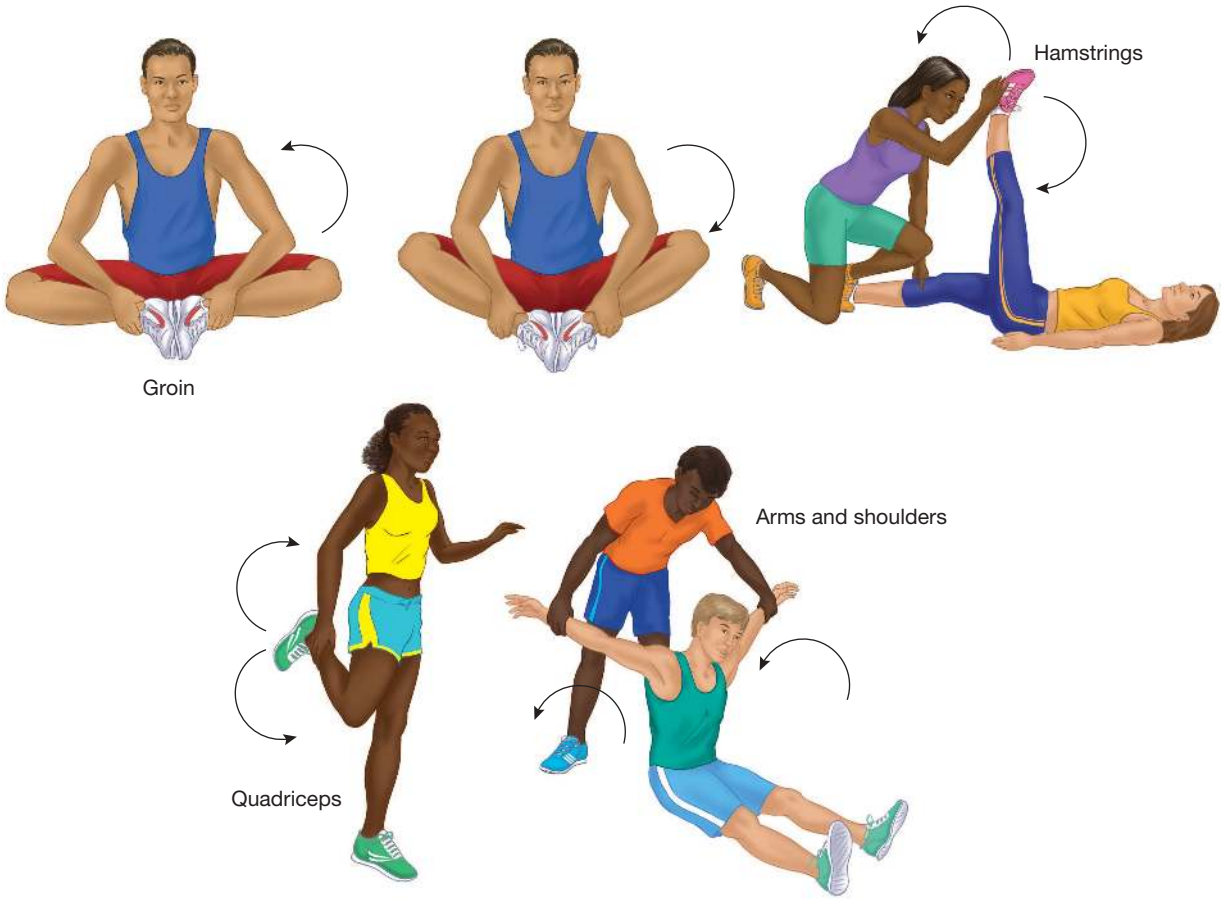
PNF stretching is considered to be 20 per cent more effective than other methods, if undertaken correctly. PNF is a technique that combines passive stretching with isometric and concentric muscle actions. This allows the muscle to lengthen and achieve a greater range of motion and increased neuromuscular efficiency.

PNF stretching comprises three phases: a passive pre-stretch, a passive stretch and an isometric contraction. These steps should be followed when undertaking PNF stretching:

1. Complete a thorough warm up.
2. Move your joint and muscle into the stretch position so that you feel the stretch sensation.
3. Your partner holds the limb in this stretched position.

4. You then push against your partner by isometrically contracting the antagonistic muscles for 6–10 seconds and then relaxing. During the contraction, your partner aims to resist any movement of the limb.
5. Your partner then moves the limb further into the stretch until you feel the stretch sensation. Hold for 10–15 seconds.
6. Repeat steps 4 and 5 three or four times before the stretch is released. PNF stretches can also be undertaken individually, as shown in figure 13.19.

FIGURE 13.19 PNF stretches — individual and partnered



Dynamic stretching

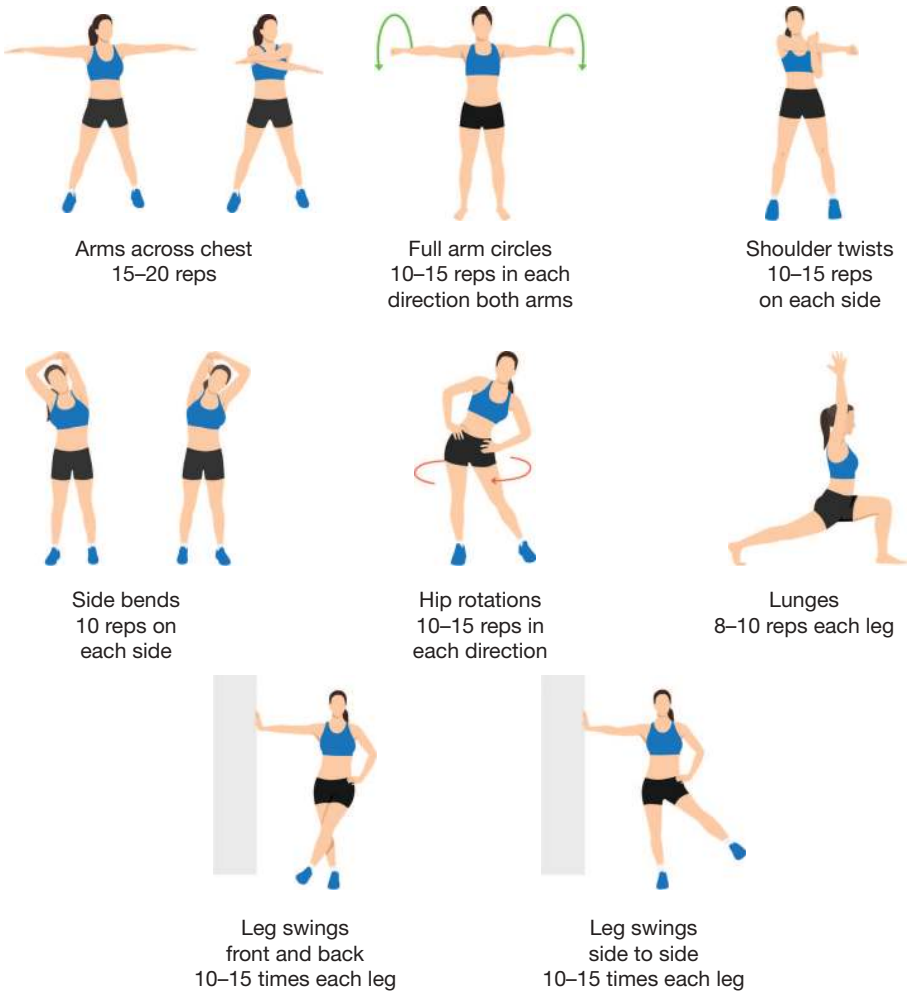
Dynamic stretching consists of slow, controlled movements through the full range of motion (see figure 13.20). For example, controlled leg and arm swings that take you gently to the limits of your range of motion.

Where the event requires a dynamic movement, then it is appropriate and perhaps necessary to conduct dynamic stretching exercises. Start with the movement at half speed for a couple of repetitions and then gradually work up to full speed.

Dynamic stretching and mobility exercises could form part of the warm up in a training session. The dynamic exercises you use should be similar to or the same as the movements you would experience in your sport or event. Current research suggests that the use of dynamic stretches is more appropriate than static ones for the warm up.

Basic examples of dynamic stretching are seen when players warm up before a game. Their hitting, kicking, running and throwing is taking various and relevant body parts through the ranges of motion needed in the game.

FIGURE 13.20 Dynamic stretching



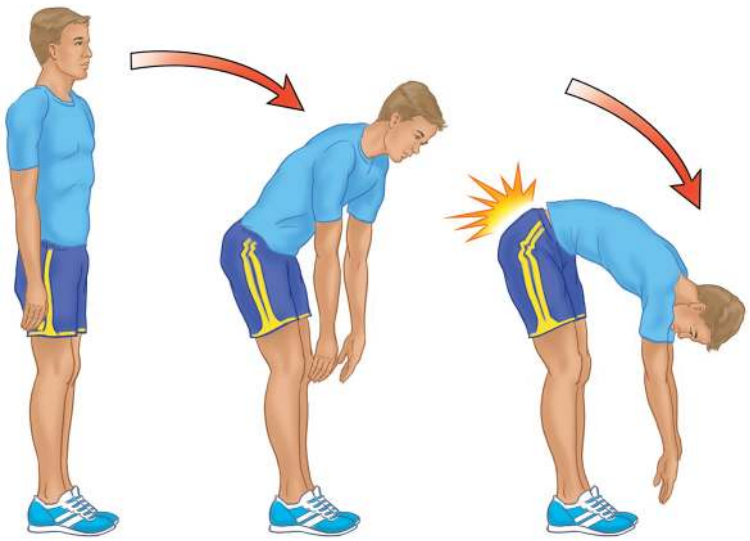
Ballistic stretching

Ballistic stretching is a controversial, higher-risk type of stretching because it involves moving through the range of motion using the momentum created rather than the muscle contraction. Only specifically conditioned athletes such as experienced dancers, high-level team players and gymnasts are recommended to use ballistic stretching (see figure 13.21). Ballistic stretching uses the momentum of a moving body or a limb in an attempt to force it beyond its normal range of motion.

A common example of ballistic stretching is bouncing down repeatedly to touch your toes. This type of stretching does not allow your muscles to adjust to, and relax in, the stretched position. It may instead cause them to tighten up by repeatedly activating the stretch reflex. However, if there are ballistic movements in the particular sport or activity that a person is training for, then it may be appropriate and even necessary to conduct ballistic stretching exercises as part of preparation.

The stretch reflex (also called the myotatic stretch reflex) attempts to resist the dynamic stretch's sudden change in muscle length by calling on the stretched muscle to contract. This is the body's attempt to prevent the suddenly stretched muscle from tearing. The more sudden the change in muscle length, the stronger the muscle's answering contractions will be.

FIGURE 13.21 Inexperienced performance of ballistic stretching can result in severe lower back problems.



Myofascial release

Myofascial release is a technique that is used to apply pressure to tight areas of the **fascia**, which underlies the muscle. This technique aims to relieve tension and improve the flexibility of the targeted joint. The most common method of myofascial release involves the use of a foam roller, and the combination of gravity and body weight controls the pressure on the particular area (see figure 13.22). The technique reduces soft tissue tension, restoring normal muscle length and therefore providing an overall improvement of muscle function.

fascia densely woven connective tissue that covers and bonds internal sections of the body

FIGURE 13.22 Myofascial release of the iliotibial band using a foam roller



13.5.3 Yoga, Pilates and somatic exercises

Yoga and **Pilates** classes both aim to improve flexibility through various movements that allow for different types of stretching to be implemented.

Pilates exercises (see figure 13.23) combine static and dynamic stretching to lengthen the muscle fibres while building strength to improve overall flexibility. It is an effective way to improve flexibility due to its combination of deliberate and controlled movements.

Yoga poses and breathing techniques (see figure 13.24) are designed to increase the mobility of muscles and joints by increasing the elasticity of the joint connective tissues and training the nervous system stretch reflex. Regular yoga practice results in an increased range of motion, decreased tension and reduced stress on the joints.

yoga a physical activity that focuses on building strength and flexibility through different poses and exercises

Pilates a type of exercise that involves a series of repetitive body movements that aim to improve your muscle strength, balance, flexibility and posture

somatic having an awareness and connection with your body. Comes from the Greek word *soma*, which means 'body'.

Somatic exercises focus on the internal experience and feeling of the movement instead of what it may look like externally. It engages the brain by using the internal experience to guide the movement, instead of pushing the body to move in a certain way. Muscular tension is released through gentle movement. The key to somatic exercises is having an awareness of how your muscles feel; this requires you to slow down enough to calmly feel the sensation of tension in your muscles and other tissues. In this way, you can release the tension that builds up in the muscles naturally. For example, you might stretch after sitting for a long time, or simply let your head hang and notice how the muscles in your neck feel. When you are in tune with how your muscles feel, you can actively contract the muscles, release the tension and increase your mobility.

FIGURE 13.23 Pilates combines deliberate and controlled movements.



FIGURE 13.24 Yoga incorporates a series of poses and breathing techniques to increase flexibility.



Flexibility training should be incorporated into every training program. It is important to focus on improving the range of motion of your joints and the elasticity of your muscles. Regular flexibility training can contribute to improved posture, reduced muscle tension and soreness, enhanced ability to perform various movement skills and decreased risk of injuries.

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PRACTICAL ACTIVITY Flexibility

Goal

To be able to design a flexibility session that effectively improves the flexibility of a range of joints.

Instructions

1. Design a flexibility session that includes six static stretches (two upper body, two core and two lower body) and three PNF stretches (one upper body, one core and one lower body).
2. Complete an aerobic warm up, then complete and record the results for the following flexibility tests:
   - sit and reach test
   - shoulder flexibility test.
3. Implement the flexibility session.
4. Complete the same aerobic warm up done at the start, then complete the flexibility tests again and record the results.

Primary data/Reflection

Static stretches	Diagram/Explanation
1. upper body	
2. upper body	
3. core	
4. core	
5. lower body	
6. lower body	

PNF stretches	Diagram/Explanation
1. upper body	
2. core	
3. lower body	

- Record participants' results prior to and after undertaking the flexibility session.

Questions

1. Compare the pre- and post-session sit and reach results and explain the reasons for the results obtained.
2. Contrast the differences between static and PNF stretching.
3. Outline another type of stretching that you could undertake to increase your flexibility.

13.5 Activity

13.5 Quick quiz on | **13.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 5, 6, 9	7	8

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TEST your understanding

1. **Define** *flexibility*.
2. **Explain** what must be done before carrying out any form of flexibility training.
3. **Define** *static stretching*.
4. **Define** *PNF stretching*. What does PNF stand for?
5. **List** some examples of dynamic stretching movements you have observed an athlete do for a sport of your choice.
6. **List** some activities for which ballistic stretching would be expected and acceptable as part of a training program.
7. **Discuss** what is meant by the term *myofascial release*.

APPLY your understanding

8. **Explain** the differences between static and slow active stretching.
9. **Describe** some PNF stretches that would increase the flexibility of the following muscle groups:
   a. pectorals
   b. hamstrings
   c. quadriceps
   d. triceps
   e. calves.

13.5 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section A, Q.7;* © ACHPER

One physiological benefit of stretching after exercise is

A. improved quality of sleep.
B. improved decision-making ability.
C. faster muscle glycogen replenishment.
D. return the muscle to normal resting length.

Question 2 (2 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.6.c;* © ACHPER

In the cool-down, participants undertook five minutes of stretching.

a. **Outline** the type of stretching recommended to be undertaken in the cool-down, following a HIIT Spin Cycle Class. **(1 mark)**
b. **Describe or draw** a suitable stretch which could be used for the quadriceps muscle group which utilises the type of stretching identified in part a. **(1 mark)**

Question 3 (3 marks)

Source: *VCE 2015, Physical Education Exam, Section A, Q.1.c;* © VCAA

Describe how each of the following types of flexibility exercises should be performed.

- Static stretching
- Dynamic stretching
- Proprioceptive neuromuscular facilitation (PNF)

Question 4 (4 marks)

Source: *ACHPER 2005, Trial Exam Units 3 & 4, Section B, Q.13;* © ACHPER

The coach of the Australian rugby team devotes approximately 30–45 minutes of each training session to 'flexibility work'.

a. Explain how slow active stretching potentially delivers greater increases to flexibility than static stretching does. **(2 marks)**

b. PNF stretching includes isometric muscle contractions. Briefly discuss how isometric contractions are different from isokinetic contractions. **(2 marks)**

Question 5 (6 marks)

Identify the following types of stretches and **outline** a benefit of each.

Stretch	Type	Benefit
		
		
 Leg swings side to side 10–15 times each leg		

More exam questions are available in your learnON title.

13.6 Key skills

Key skills

- design a training program that demonstrates the correct application of methods to enhance and/or maintain fitness components
- analyse training data to identify and prescribe appropriate modifications to a training program
- evaluate and critique the effectiveness of different training programs

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

13.6.1 Tell me

To address these key skills, it is important to:

- be able to select the most appropriate training methods to train the relevant fitness components for a variety of sports
- know how to correctly apply each of the training principles to each type of training method
- be able to identify the aspects of a training program that make it successful
- know how to use different monitoring strategies to assess the effectiveness of a training program.

13.6.2 Show me

Practice question (4 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

The following is an example of the conditioning phase of a week of pre-season training designed to improve the muscular power and speed of a hurdler.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
5 sets × 8 reps of 20 m sprints at maximal intensity, with 20 s recovery between reps and 4 min passive recovery between sets	Rest	2 sets × 10 reps of 15 m sprints at maximal intensity, with 50 s recovery between reps and 4 min passive recovery between sets	Rest	Rest	2 sets × 6 reps of 30 m sprints at maximal intensity, with 60 s recovery between reps and 4 min passive recovery between sets	Rest
3 min rest		3 min rest			3 min rest	
5 × 10 × box jumps — 40 cm high box, 2 min recovery between sets 6 × 10 × single leg hops for distance — using alternate leg for each set, 1 min recovery between sets		5 × 10 × lateral bench jumps — 25 cm high bench, 2 min recovery between sets 6 × 10 × double skips, 2 min recovery between sets			5 × 10 × box jumps — 50 cm high box, 2 min recovery between sets 6 × 10 × bench hops 20 cm high, 1 min recovery between sets	

6 × 8 × two feet stair jumps, 2 min recovery between sets		6 × 8 × two feet stair jumps, 2 min recovery between sets				

Evaluate the effectiveness of this training program to improve the *muscular power* and *speed* of a hurdler. (4 marks)

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Evaluate — make a judgment using the training program information supplied, and your own knowledge and understanding to consider a logical argument with supporting evidence for and against its effectiveness in improving muscular power and speed.
- **Key terminology** — *Muscular power* — define muscular power and outline the components/characteristics of the training methods that are designed to improve it.
  Speed
- **Key concepts** — Effectiveness of the training program — discuss the positives and negatives of the training program in relation to improving muscular power and speed. State whether you believe that the training program is effective or not.
- **Marking scheme** — 4 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

The *plyometrics activities* on Wednesday are appropriate to build the *muscular power* of the *hurdler* and the two minutes between each activity is an adequate recovery time. The activities included in the plyometrics component are appropriate to *improve muscular power (the ability of the muscles to exert a force quickly)* of the hurdler, as the exercises mimic the physiological movement patterns of the sport. The distances covered are appropriate to *improve* the *speed of the hurdler* (i.e. how quickly they can move from one point to another). The frequency of three times each week with a rest day between is *appropriate for the experienced hurdler*. However, due to the fatiguing nature of plyometric, this section of the training should not be undertaken after the sprinting activities and short interval training sessions. The recovery time between sprint efforts on Monday is too short at 20 seconds between repetitions. Overall, the plyometrics session is *too challenging and not a safe and effective way to improve muscular power*.

It is *recommended* that the plyometrics training is undertaken prior to the short interval in each training session, to ensure the athlete is *not fatigued and at risk of injuring themselves*. The recovery time between bench hops on Friday should be *increased* from 1 minute to 2 or 3 minutes for improved recovery. The recovery time between the 20-metre sprint efforts should be *increased* from 20 seconds to 40 to 60 seconds.

Award 1 mark for providing an overall statement that the program will be mostly effective in improving the muscular power and speed of a hurdler.

Award 1 mark for stating one advantage of the training program.

Award 1 mark for stating one disadvantage of the training program.

Award 1 mark for making an appropriate recommendation to improve the training program.

13.6.3 Let me do it

Question 1 (4 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.11;* © VCAA

Scott brings his friend Renee to his group fitness classes, where everyone completes the same strength-based resistance training program. The weekly program is shown below.

Monday	back squat 5 sets × 3 repetitions @85% of 1 repetition maximum (RM)	front squat 5 sets × 3 repetitions @85% of 1 RM	weighted walking lunges 3 sets × 20 m
Tuesday	shoulder press 5 sets × 3 repetitions @85% of 1 RM	weighted pull-ups 3 sets × 3 repetitions	long interval rowing 1 set × 3 repetitions (1 km) @85% HR max W:R = 1:1
Thursday	deadlift 5 sets × 3 repetitions @85% of 1 RM	weighted single-leg squat 4 sets × 4 repetitions	kettlebell swings 10 sets × 20 repetitions 60 sec rest after each set
Friday	bench press 5 sets × 3 repetitions @85% of 1 RM	weighted pull-ups 3 sets × 3 repetitions	burpees 4 sets × 25 repetitions 2 min rest after each set

Scott has been training for two years and Renee has never done formal strength-based resistance training before.

Critique the training program for its effectiveness in improving Scott's strength and maintaining his anaerobic capacity.

13.7 Review

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13.7.1 Summary

Continuous, fartlek and interval training

- Continuous training: slow distance activities, such as running, that are designed to improve aerobic fitness.
- Fartlek training: slow distance activities, such as cycling, that are interspersed with higher-intensity efforts, such as sprints, and three-quarter pace efforts. This method is designed to improve the aerobic system and, to a lesser extent, the anaerobic system. It is an excellent method for activities such as team sports where the interplay between energy systems is important.
- Interval training: periods of work followed by periods of rest and recovery. This method is excellent for team games and individual activities where the interplay between and recovery of energy systems are important. Short, intermediate, long and high-intensity interval training are all specifically designed to bring about different chronic adaptations.

Weight/resistance and plyometrics training

- Weight/resistance training: movement of a load by a particular muscle group or groups to improve endurance, size, strength or power. There are different forms of resistance training.
- Plyometrics training: an explosive movement, such as skipping, that results from lengthening then shortening the muscle. It creates an increase in muscular power.

Circuit training

- A sequence of activities that are specific to the fitness component and energy system requirements of an activity or sport.
- It allows the athlete to train several fitness components and energy systems at the one time, and can be done by large numbers of people in a confined space.

Flexibility training

- The stretching of individual muscle groups to allow an increase in the range of motion for the joint.
- There are different types of flexibility training — PNF, static, slow active, dynamic and myofascial release.

13.7.2 Key terms

circuit training involves working at a variety of activity stations in sequence, training a number of fitness components at once
continuous training involves continuous activity that lasts a minimum of 20 minutes at the required intensity using the aerobic energy system. It is submaximal and requires an intensity of 70–85 per cent of maximum heart rate. Also known as long, slow distance training.
eccentric a contraction in which the muscle lengthens as it contracts
fartlek training a type of training that works both the aerobic and anaerobic energy systems by interspersing continuous low/medium-intensity efforts with high-intensity efforts
fascia densely woven connective tissue that covers and bonds internal sections of the body
flexibility the range of movement around a joint
high-intensity interval training (HIIT) involves repeated work intervals that are relatively brief in duration, performed at a high level of intensity close to VO_2 maximum, followed by less intense recovery/rest intervals

interval training consists of repeated periods of work followed by periods of rest or recovery
isometric a contraction in which the muscle length remains the same as it contracts under tension
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.
Pilates a type of exercise that involves a series of repetitive body movements that aim to improve your muscle strength, balance, flexibility and posture
plyometrics involves the use of the stretch-shortening muscle cycle to produce powerful and explosive movements
potential energy the capacity of the muscle to do work based on its position. This happens in the eccentric phase of contraction. The greater the stretch, the greater the capacity of the concentric muscle contraction.
proprioception the body's ability to sense its location, movements and actions
weight/resistance training training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance
somatic having an awareness and connection with your body. Comes from the Greek word *soma*, which means 'body'.
static stretches involve holding the end point of a stretch for up to 30 seconds
stretch reflex occurs when an impulse is immediately sent to the spinal cord for a muscle to contract when it is stretched, to prevent overstretching
yoga a physical activity that focuses on building strength and flexibility through different poses and exercises

13.7 Exam questions

13.7 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.10;* © VCAA

An athlete completes a resistance training exercise with the following variables.

Sets: 3 Reps: 20 Load: 50–60% 1 RM

What fitness component is this exercise targeting?

A. muscular power
B. muscular strength
C. anaerobic capacity
D. muscular endurance

Question 2 (1 mark)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section A, Q.6;* © ACHPER

Muscle contractions producing the greatest force are:

A. eccentric.
B. isometric.
C. isokinetic.
D. concentric.

Question 3 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.3;* © ACHPER

The table below is an example of an interval training session.

Energy system	Sets	Repetitions	Exercise	Work time (secs)	Intensity (RPE)	Rest time (Secs)
Anaerobic glycolysis	2 (5 mins rest b/w sets)	5	50 m sprints	7	8/9	

The rest time which should be given after each repetition aimed at or targeting training the anaerobic glycolysis energy system is

A. 7 seconds.
B. 21 seconds.
C. 42 seconds.
D. 70 seconds.

Question 4 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.10;* © ACHPER

The table below represents four different resistance training programs.

	% Repetition maximum	Repetition range	Sets	Repetition speed	Rest between sets
Program A	30–60	8–10	3	as fast as possible	2–3 minutes
Program B	80	3–6	3	slow to moderate	2–3 minutes
Program C	30–60	3–6	3	as fast as possible	2–3 minutes
Program D	30–60	3–6	3	as fast as possible	1 minute

The program which is best suited to improving muscular power is represented by

A. Program A.
B. Program B.
C. Program C.
D. Program D.

Question 5 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.5;* © VCAA

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

Question 6 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.5;* © VCAA

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

Question 7 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.1;* © VCAA

Which one of the following training methods would be the best way to train for weightlifting?

A. fartlek
B. resistance
C. continuous
D. plyometrics

Question 8 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.1;* © ACHPER

Use the following information to answer questions 8–10

Rhonda is a university student who has been training regularly at both her gym and local park. She trains on alternate days, rotating through the programs below, depending on how she is feeling.

Program 1

Sets	Reps	Exercise	Rest after sets
2	4	depth jumps	3 min
2	4	squat jumps	3 min
2	5	clap push-ups	3 min
3	4	burpees	3 min

Program 2

Sets	Reps	Running distance	Work time	Rest time
2	3	300 m	45 s	1 min 30 s
1	5	200 m	28 s	1 min

Program 3

Sets	Reps	% 1 RM	Exercise	Rest after sets
2	5	60	front squats	3 min
2	4	50	bench press	3 min
2	5	50	sumo dead lifts	3 min

Key	reps – repetitions	RM – repetition maximum	s – seconds

The fitness program targeted by Program 1 is

A. speed.
B. aerobic power.
C. muscular power.
D. anaerobic capacity.

Question 9 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.2;* © ACHPER

The fitness program targeted by Program 2 is

A. speed.
B. aerobic power.
C. muscular power.
D. anaerobic capacity.

Question 10 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.3;* © ACHPER

The fitness program targeted by Program 3 is

A. speed.
B. aerobic power.
C. muscular power.
D. anaerobic capacity.

13.7 Section B – Short answer questions

Question 1 (9 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.9;* © VCAA

Emily is a well-trained recreational runner who is training to complete the 10 km run at the Melbourne Marathon Festival. She hopes to complete the run in 35 minutes. To prepare for the run, she has completed a 12-week training program. Below is an example of a typical training session that Emily would complete.

Running around the athletics track for 6 × 4-minute repetitions with 2 minutes' rest between repetitions at 75–85% HR max.

a. **Name** the training method Emily used. **(1 mark)**
b. **Provide one example** of how Emily could apply progression to her training session. **(1 mark)**
c. **Outline** how Emily could apply variety to her training session. **(1 mark)**
d. Using a different aerobic training method to the one identified in **part a**, **design** the conditioning phase of an alternative training method Emily could complete in preparation for the 10 km run. **(3 marks)**
e. **Identify one** strategy that Emily could use to monitor her training. **(1 mark)**
f. **Explain** how using the strategy identified in **part e** could prevent overtraining. **(2 marks)**

Question 2 (3 marks)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section B, Q.7.a,b;* © ACHPER

Each January many of Australia's elite distance runners spend three weeks at a summer training camp at Falls Creek in the Australian Alpine region. Falls Creek is situated at approximately 1600 m above sea level.

Below is one week of training that a 5000m runner undertook. His personal best for this event is 14 minutes 10.22 seconds.

Table 1

	Morning Session	Afternoon Session
Monday	– Easy 8 km run @ 70% Heart Rate Maximum (HR max)	– 12 km run @ 80% HR max
Tuesday	– Easy 8 km run @ 70% HR max	– 10 minute warm up @ 70% HR max – 2 × 3 × 1 000 m in 3 minutes @ 88% HR max with 3 minutes recovery between each repetition – 10 minute cool-down @ 60% HR max
Wednesday	– Rest	– 16 km run @ 80% HRM
Thursday	– Easy 8 km run @ 70% HR max	– 8 km run with random bursts of speed over varying distances @ 75–90% HR max
Friday	– Easy 12 km run @ 70% HR max	– Rest
Saturday	– 10 minute warm-up @ 70% HR max – 2 × 6 × 600 m 88% HR max in 90 seconds with 90 second recovery between each repetition – 10 minute cool-down @ 60% HR max	– Easy 5 km run @ 70% HR max
Sunday	– Easy 20 km run @ 70% HR max	– Rest

a. **Identify** the main training method that this athlete undertakes at the following times.

i. Thursday pm

ii. Saturday am **(2 marks)**

b. **Apply** correct overload to the Saturday morning session.

Sets	Repetitions	Distance	% HR max	Recovery
2	6	600	88% HR max	90 seconds

(1 mark)

Question 3 (2 marks)

Source: *VCE 2014, Physical Education Exam, Section B, Q.8b;* © VCAA

After 12 weeks of training, an untrained runner brings their 5 km run time down from 45 minutes to 40 minutes, while a trained runner only brings their time down from 13:23 minutes to 13:11 minutes.

The untrained runner decided to use continuous training as a method to improve their aerobic capacity.

Outline two advantages to the untrained runner of choosing continuous training over long interval training.

Question 4 (3 marks)

Source: *ACHPER 2016, Trial Exam Units 3 & 4, Section B, Q.11.c;* © ACHPER

Explain or draw one *different plyometrics exercise* that is appropriate for each of the athletes to improve their performance.

a. 200 m freestyle swimmer
b. Shot putter
c. 10 000 m runner.

Question 5 (4 marks)

Source: *VCE 2015, Physical Education Exam, Section B, Q.14.a–c;* © VCAA

Participation in physical activity generally poses little risk. When an athlete completes core strength training, the risk of injury is also lowered.

a. **State** two other benefits of completing core strength training to performance in sport. **(2 marks)**
Core strength training can be completed without equipment or it can be undertaken with equipment such as stability balls, medicine balls and balance boards (shown below).



Stability ball



Medicine balls



Balance board

b. Select **one** piece of equipment shown and **describe or draw** a core exercise that uses the piece of equipment selected. **(1 mark)**
c. **Describe or draw** an alternative exercise that will overload the same muscle or muscle groups that were used in **part b.** **(1 mark)**

Continue to build your exam skills

Access the Unit 4 Area of Study 2 Review at the end of Topic 14. This includes:
- Practice extended response
- Practice examination
- Practice school-assessed coursework.

14 Chronic adaptations to training

14.1 Overview

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LEARNING SEQUENCE

14.1 Overview
14.2 Chronic training adaptations: aerobic, anaerobic and resistance training
14.3 Chronic adaptations to aerobic training: respiratory
14.4 Chronic adaptations to aerobic training: cardiovascular
14.5 Chronic adaptations to aerobic training: muscular
14.6 Chronic adaptations to aerobic training: VO_2 maximum and lactate inflection point
14.7 Chronic adaptations to anaerobic training: muscular
14.8 Chronic adaptations to resistance training: neuromuscular
14.9 Key skills
14.10 Review

14.1.1 Introduction

Understanding chronic adaptations to training is the cornerstone of optimising athletic performance and enhancing overall physical wellbeing. Chronic adaptations refer to the long-term physiological changes that occur in response to consistent exercise training (aerobic, anaerobic and/or resistance) over extended periods. The body adapts to become more metabolically efficient in relation to the specific exercise demands that are placed upon it. These adaptations encompass various bodily systems, including cardiovascular, respiratory, muscular and neuromuscular adaptations. By comprehending how the body adapts to sustained training stimuli, you can effectively design training programs tailored to specific athletic goals and better understand the mechanisms underlying athletic performance enhancement.

FIGURE 14.1 What are the chronic adaptations that would allow Australian race walker Jemima Montag to perform at her best for the 20-kilometre walk?

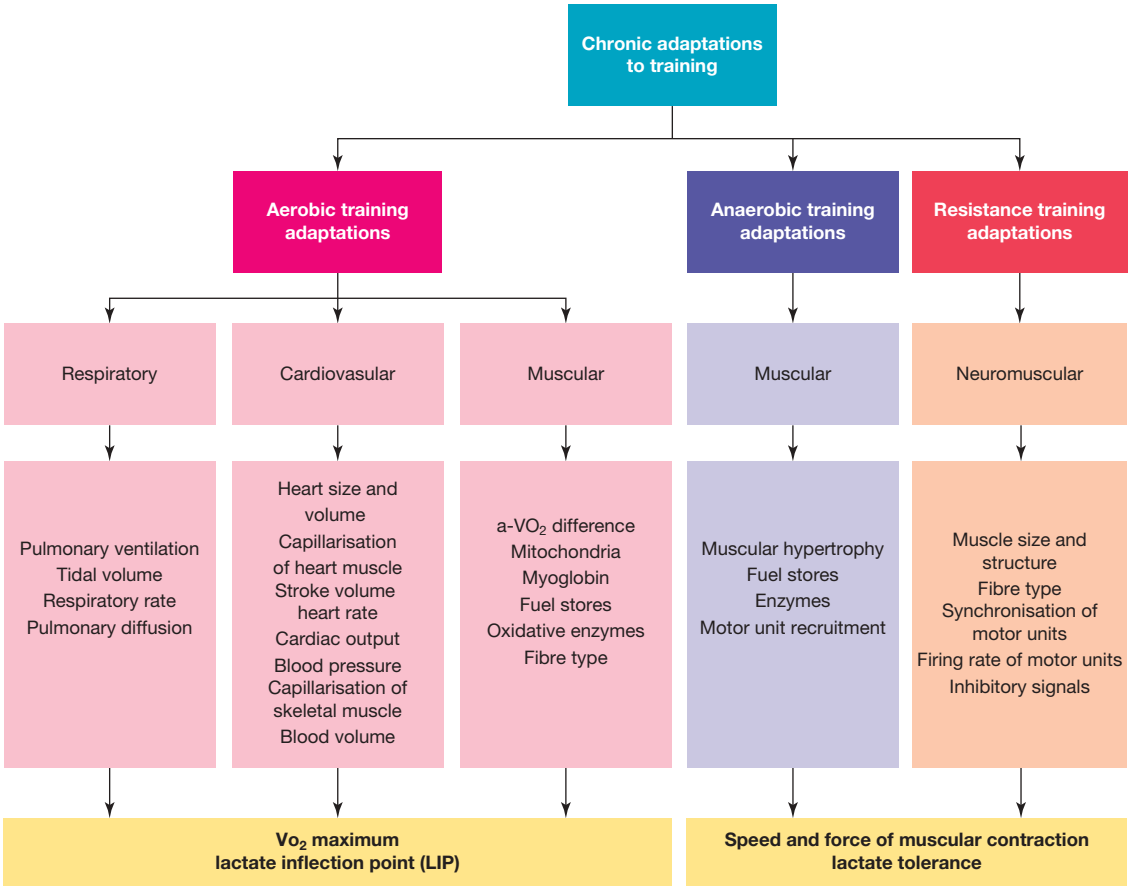


14.1.2 Key knowledge and Key skills

Key knowledge	Key skill	Subtopic
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic, anaerobic and resistance training that produce improvements	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance	**14.2**
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic and resistance training that produce improvements in: – VO_2 max – lactate inflection point (LIP)		**14.3** **14.4** **14.5** **14.6**
• chronic adaptations of the muscular system to anaerobic and resistance training that produce improvements in: – speed and force of muscular contraction – lactate tolerance		**14.7** **14.8**

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14.1.3 Topic preview



14.2 Chronic training adaptations: aerobic, anaerobic and resistance training

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic, anaerobic and resistance training that produce improvements	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

chronic adaptations the body's long-term responses of the cardiovascular, respiratory and muscular systems that develop over a period of time when training is repeated regularly

Exercise or training undertaken regularly over an extended period of time (usually at least three times per week for a minimum of 6–8 weeks) leads to the development of long-term or **chronic adaptations** to training. Adaptations occur when the body responds by making specific changes that allow it to better cope with the demands placed upon it. Some of these adaptations are evident when an individual is at rest, and others can be measured when the body is engaged in exercise or activity. Some adaptations are apparent when the individual is working at submaximal exercise intensities, whereas others are evident when the individual is engaged in maximal exercise. Once achieved, these adaptations are retained unless training ceases. Upon cessation, the body will gradually revert to its pre-training condition. This process is referred to as reversibility or detraining (see topic 12).

Chronic adaptations to training vary greatly and are dependent upon:

The type and method of training

Chronic training responses are highly specific to the type of training undertaken (e.g. aerobic, anaerobic or resistance training). This is known as the SAID (specific adaptation to imposed demands) principle.

The frequency, duration/time and intensity of the training

The greater the frequency, duration and intensity of training. the more pronounced the adaptations. However, factors such as overtraining and the principle of diminishing returns (see topic 12) need to be kept in mind.

The individual's capacities and hereditary factors

(i.e. genetic make-up or potential), such as their VO_2 max and distribution of muscle fibre types (fast-twitch and slow-twitch). According to some research, 97 per cent of fibre types are genetically determined.

Chronic training adaptations may occur at both the system level, particularly the cardiovascular, respiratory and/or muscular systems, and also within the neuromuscular interface.

The combined effect of all chronic adaptations is known as the training effect. The correct application of training methods and principles (see topic 12), and the use of fitness testing (see topic 10) and training monitoring (see topic 11) allow individuals to tailor, measure and monitor their progress to bring about the chronic adaptations described in this chapter.

FIGURE 14.2 Each of these athletes will develop chronic adaptations specific to their training programs.



14.2.1 Chronic adaptations to aerobic training

The minimum period for chronic adaptations to occur with aerobic (endurance) training is six weeks, although they are more evident after 12 weeks. Chronic cardiovascular and respiratory system adaptations to aerobic training are primarily designed to bring about the more efficient delivery of larger quantities of oxygen to working muscles. Specifically:

- respiratory system improvements allow for better oxygen *uptake*
- cardiovascular system improvements increase blood flow and the *transportation* of oxygen
- muscular system improvements enhance the *utilisation* of oxygen (see figure 14.3).

FIGURE 14.3 Systems responsible for oxygen uptake, transport and utilisation



Respiratory system
Uptake of O_2



Cardiovascular system
Transportation of O_2



Muscular system
Utilisation of O_2

Aerobic training effects are developed through continuous, fartlek, long and high-intensity interval training. Circuit and resistance training can also generate aerobic training effects if the exercises are designed specifically for aerobic and local muscular endurance benefits.

Chronic aerobic adaptations increase the athlete's ability to produce ATP aerobically, or improve their **economy**.

The effectiveness of oxygen uptake, transportation and utilisation is the most significant factor in aerobic exercise. This depends on:

- the ability of the *lungs* to ventilate large volumes of oxygen
- the ability of the *blood* to exchange oxygen at the lungs (transported by **haemoglobin** in red blood cells)
- the ability of the *heart* to pump large volumes of blood to the muscles ($\dot{Q} = HR \times SV$)
- the ability of the *muscles* to extract oxygen from blood (role of **myoglobin**)
- the ability of the *muscles* to use oxygen to break down fuels to produce ATP (in the **mitochondria**; requires oxidative, glycolytic and lipolytic enzymes).

14.2.2 Chronic adaptations to anaerobic training

The minimum time for chronic adaptations to occur with anaerobic training is six weeks. The greatest adaptations occur in the muscular system; however, minor changes also occur in the cardiovascular system. Adaptations to anaerobic training are designed to improve the athlete's capacity to generate energy anaerobically and to increase their muscle size (as measured by cross-sectional area), enabling greater force production, power output, strength and speed. Further adaptations at the muscle-tissue level improve anaerobic capacity and tolerance to metabolic by-products.

Anaerobic training effects are developed through short and intermediate interval training, plyometric training and circuit training (if designed to include anaerobic-based exercises). Anaerobic adaptations will also be achieved by undertaking strength and power type resistance training.

14.2.3 Chronic adaptations to resistance training

Many athletes incorporate resistance training into their overall training program. This method of training is as important for elite athletes wanting to achieve higher levels of performance as it is for the general population seeking health benefits. Muscle size is a significant contributor in relation to the strength of a muscle. However, in the initial stages of undertaking a resistance training program (i.e. the first 8–10 weeks), increases in strength can be primarily attributed to the neural adaptations that occur. Only after about 10 weeks of training does **muscular hypertrophy** become the main factor contributing to increased strength.

The specific neural adaptations that increase the strength and force production of a muscle are not fully understood. However, there are some general factors that are thought to contribute, and these are discussed later in this topic.

economy the quantity of oxygen (mL/kg/min) required to generate movement at any given speed or intensity

haemoglobin a substance in the blood that transports oxygen around the body

myoglobin an oxygen-binding protein in skeletal muscle cells that attracts oxygen from the bloodstream and shuttles it to the mitochondria in the muscles for aerobic energy production

mitochondria cell structures (organelles) that serve as the power generators of the cell, converting nutrients into ATP in the presence of oxygen (aerobically)

muscular hypertrophy an increase in the cross-sectional size of a muscle

14.2 Activity

14.2 Quick quiz on | **14.2 Exercise**

Learning pathways

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TEST your understanding

1. **Define** the term *chronic adaptation*.
2. **Identify** and **discuss** the three main factors that affect chronic adaptations to training.
3. **Name** the training methods used to develop:
   a. chronic aerobic adaptations
   b. chronic anaerobic adaptations.
4. **Outline** the main factor that explains strength improvements in the first few weeks of undertaking a resistance training program.

APPLY your understanding

5. Select one of the athletes depicted in figure 14.4.

FIGURE 14.4 Each of these athletes will develop chronic adaptations specific to their training programs.



   a. **Explain** what type of training method would be most suitable for their sport.
   b. **Suggest** the physiological adaptations that would be needed for them to perform at the highest level in their particular sport.

14.2 Exam questions

Question 1 (4 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.2.b;* © ACHPER

At a recent swimming carnival, the winner of the women's 50 m freestyle swimming event swam a time of 23.78 seconds. Her teammate won the women's 800 m freestyle event in 8 minutes 20.02 seconds.

With reference to chronic training adaptations, **explain** why anaerobic training is an important training type for both events, enabling both swimmers to compete successfully at an elite level.

Question 2 (4 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.1.a,b;* © ACHPER

Julia and Gus both participated in a 5 km fun run over the weekend.

Heart rates during 5 km run and 3-minute recovery

	Resting HR	1 km HR	2 km HR	3 km HR	4 km HR	5 km HR	Recovery HR 1 min	Recovery HR 2 min	Recovery HR 3 min
Julia	45	88	118	119	118	119	105	83	58
Gus	65	113	135	158	159	158	140	129	108

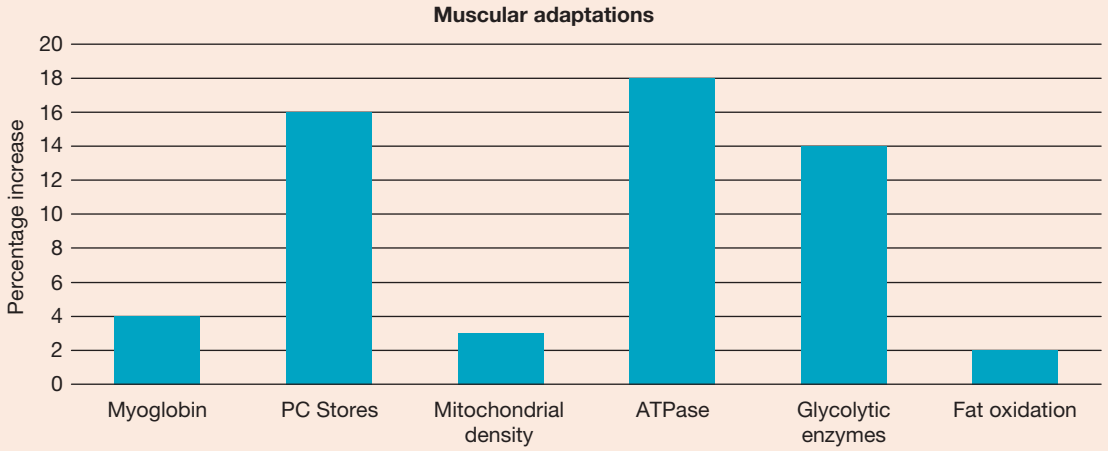
a. **Identify** which competitor, Julia or Gus, was more aerobically trained. **(1 mark)**

b. **Provide** three pieces of data from the table above to support the competitor identified in part a. **(3 marks)**

Question 3 (3 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.11.a,b;* © ACHPER

Sam has been training consistently, following the correct principles of frequency, intensity, time, and type. The results below detail some of the improvements after six months of training.



a. What type of training has Sam participated in to bring about these adaptations? Use data to **support** your response. **(2 marks)**

b. **Outline** one training method Sam may be utilising. **(1 mark)**

Question 4 (6 marks)

Chronic adaptations to exercise occur from undertaking long-term aerobic, anaerobic and/or resistance training.

a. **State** an athlete who would benefit from each type of training. **(3 marks)**
- Aerobic training
- Anaerobic training
- Resistance training

b. **Outline** the benefits to the performance of an athlete undertaking each type of training. **(3 marks)**
- Aerobic training
- Anaerobic training
- Resistance training

Question 5 (6 marks)

An AFL midfielder may include both long interval training and short interval training as a part of their training program.

a. **Identify** which types of chronic adaptations would occur after undertaking each training method. **(2 marks)**
- Long interval training
- Short interval training

b. **Outline** why an AFL midfielder may incorporate both of the above training methods in their training program. **(4 marks)**

More exam questions are available in your learnON title.

14.3 Chronic adaptations to aerobic training: respiratory

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular system to aerobic, anaerobic and resistance training that produce improvements	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

14.3.1 Increased pulmonary ventilation during maximal exercise

Pulmonary ventilation is the movement of air into and out of the lungs. It involves the exchange of gases (oxygen and carbon dioxide) between the respiratory system and the external environment. Regular aerobic training results in more efficient and improved pulmonary **ventilation** (see figure 14.5), which is sometimes also referred to as minute ventilation. At rest and during submaximal exercise, ventilation may be reduced due to improved oxygen extraction. However, during maximal workloads (see table 14.1), ventilation is increased because of increased **tidal volume (TV)** and **respiratory frequency (RF)**. **Pulmonary diffusion** is also enhanced as a result of training. Improvements in pulmonary ventilation associated with aerobic training result in better respiratory efficiency and increased oxygen uptake.

ventilation the amount of air inspired or expired per minute by the lungs. Ventilation (V) = respiratory frequency (RF) × tidal volume (TV)

tidal volume (TV) the amount of air inspired and expired by the lungs per breath

respiratory frequency (RF) the amount of times a person breathes in and out each minute

pulmonary diffusion the movement of oxygen and carbon dioxide from areas of high concentration to areas of low concentration between the alveoli and the surrounding capillaries

FIGURE 14.5 Pulmonary ventilation



Inspiration	Expiration
Diaphragm contracts, pushing downwards	Diaphragm relaxes, pushing upwards
Intercostal muscles contract and move the ribs upwards and outwards.	Intercostal muscles relax so the ribs move inwards and downwards.
Lungs expand as pressure inside chest decreases.	Lungs decrease in size as the pressure inside the chest increases.
Air drawn in from external atmosphere through nose and mouth (high in oxygen and low in carbon dioxide).	Air expelled out to external atmosphere through nose and mouth (low in oxygen and high in carbon dioxide).

14.3.2 Increased tidal volume

Tidal volume is the amount of air that can be inspired and expired with each breath. Aerobic training increases the amount of air inspired and expired by the lungs per breath. This is attributed to the increased strength and endurance of the respiratory muscles, allowing an athlete to exhale more air and inhale more air from the atmosphere. This allows for a greater amount of oxygen to be diffused into the alveoli capillaries and delivered to the working muscles.

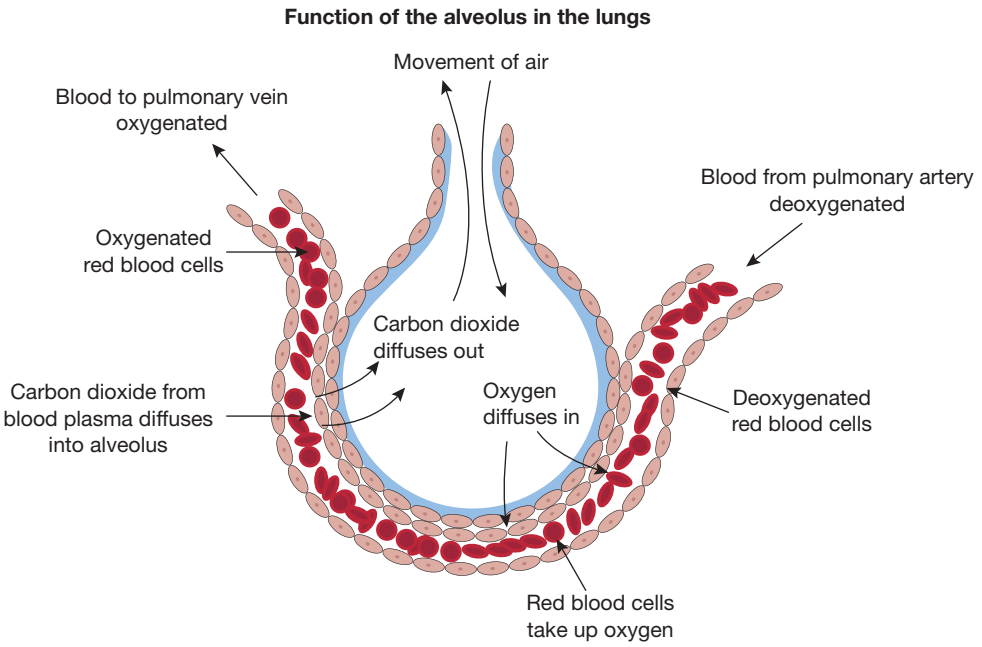
14.3.3 Decreased resting and submaximal respiratory frequency

The number of times an athlete breathes in and out per minute is reduced at rest and when working at submaximal levels. This is mainly due to improved pulmonary function and capacity, which increases the extraction of oxygen from the alveoli to the surrounding capillaries. Aerobic training improves the efficiency of the diaphragm and intercostal muscles, enabling them to function more effectively with each breath.

14.3.4 Increased pulmonary diffusion

Aerobic training results in an increase in the surface area of the alveoli, which in turn increases pulmonary diffusion (see figure 14.6). This increases the amount of oxygen and carbon dioxide that can be exchanged between the alveoli and the surrounding capillaries. This means that more oxygen can be extracted from the alveoli to the surrounding capillaries and more carbon dioxide can be diffused from the capillaries into the alveoli.

FIGURE 14.6 An increased alveolus surface area allows for a greater amount of diffusion of oxygen and carbon dioxide.



The increase in ventilation and pulmonary diffusion allows more oxygen to be inhaled, extracted and transported to the working muscles.

TABLE 14.1 Chronic adaptations to aerobic training: respiratory

	Adaptation to aerobic training		
Total lung capacity	Increase		
	Rest	**Submaximal exercise**	**Maximal exercise**
Pulmonary ventilation	Decrease	Decrease	Increase
Tidal volume	No change	Increase	Increase
Respiratory frequency	Decrease	Decrease	Increase
Pulmonary diffusion	Increase	Increase	Increase

EXAM TIP

Pulmonary ventilation is the product of tidal volume and respiratory frequency, so if you identify pulmonary ventilation as an improvement, you cannot separately identify tidal volume and/or respiratory frequency as additional improvements

EXAM TIP

Make sure that you include the measurement reference in your responses. Examples include:

Tidal Volume (V_T) = mL/breath

Respiratory Frequency (RF) = breaths/minute

Ventilation (VE) = L/ min

on Resources

Weblinks Pulmonary ventilation
Mechanics of ventilation

doc-41982

PRACTICAL ACTIVITY Respiratory chronic adaptations to aerobic training

Goal

To be able to explain how the respiratory system chronic adaptations to aerobic training lead to improved performance.

Instructions

1. Working in pairs, complete the following.

Person 1
- Sit down comfortably and give yourself 5 minutes to relax. This is you at rest.

Person 2
- Measure your partner's breathing rate by looking at the rise and fall of their rib cage. One rise is the equivalent of one breath. While the person is at rest, count the number of breaths over a 30-second period. Double it to get the result for breaths per minute (or measure it for 15 seconds and multiply by 4).
- Repeat a second time and find the average rate per minute: this is the resting rate.

Person 1
- Go for a brisk walk or jog for 5 minutes.

Person 2
- Immediately after your partner finishes exercising, count their number of breaths over a 30-second period. Double it to get the result for breaths per minute (or measure it for 15 seconds and multiply by 4).
- Repeat this every minute after exercise for 5 minutes.

2. Repeat the process, swapping roles.

Primary data/Reflection

TABLE 1 Results for person 1 and person 2

	Person 1	Person 2
Resting 1 respiratory rate		
Resting 2 respiratory rate		
Immediately post-exercise		
1 minute post-exercise		
2 minutes post-exercise		
3 minutes post-exercise		
4 minutes post-exercise		
5 minutes post-exercise		

- Enter the results on a line graph.

Questions

1. Compare the respiratory rate responses for person A and person B.
2. Identify which person is likely to be more aerobically trained. Justify your response.
3. Other than respiratory rate, list two respiratory adaptations that a person would experience as a result of undertaking an aerobic training program.
4. Discuss how the respiratory adaptations you listed in question 3 would contribute to improved performance for a triathlete.

14.3 Activity

14.3 Quick quiz on

14.3 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL3
1, 2	5	3, 4

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TEST your understanding

1. **Complete** the following table by indicating whether the physiological parameter has increased, decreased or remained unchanged as a result of the athlete's involvement in a long-term aerobic training program.

Physiological parameter	At rest	During submaximal exercise	During maximal exercise
Ventilation			
Tidal volume			
Respiratory frequency			
Pulmonary diffusion			

2. a. **Identify** three types of athlete who are likely to develop chronic respiratory adaptations as a result of participating in a long-term aerobic training program.
   b. **Define** pulmonary ventilation and outline its parameters.

APPLY your understanding

3. **Explain** how aerobic training can result in more efficient pulmonary ventilation.
4. **Explain** pulmonary diffusion and how it is affected by aerobic training.
5. **Discuss** how the aerobic adaptations of pulmonary ventilation and pulmonary diffusion would lead to the improved performance of a marathon runner.

14.3 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2017, Trial Exam Units 3 & 4, Section A, Q.12;* © ACHPER

Chronic respiratory adaptations, as a result of a Year 12 student participating in an 8-week training program to improve aerobic capacity, would include:

A. increased stroke volume, increased pulmonary diffusion, improved efficiency of respiratory musculature.
B. increased mitochondria, increased cardiac output at maximal levels, improved pulmonary diffusion.
C. increased mitochondria, improved efficiency of respiratory musculature, increased stroke volume.
D. improved efficiency of respiratory musculature, improved pulmonary diffusion, increased total lung volume.

Question 2 (1 mark)

Which of the following illustrates the accurate relationship between pulmonary ventilation (V), respiratory frequency (RF) and tidal volume (TV)?

A. V × RF = TV
B. TV × RF = V
C. TV × V = RF
D. Pulmonary diffusion × RF = V

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.3;* © VCAA

a. **State** the formula for ventilation. In your response, do not use abbreviations.
b. During submaximal exercise, it is possible for trained aerobic athletes to have a lower ventilation than untrained individuals. **Explain** how this is possible.

Question 4 (2 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.14.e;* © VCAA

Kobe Bryant, an NBA basketball player with the LA Lakers, retired in 2016.

In his final NBA game, Bryant scored 60 points in 42 minutes of play. His actions during the last three minutes and five seconds are presented in the game log below. Overall, in that period, the two teams were together responsible for two timeouts, two substitutions and three sets of free throws.

Score	Actions performed by Kobe Bryant	Time remaining
HOME AWAY 86 - 94	Reverse lay-up	03 : 05 : 00 HRS MINS SECS
HOME AWAY 88 - 96	Two free throws	02 : 16 : 00 HRS MINS SECS
HOME AWAY 90 - 96	Fast-driving lay-up	01 : 45 : 00 HRS MINS SECS
HOME AWAY 92 - 96	Pull-up jump shot from approximately 5 metres	01 : 27 : 00 HRS MINS SECS
HOME AWAY 95 - 96	3-point pull-up jump shot	00 : 59 : 70 HRS MINS SECS
HOME AWAY 97 - 96	Pull-up jump shot from approximately 6 metres	00 : 31 : 60 HRS MINS SECS
HOME AWAY 99 - 96	Two free throws	00 : 14 : 80 HRS MINS SECS
HOME AWAY 101 - 96	Substituted from match	00 : 04 : 10 HRS MINS SECS

Source: Adapted based on data from National Basketball Association, Official Scorer's Report, Final Box, 13 April 2016; © 2016 NBA Properties, INC.

Other than tidal volume, **state** two chronic respiratory adaptations that would have aided Bryant's performance.

Question 5 (1 mark)

Source: *VCE 2011, Physical Education Exam, Section B, Q.11.b.i;* © VCAA

A chronic respiratory adaptation to aerobic training is an increase in pulmonary diffusion.

State what occurs physiologically with an increase in pulmonary diffusion.

More exam questions are available in your learnON title.

14.4 Chronic adaptations to aerobic training: cardiovascular

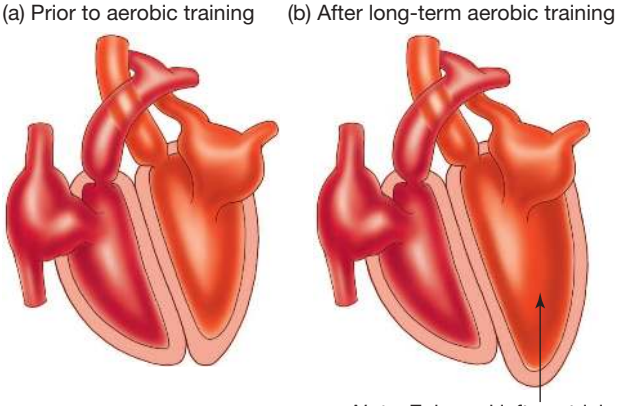
Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic, anaerobic and resistance training that produce improvements	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

14.4.1 Increased left ventricle size and volume

Sustained aerobic training results in the enlargement of the heart muscle itself. This enlargement is referred to as **cardiac hypertrophy**. In endurance athletes, there is an increase in the size, and therefore volume, of the ventricular chambers, particularly the left ventricle (see figure 14.7). This in turn significantly increases stroke volume and **cardiac output** at maximal intensities, allowing a greater volume of blood to be ejected from the heart and providing more oxygen for the athlete to use.

FIGURE 14.7 Effects of aerobic training on cardiac hypertrophy following intense, sustained aerobic training. The size of the ventricular cavities, particularly the left ventricle, increases.



Note: Enlarged left ventricle

14.4.2 Increased capillarisation of the heart muscle

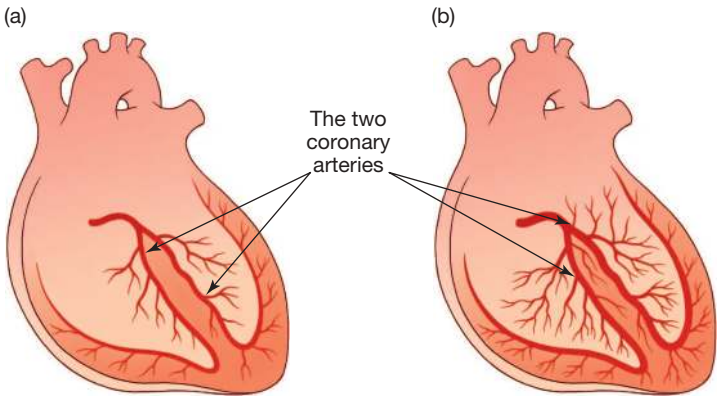
Cardiac hypertrophy also leads to an increase in the **capillarisation** of the heart muscle itself (see figure 14.8). The process of forming new blood vessels is known as angiogenesis. Aerobic exercise simulates the growth of new heart muscle capillaries. The increased supply of blood and oxygen allows the heart to beat more strongly and efficiently during both exercise and rest. Increased capillarisation of the heart muscle provides a greater surface area for the exchange of gases and nutrients. This enhances oxygen supply, removal of carbon dioxide and also the delivery of nutrients to the heart.

cardiac hypertrophy an enlargement of the heart muscle as a result of training

cardiac output ($\dot{Q}$) the amount of blood ejected from the left ventricle of the heart per minute. $\dot{Q}$ = heart rate (HR) × stroke volume (SV).

capillarisation an increase in the capillary density and blood flow to skeletal or cardiac muscle as a result of aerobic training

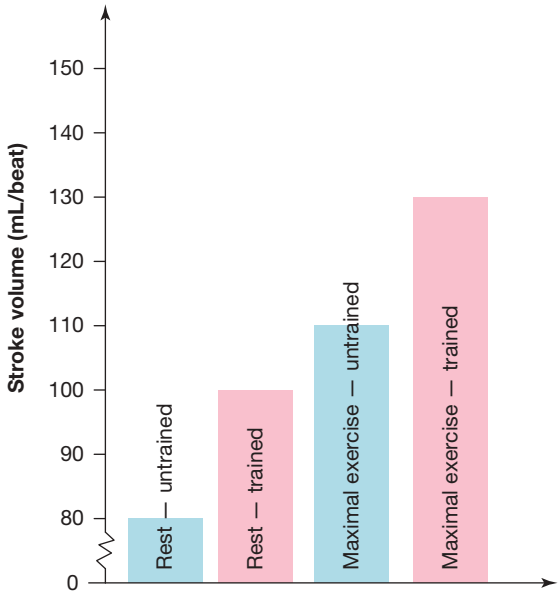
FIGURE 14.8 Capillarisation (blood supply) to the heart **(a)** before and **(b)** after a long-term aerobic training program



14.4.3 Increased stroke volume of the heart

The increased hypertrophy (capacity of the left ventricle) of the heart, reduced systemic peripheral resistance, a greater blood volume (plasma volume expansion), increased venous return and an increased ability of the ventricle to stretch are all factors that contribute to a significant increase in the heart's **stroke volume** following aerobic training. Stroke volume is greater at rest, during submaximal exercise and during maximal workloads for a trained athlete compared with an untrained person. For example, the average stroke volume at rest for an untrained male is about 70–80 millilitres per beat, whereas trained male endurance athletes may have stroke volumes at rest of 100 or more millilitres per beat. During maximal exercise, these values may increase to about 110 millilitres per beat for an untrained person and 130 millilitres per beat for a trained athlete (see figure 14.9).

FIGURE 14.9 Stroke volume in response to aerobic training for males. Stroke volume is greater for trained endurance athletes at rest and at all exercise intensities. (*Note:* Only maximal intensities shown here.)



Elite endurance athletes may have stroke volume values as high as 190 millilitres per beat. Trained and untrained females have lower stroke volumes than their male counterparts under all exercise conditions, mainly due to their smaller heart size.

As greater stroke volume allows more oxygen to be delivered to the working muscles, this allows the athlete to use more oxygen and thus improves their ability to resynthesise ATP aerobically. This results in the athlete being able to work at higher intensities for longer, with fewer fatiguing factors, inevitably producing an improved overall performance.

14.4.4 Decreased resting and submaximal heart rate and faster recovery heart rate

An athlete's heart rate is a good indicator of their aerobic fitness. Aerobic training has a significant effect on an athlete's resting and submaximal heart rate and also how quickly their heart rate returns to pre-exercise levels during recovery. The effect that aerobic training has on an athlete's maximal heart rate is minimal, as this is largely affected by age and genetics.

stroke volume the amount of blood ejected from the left ventricle with each beat (contraction) of the heart

on Resources

Weblink The cardiac cycle

14.4.5 Decreased resting heart rate

The amount of oxygen required by an individual while at rest does not change as a result of their training status. At rest, it takes about 5 litres of blood per minute (cardiac output) to circulate around the body in order to supply the required amount of oxygen to the body cells (whether the individual is trained or untrained). Cardiac output ($\dot{Q}$) is equal to stroke volume (SV) multiplied by heart rate (HR):

$$\dot{Q} = SV \times HR$$

However, if an individual has developed a greater stroke volume, the heart does not have to beat as frequently to supply the required blood flow (and oxygen); the heart is more efficient. For example, before training:

$$\dot{Q} = SV \times HR$$
$$5 \text{ L/min} = 70 \text{ mL/beat} \times 71 \text{ beats/min}$$

Whereas after training:

$$\dot{Q} = SV \times HR$$
$$5 \text{ L/min} = 100 \text{ mL/beat} \times 50 \text{ beats/min}$$

For this reason, the **resting heart rate** is a useful indicator of aerobic fitness. Generally, the lower the resting heart rate, the greater the individual's level of aerobic fitness. The resting heart rate may be as low as 35 beats per minute for elite endurance athletes, such as marathon runners, triathletes, road cyclists and distance swimmers, compared with the average resting heart rate of around 70 beats per minute for an average adult male.

resting heart rate the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult

EXAM TIP

A decrease in resting heart rate is an indication of improved efficiency of the cardiovascular system. Remember that the heart rate's response during exercise has a direct impact on performance.

EXAM TIP

Make sure that you include the measurement reference in your responses. Examples include:

Stroke volume (SV) = mL/beat

Heart rate (HR) = bpm

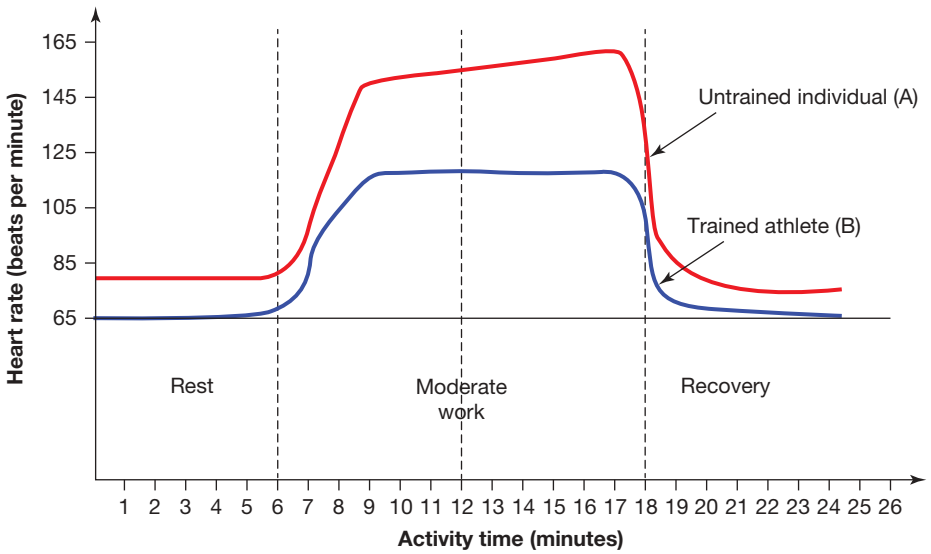
Cardiac output (Q.) = L/min

14.4.6 Decreased heart rate during submaximal workloads

Trained aerobic athletes have lower heart rates at submaximal workloads compared with those of untrained individuals. This is mainly a result of their increased stroke volume, which means that more blood is pumped with each beat of the heart, and therefore the heart does not have to work as hard to supply the required blood flow and oxygen. Put quite simply, the heart works more efficiently.

Regular aerobic training also results in a slower increase in heart rate during exercise and a faster attainment of a steady state during similar exercise intensities as prior to training. Figure 14.10 clearly indicates the training effect on heart-rate response to submaximal workloads.

FIGURE 14.10 Heart rate response before, during and after submaximal exercise for a trained athlete and an untrained individual. Note that the heart-rate response of a trained endurance athlete (B) is lower than that of an untrained person (A) at rest and at all exercise intensities. The heart rate of a trained athlete also returns to resting values more quickly upon cessation of exercise compared with an untrained person.

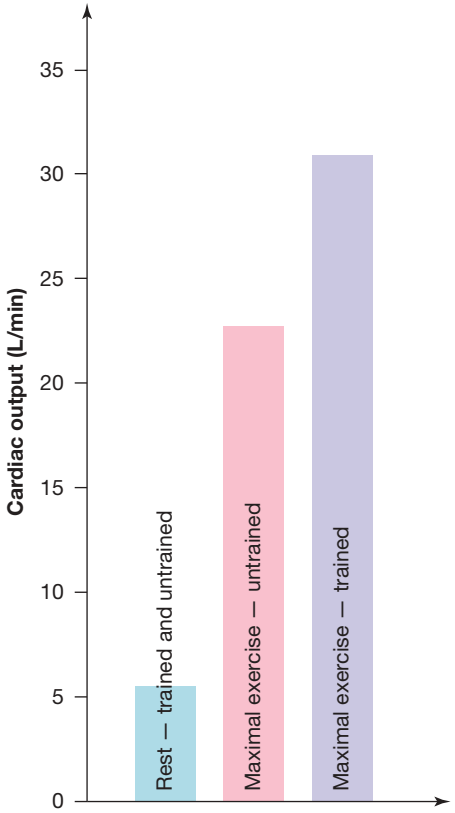


The heart rate increases just prior to exercise (anticipatory response) in both the trained athlete and untrained individual. It then increases quickly to around 15 bpm for the untrained individual and 120 bpm for the trained athlete. The trained athlete reaches a steady state faster and records a lower submaximal exercise heart rate than the untrained individual at the same intensity. The trained athlete's heart rate also returns back to resting levels faster.

14.4.7 Faster heart rate recovery rates

Faster heart rate recovery rates mean that the heart rate of a trained athlete will return to pre-exercise levels (resting heart rate) in a much shorter time than that of an untrained individual (see figure 14.10). A quicker heart rate recovery occurs after both maximal and submaximal exercise. This is due to the greater efficiency of the cardiovascular system in producing energy aerobically. Recovery heart rate is a very good indicator of an athlete's aerobic fitness. The quicker their heart rate recovers back to resting levels, the more aerobically fit they are.

FIGURE 14.11 Cardiac output at rest and at maximal exercise for trained athletes and untrained males



14.4.8 Increased cardiac output during maximal exercise

While cardiac output remains unchanged at rest and even during submaximal exercise, regardless of training status, it does increase during maximal workloads. During maximal exercise, cardiac output may increase to values of 20–22 litres per minute for untrained males and 15–16 litres per minute for untrained females. In contrast, highly trained athletes have recorded values exceeding 30 litres per minute (see figure 14.11). The increase in cardiac output during maximal exercise is mainly due to the increase in stroke volume because maximum heart rate changes due to aerobic training are minimal.

EXAM TIP

Cardiac Output $\dot{Q}$ is the product of stroke volume and heart rate, so if you identify cardiac output as an improvement, you cannot separately identify stroke volume and/or heart rate as additional improvements.

14.4.9 Decreased blood pressure

An aerobic training program may lower blood pressure, especially among people who suffer from **hypertension**. Both **systolic** and **diastolic blood pressure** levels may decrease during both rest and exercise as a result of training. Improved blood vessel elasticity and function and reduced peripheral resistance contribute to a more efficient blood flow, which lowers blood pressure. This helps to reduce resistance to blood flow and reduces strain on the heart, thereby decreasing the risk of heart attack and other cardiovascular conditions.

FIGURE 14.12 A healthy blood pressure is generally considered to be systolic 120 mmHg / diastolic 80 mm/Hg.



14.4.10 Increased capillarisation of skeletal muscle

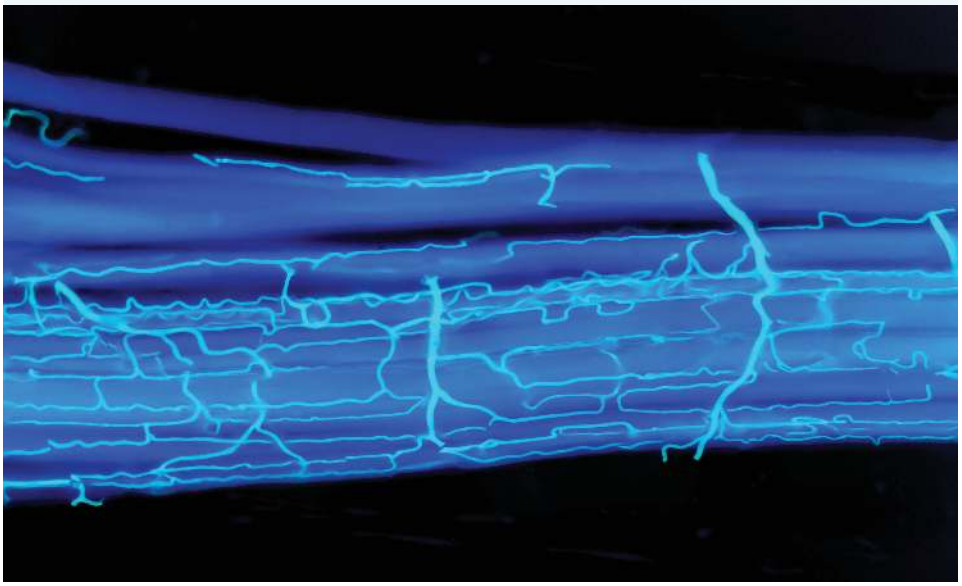
Long-term aerobic training leads to increased capillarisation of skeletal muscle (see figure 14.13). The average number of capillaries supplying each muscle fibre is 5.9 for trained athletes compared with 4.4 for untrained individuals. Greater capillary supply means increased blood flow, which in turn allows for greater supply of oxygen and nutrients to the muscles, and increased removal of by-products. An increase in the number of capillaries surrounding each muscle fibre is one of the most significant factors that leads to an increase in an athlete's VO_2 max. The diffusion of oxygen from the capillaries into the mitochondria is a major factor in maximising the rate of oxygen consumption by the muscles.

hypertension high blood pressure

systolic blood pressure the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure value

diastolic blood pressure the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.

FIGURE 14.13 A light micrograph image showing the blood supply to muscle fibers.

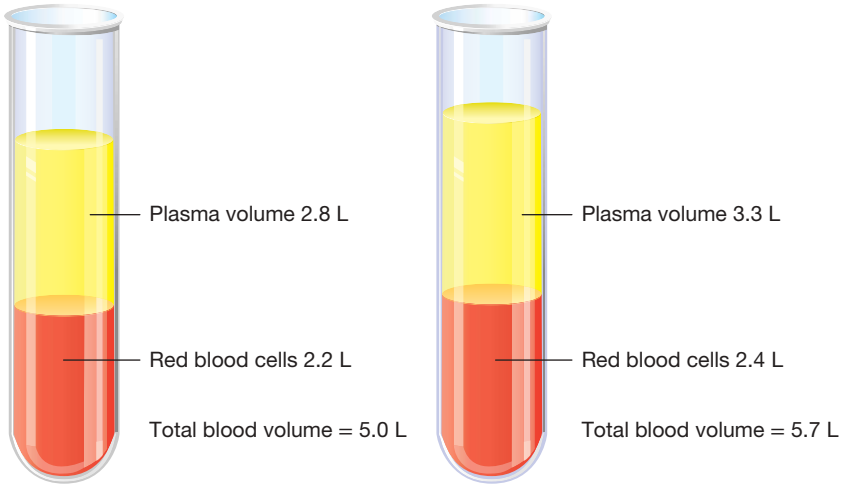


14.4.11 Increased blood volume

Regular and sustained aerobic training may lead to total blood volume rising by up to 25 per cent (from 5.25 litres to 6.6 litres) for an average adult male. As a result, red blood cells may increase in number and the haemoglobin content and oxygen-carrying capacity of the blood may also rise. This allows for a greater amount of oxygen to be delivered to the muscles and used by the athlete.

Blood plasma volume also increases significantly, from around 2.8 litres to 3.3 litres (see figure 14.14). This results in an increased ratio of plasma in the blood cells, which reduces the viscosity of the blood, allowing it to flow smoothly through the blood vessels. This improved blood flow enhances oxygen delivery to the muscles and also increases the capacity for thermoregulation.

FIGURE 14.14 Aerobic training effects on blood volume



on Resources

Digital document Recording sheet (doc-21031)

TABLE 14.2 Summary of the chronic adaptations to aerobic training: cardiovascular

	Adaptation to aerobic training
Heart size and volume	Increase
Capillarisation of heart muscle	Increase
Capillarisation of skeletal muscle	Increase
Total blood volume • Red blood cells/haemoglobin • Plasma volume	Increase Increase Increase

	Rest	Submaximal exercise	Maximal exercise
Stroke volume	Increase	Increase	Increase
Heart rate	Decrease	Decrease	No change
Recovery heart rate	N/A	Faster	Faster
Cardiac output	No change	No change	Increase
Blood pressure	Slight decrease	Slight decrease	Slight decrease

doc-41983

PRACTICAL ACTIVITY Cardiovascular chronic adaptations to aerobic training

Goal

To be able to explain how the cardiovascular system chronic adaptations to aerobic training lead to improved performance.

Instructions

1. Working with a partner of the same gender, you will both complete an exercise of the same intensity, for the same amount of time/duration (e.g. a 10-minute ride on a stationary bike set at the same cadence and resistance).
2. Use heart rate monitors or manual methods to measure your resting heart rate, each minute of your exercise heart rate and each minute of your recovery heart rate. Both partners need to do this.

Quick and simple guidelines to manually measure your heart rate.

- Place two fingers on the side of your neck to find your carotid pulse.
- Press firmly, but not too forcefully, so that you can feel the pulse.
- Count the number of beats for 10 seconds (count the first beat as 0), then multiply that number by 6.
- This will give you the number of times your heart beats per minute (bpm).

Primary data/Reflection

	Person 1	Person 2
Resting heart rate (HR)		
Exercise H — 1 minute		
Exercise HR — 2 minutes		
Exercise HR — 3 minutes		
Exercise HR — 4 minutes		
Exercise HR — 5 minutes		
Exercise HR — 6 minutes		
Exercise HR — 7 minutes		
Exercise HR — 8 minutes		
Exercise HR — 9 minutes		
Exercise HR — 10 minutes		
Recovery HR — 1 minute		
Recovery HR — 2 minutes		
Recovery HR — 3 minutes		
Recovery HR — 4 minutes		
Recovery HR — 5 minutes		

- Enter the results on a line graph.
- Analyse the results for the resting heart rates, the exercise heart rates and the recovery heart rates.

Questions

1. Compare the heart rate responses for each person.
2. Identify which person is likely to be more aerobically trained. Justify your response.
3. List three other cardiovascular adaptations that a person would experience as a result of undertaking aerobic training.
4. Discuss how each of the cardiovascular adaptations you listed in question 3 would contribute to improved road cycling performance.

14.4 Activity

14.4 Quick quiz on | **14.4 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1	2, 4, 6	3, 5

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TEST your understanding

1. a. **Identify** three types of athlete who are most likely to benefit from cardiovascular adaptations as a result of participating in a long-term aerobic training program.
   b. **Define** *cardiac output* and outline its parameters.
2. **Complete** the table below by indicating whether the physiological parameter has increased, decreased or remained unchanged as a result of participating in a long-term aerobic training program.

Physiological parameter	At rest	During submaximal exercise	During maximal exercise
Left ventricle size and volume			
Heart rate			
Stroke volume			
Cardiac output			
Blood pressure			
Capillarisation of skeletal muscle			
Blood volume			

APPLY your understanding

3. a. **Outline** four chronic adaptations that may occur in the cardiovascular system as a result of participating in a long-term aerobic training program.
   b. Clearly **explain** how these adaptations bring about improved performance.
4. **Discuss** the relationship between heart rate, stroke volume and cardiac output.
5. **Explain** why heart rate decreases at rest and during submaximal workloads but not during maximal workloads.
6. **Discuss** why trained athletes are able to deliver more oxygen to their working muscles as a result of blood volume changes.

14.4 Exam questions

Question 1 (1 mark)

Source: *VCE 2018, Physical Education Exam, Section A, Q.7;* © VCAA

During exercise, an individual's heart rate and the force of their heart's contractions are increased.

As a result, there is

A. no change in systolic blood pressure.
B. a decrease in systolic blood pressure.
C. an increase in systolic blood pressure.
D. a large decrease in diastolic blood pressure.

Question 2 (1 mark)

Source: *VCE 2021, Physical Education Exam, Section A, Q.6;* © VCAA

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

Which of the following most accurately identifies the cardiovascular responses shown in the table above?

A.

Response 1	Response 2	Response 3	Response 4
maximal cardiac output (L/min)	resting heart rate (bpm)	maximal stroke volume (mL/beat)	maximal heart rate (bpm)

B.

Response 1	Response 2	Response 3	Response 4
maximal stroke volume (mL/beat)	maximal heart rate (bpm)	maximal cardiac output (L/min)	resting heart rate (bpm)

C.

Response 1	Response 2	Response 3	Response 4
maximal cardiac output (L/min)	maximal heart rate (bpm)	maximal stroke volume (mL/beat)	resting heart rate (bpm)

D.

Response 1	Response 2	Response 3	Response 4
maximal heart rate (bpm)	maximal stroke volume (mL/beat)	maximal cardiac output (L/min)	resting heart rate (bpm)

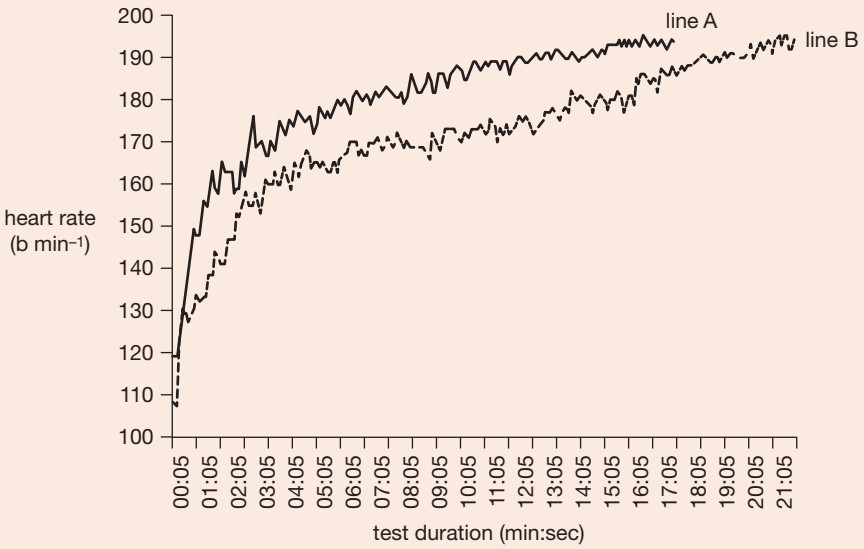
Question 3 (4 marks)

Source: Adapted from *VCE 2022, Physical Education Exam, Section B, Q.10.d;* © VCAA

During a soccer match, soccer referees cover significant ground to be able to best adjudicate the game.

Before commencing the fartlek training program, the soccer referees completed an aerobic fitness test. The aerobic fitness test was repeated after they finished the fartlek training program. The test results for one referee are shown in the graph below.

Heart rate response during aerobic fitness test before and after fartlek training program



Source: Adapted from M Weston et al., 'The impact of specific high-intensity training sessions on football referees' fitness levels', *The American Journal of Sports Medicine*, vol. 32, no. 1, suppl., 2004, p. 58S; © 2004 AJSM/SAGE; reprinted by permission of SAGE Publications

Referring to the data in the graph above, **identify** which line — line A or line B — shows the test result after the fartlek training program. **Justify** your response by referring to **two** chronic adaptations that would explain the improved test result.

Question 4 (3 marks)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.14.d;* © ACHPER

Chronic adaptations achieved by undertaking a Long Interval training method include decreased resting and submaximal heart rates.

Using your understanding of the relationship of cardiac output, stroke volume and heart rate, **explain** how these adaptations will lead to improved performance of a recreational cyclist at maximal intensities.

Question 5 (10 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.3;* © VCAA

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
submaximal heart rate (bpm)	140	130	160	160	130	125
stroke volume (sub-maximal) (mL/beat)	110	135	110	115	140	155
maximum a-vO_2 diff (mL of O_2/100 mL of blood)	12	16	12	12	16	18

Subject 1 and Subject 3 undertook the same training program for the three-month period. Subject 2 participated in a different training program.

a. What type of training did Subject 1 and Subject 3 most likely undertake? **Justify** your response using data from the results table above. **(3 marks)**

b. **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. **(3 marks)**

c. With reference to intensity, **discuss** reasons why Subject 3 did not show the same improvement as Subject 1. Use data from the results table above to support your response. **(4 marks)**

More exam questions are available in your learnON title.

14.5 Chronic adaptations to aerobic training: muscular

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular system to aerobic, anaerobic and resistance training that produce improvements	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

Chronic aerobic training adaptations within muscle tissue are best produced through continuous, fartlek and long interval training, high-intensity interval training, aerobic circuit training or high-repetition, low-weight resistance training.

14.5.1 Aerobic training

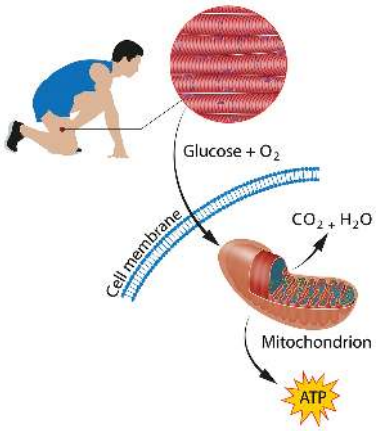
Aerobic training enhances the body's ability to attract oxygen into the muscle cells and then use it to resynthesise adenosine triphosphate (ATP) for muscular contractions. More oxygen initially surrounds the muscle through increased capillary density, and then the myoglobin and mitochondria work together to use the oxygen to resynthesis ATP aerobically. This process relies on the increased size and number of mitochondria and increased myoglobin stores.

Increased size and number of mitochondria

The mitochondria are the sites of aerobic ATP resynthesis and where glycogen and triglyceride stores are oxidised (see figure 14.15).

The greater the number and size of the mitochondria located within the muscle, the greater the oxidisation of fuels to produce ATP aerobically.

FIGURE 14.15 Aerobic ATP production occurs in the mitochondria.

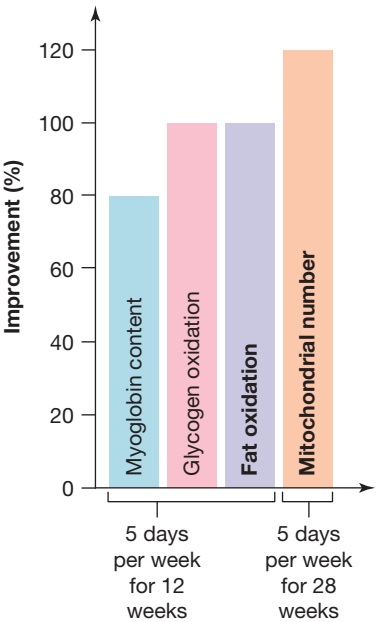


Increased myoglobin stores

Aerobic training increases the myoglobin content in the muscle and therefore its ability to extract oxygen and deliver it to the mitochondria for energy production. When oxygen is diffused into the muscle fibre, it binds with myoglobin, which then shuttles the oxygen to the mitochondria. Myoglobin stores can increase up to 80 per cent from undertaking an aerobic training program.

Figure 14.16 illustrates the effect of aerobic training on mitochondrial numbers and myoglobin content in muscle tissue.

FIGURE 14.16 Effects of aerobic training on muscle tissue



EXAM TIP

Think of myoglobin as a *taxi* that picks up the oxygen from the haemoglobin in the red blood cells and delivers it to the mitochondria in the muscle cells.

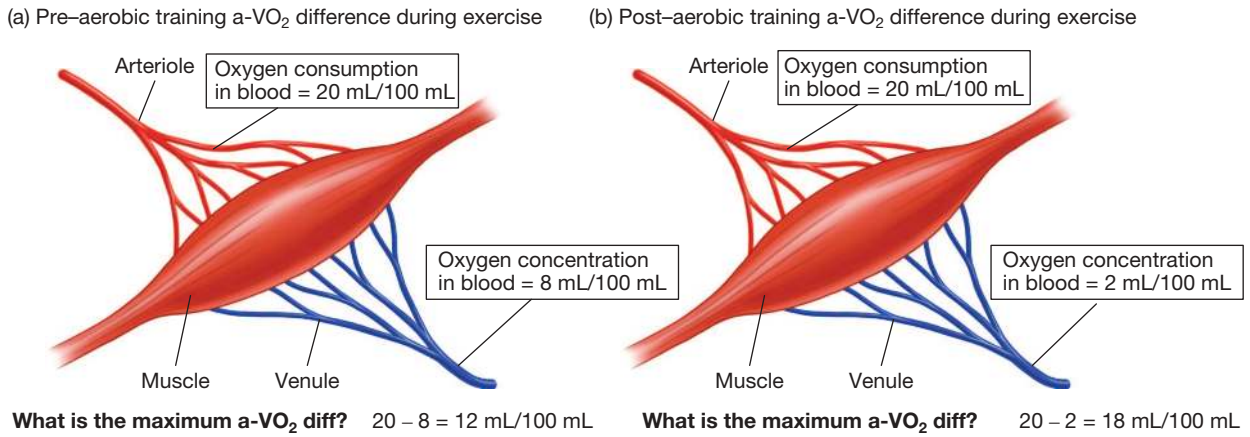
on Resources

Weblink Mitochondria

14.5.2 Increased arteriovenous oxygen difference

Trained athletes are able to extract more oxygen from their bloodstream into their muscles during exercise performance compared with untrained individuals. This is due to increased muscle myoglobin stores and an increased number and size of mitochondria within their muscles (muscular aerobic adaptations). As a result of this, the concentration of oxygen within the venous blood is lower, and subsequently the **arteriovenous oxygen difference (a-VO_2 diff)** is increased during both submaximal and maximal exercise. An increased a-VO_2 diff indicates a greater uptake of oxygen by the muscles, which gives the athlete a greater capacity to produce energy aerobically (see figure 14.17). A greater a-VO_2 diff due to aerobic training is also caused by the increased distribution of blood flow to the working muscles as a result of improved cardiovascular parameters.

FIGURE 14.17 Effects of aerobic training on muscle tissue



14.5.3 Increased muscular fuel stores and oxidative enzymes

Aerobic training increases the muscular storage of glycogen and triglycerides in the slow-twitch muscle fibres, and there is also an accompanying increase in the **oxidative enzymes** that are responsible for metabolising these fuel stores to produce ATP aerobically. This means that there is less reliance upon the anaerobic glycolysis system until higher intensities.

14.5.4 Increased oxidation of glucose and triglycerides

The muscular adaptations already discussed in this section result in an increase in the capacity of muscle fibres to oxidise both glucose and triglycerides. In other words, the capacity of the aerobic system to metabolise these fuels is increased (see figure 14.16). Furthermore, the increased oxidation of fats as a fuel source — due to the increased storage of triglycerides, plus the vastly increased levels of enzymes associated with triglyceride metabolism — means that, at any given exercise intensity, a trained athlete has to rely less on glycogen, thereby 'sparing' their glycogen stores. This process is referred to as **glycogen sparing**. In essence, this allows the athlete to sustain a higher level of intensity, maintaining a faster pace, which ultimately results in an improved aerobic performance.

arteriovenous oxygen difference (a-VO_2 diff) a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.

oxidative enzymes enzymes that, with the use of oxygen, speed up the breakdown of nutrients to resynthesise ATP

glycogen sparing the process whereby glycogen stores are not used as early in an exercise bout due to the increased ability to use triglycerides to produce energy. This delays depletion of glycogen stores, and thereby delays the time to exhaustion.

14.5.5 Adaptation of muscle fibre type

On the basis of various structural and functional characteristics, skeletal muscle fibres are classified into three types: type 1 slow-twitch oxidative fibres, type 2A fast-twitch oxidative fibres and type 2B fast-twitch glycolytic fibres (see table 14.3). Some evidence has shown that fast-twitch skeletal muscle type A fibres can take on the characteristics of slow-twitch type fibres as a result of endurance training. Some researchers have also demonstrated that fast-twitch type 2B fibres are recruited more in a manner that represents the more oxidative fast-twitch type 2A fibres as a result of endurance training. Slow-twitch muscle type fibres will increase in cross-sectional area as a result of endurance training, and the extent of the increase depends on the intensity and duration of training.

Type 1 slow-twitch oxidative fibres contain large amounts of myoglobin, and large numbers of mitochondria and blood capillaries. Type 1 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 through oxidative metabolic processes.

Type 2A fast-twitch oxidative fibres contain a large amount of myoglobin, and large numbers of mitochondria and blood capillaries. Type 2A fibres are red, have a very high capacity for generating ATP through oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity, and are resistant to fatigue.

Type 2B fast-twitch glycolytic fibres contain a low myoglobin content, relatively few mitochondria and blood capillaries, and large amounts of glycogen. Type 2B fibres are white, are geared to generate ATP through anaerobic metabolic processes, fatigue easily, split ATP at a fast rate, and have a fast contraction velocity.

type 1 slow-twitch oxidative fibres contain large and numerous mitochondria, high levels of myoglobin and a high capillary density. They are very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolism.

type 2A fast-twitch oxidative fibres red fibres; have a very high capacity for generating ATP by oxidative metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.

type 2B fast-twitch glycolytic fibres white fibers; are geared to generate ATP by anaerobic metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and fatigue easily.

TABLE 14.3 Characteristics of fast- and slow-twitch muscle fibres

Characteristic	Slow-twitch	Fast-twitch oxidative	Fast-twitch glycolytic
Also known as	Type 1	Type 2A	Type 2B
Colour	Red	Red	White
Used for	Aerobic	Anaerobic (long-term)	Anaerobic (short-term)
Fibre size	Small	Medium	Large
Motor neuron size	Small	Large	Very large
Resistance to fatigue	High	Medium	Low
Force production	Low	High	Very high
Speed of contraction	Slow	Fast	Very fast
Hypertrophy potential	Low	High	High
Mitochondrial density	High	High	Low
Capillary density	High	Medium	Low
Myoglobin content	High	Medium	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	High	High
Major fuel	Triglycerides	Creatine phosphate/glycogen	Creatine phosphate/glycogen

Individual muscles are a mixture of the three types of muscle fibres (see figure 14.18), but their proportions vary depending on the action of the muscle and the genetic make-up of the individual. The Type 2B muscle fibre transformation is a very gradual process and can actually take years to manifest. The transformed fibres show a slight increase in diameter, mitochondria and capillaries but not a change in fibre type. This brings them to a level at which they are able to perform oxidative metabolism as effectively as the Type 1 slow-twitch fibres of untrained individuals.

FIGURE 14.18 Cross-section of skeletal muscle fibre

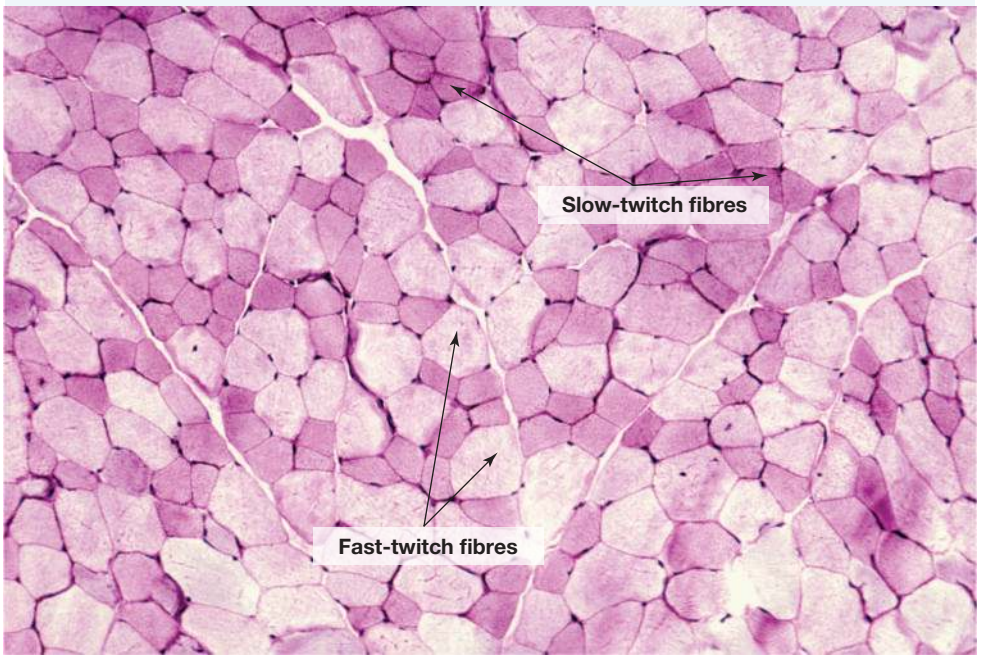


TABLE 14.4 Summary of chronic adaptations to aerobic training: muscular

	Adaptation to aerobic training		
Mitochondria size and number	Increase		
Myoglobin content/stores	Increase		
Fuel stores • Glycogen stores • Triglyceride stores	 Increase Increase		
Oxidative enzymes	Increase		
Slow-twitch muscle fibre size	Increase		
Muscle fibre type	No change; however, fast-twitch oxidative (type 2A) fibres may take on characteristics of slow-twitch fibres		
	Rest	**Submaximal exercise**	**Maximal exercise**
a-VO_2 difference	N/A	Increase	Increase
Oxidation of fat	Increase	Increase	
Oxidation of glycogen		Decrease	Increase
Glycogen sparing	N/A	Increase	

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PRACTICAL ACTIVITY Muscular chronic adaptations to aerobic training

Goal

To be able to explain how the muscular system chronic adaptations to aerobic training lead to improved performance.

Instructions

1. Design an aerobic-based fixed-time circuit training session for a sport of your choice (refer to topic 13) for your class to participate in.
2. Make sure that you incorporate a proper warm up and cool down.

Primary data/Reflection

- You may like to use the template below to design and record the training session, or you can create your own.
- Take notes about how the participants are feeling when completing each activity.

TABLE 1 Sample template to record information from the training session

Exercise	Intensity/Load	Work period Time/Duration	Rest period Time/Duration	W:R ratio	Sets	Notes and reflections
1. Skipping	NA	30 seconds	30 seconds	1:1	3	
2. Abdominal curls	Body weight	30 seconds	30 seconds	1:1	3	
3. Step-ups	NA	30 seconds	30 seconds	1:1	3	
4. Push-ups	Body weight	30 seconds	30 seconds	1:1	3	
5. Fast feet	NA	30 seconds	30 seconds	1:1	3	
6. Lunges	Body weight	30 seconds	30 seconds	1:1	3	
7. Prone medicine ball throw	3 kilograms	30 seconds	30 seconds	1:1	3	
8. 10-metre shuttle runs	NA	30 seconds	30 seconds	1:1	3	

Questions

1. List the muscular adaptations that would occur for an athlete undertaking this type of training session 3 × week for 6 weeks.
2. Discuss how each of the muscular adaptations you listed in question 1 would contribute to improved performance while competing in an endurance ocean swim.

14.5 Activity

14.5 Quick quiz on | **14.5 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3	1	4, 5, 6, 7

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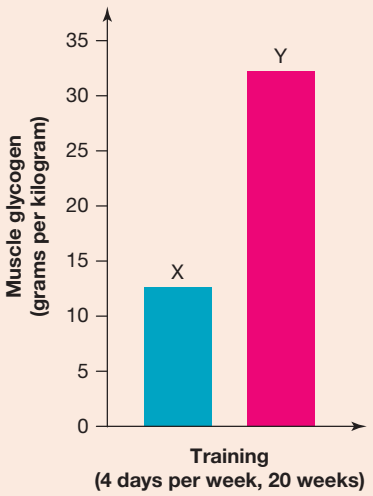
1. **Complete** the table below by indicating whether the physiological parameters have increased, decreased or remained unchanged as a result of involvement in a long-term aerobic training program.

Physiological parameter	At rest	During submaximal exercise	During maximal exercise
a-VO_2 difference			
Size and number of mitochondria			
Myoglobin stores			
Muscular fuel stores (glycogen, triglycerides)			
Oxidisation of fats			
Oxidation of glycogen			

2. **Outline** the adaptations to muscle fibre type that have been shown to occur as a result of aerobic training.
3. a. **Identify** the role of mitochondria and explain how they are affected by undertaking an aerobic training program.
   b. **Identify** the role of myoglobin and explain how it is affected by undertaking an aerobic training program.

APPLY your understanding

4. **Explain** how increased mitochondria and myoglobin in the muscle cell improves aerobic performance.
5. Refer to the figure below. Which column (X or Y) indicates muscle glycogen stores after completion of a 20-week aerobic training program? **Explain** your answer.
6. **Explain** which particular characteristics of fast-twitch type 2A fibres would be of benefit to an endurance athlete.
7. **Explain** how an increase in the number of oxidative enzymes will benefit the performance of an endurance athlete.



14.5 Exam questions

Question 1 (3 marks)

Source: *VCE 2021, Physical Education Exam, Section B, Q.11;* © VCAA

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.

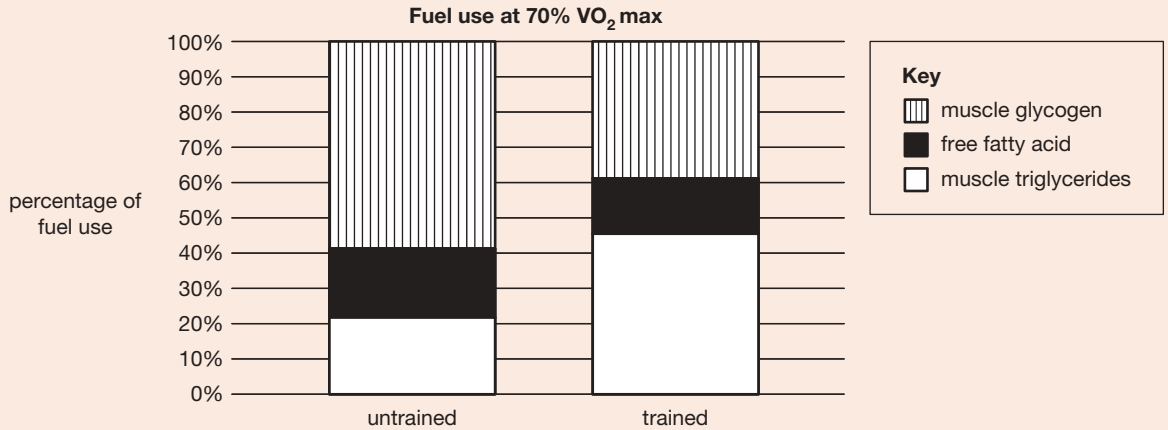
A well-trained 800 m track runner attempted to hold Kipchoge's average pace. They had to run at maximal intensity and, due to fatigue, they were unable to continue after 1 km.

i. **State one** chronic muscular adaptation that leads directly to an improvement in LIP. **(1 mark)**
ii. **Describe** the role that the chronic muscular adaptation stated in **part a.i.** plays in improving LIP. **(2 marks)**

Question 2 (4 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.11;* © VCAA

The graph below shows the changes in fuel use for a cross-country runner before and after a 12-week training program.



a. **Identify** the type of training that would cause the changes shown in the graph. **(1 mark)**
b. Referencing the data, **explain** how the adaptation shown in the graph will improve the performance of the cross-country runner. **(3 marks)**

Question 3 (3 marks)

Source: *ACHPER 2019, Trial Exam Units 3 & 4, Section B, Q.6.d;* © ACHPER

An instructor at a local gymnasium conducted a High Intensity Interval Training (HITT) session in a 'Spin Cycle' class for a group of adults aged over 18.

Warm Up	2 minutes cycling at 60% Heart Rate Maximum (HRM) 4 minutes cycling at 65% (HRM) 4 minutes cycling at 70% (HRM)
Training Bout	7 repetitions × • 40 seconds cycling at 90% (HRM) • 20 seconds cycling at 65% (HRM)
Cool Down	5 minutes cycling at 60% (HRM) 5 minutes stretching

a. **Identify two** muscular training adaptations likely to occur if participants completed this class three times each week for six weeks. **(1 mark)**
b. Select one of your responses from **part a** and **explain** how this adaptation would lead to improved performance for the participant in this class. **(2 marks)**

Question 4 (3 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.13.b;* © VCAA

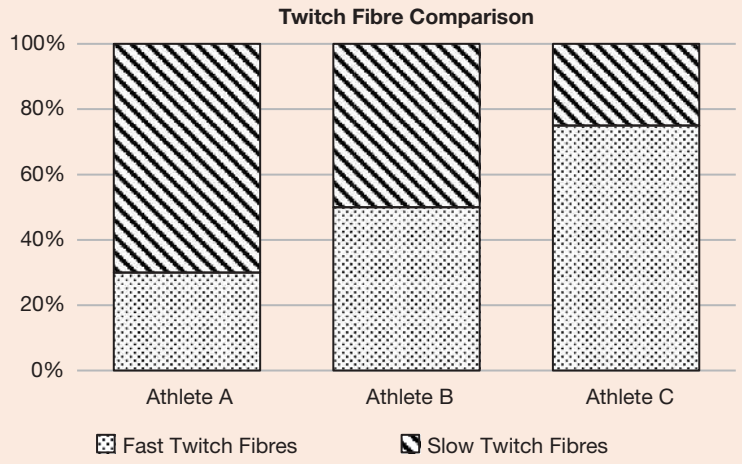
At the onset of exercise, oxygen consumption does not increase to a steady state immediately. Trained athletes are able to achieve a steady state more rapidly than untrained individuals.

Other than an increase in the oxidative enzymes, what are three chronic adaptations to the muscular system that facilitate the rate of reaching a steady state for the trained athlete?

Question 5 (3 marks)

Source: Adapted from *ACHPER 2016, Trial Exam Units 3 & 4, Section B, Q.11.a,b;* © ACHPER

The following graph shows the percentage of fast twitch fibres in the gastrocnemius (calf) muscle of three trained athletes.



a. Provide two characteristics of slow twitch muscle fibres. **(2 marks)**
b. **Identify** which athlete A, B or C would be best suited to aerobic events. **(1 mark)**

More exam questions are available in your learnON title.

14.6 Chronic adaptations to aerobic training: VO_2 maximum and lactate inflection point

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic, anaerobic and resistance training that produce improvements in: – VO_2 max – lactate inflection point (LIP)	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

14.6.1 Increased maximum oxygen uptake: VO_2 max

Aerobic training results in an increase in the **maximum oxygen uptake (VO_2 max)** during maximal exercise. This improvement can be in the range of 5–30 per cent, following a regular and sustained training program. It comes about because of adaptations such as increases in cardiac output, red blood cell numbers, a-VO_2 difference and muscle capillarisation, as well as greater oxygen extraction by the muscles by the myoglobin.

VO_2 max is the maximum amount of oxygen that can be taken in by the respiratory system, transported by the cardiovascular system and utilised by the muscular system to produce ATP. It is the point at which an athlete cannot increase the amount of oxygen they take in, transport and utilise, despite an increase in their exercise intensity. An increase in VO_2 max from aerobic training is due to aerobic chronic adaptations in the respiratory system (e.g. increased pulmonary diffusion), cardiovascular system (e.g. increased blood haemoglobin concentration) and muscular system (e.g. an increase in mitochondria).

maximum oxygen uptake (VO_2 max) the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production

relative VO_2 max a measurement that takes into account body weight and is given in mL/kg/min

absolute VO_2 max a measurement of the total amount of oxygen consumed in L/min

lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.

- An athlete's VO_2 max is simply a combination of their cardiac output ($\dot{Q}$) × a-VO_2 difference.
- **Relative VO_2 max** is measured in millilitres of oxygen per kilogram of body weight per minute (mL/kg/min).
- Body weight is taken into account so that comparisons can be made between athletes. This measurement determines how much oxygen is used per kilogram of body weight.
- **Absolute VO_2 max** is measured in litres per minute (L/min) and identifies the amount of oxygen consumed, irrespective of body weight. This does not allow for comparisons between athletes.

on Resources

Weblink VO_2 maximum

14.6.2 Increased lactate inflection point

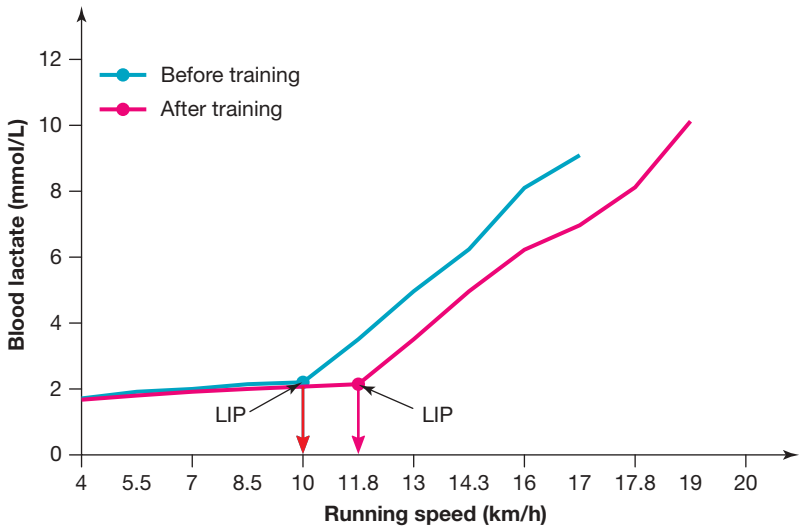
As a result of the aerobic adaptations that improve oxygen delivery and use in the muscles (more efficient aerobic energy system usage) and economy, a higher **lactate inflection point (LIP)** develops. LIP represents the highest intensity point at which there is a balance between lactate production and removal from the blood.

It is identified as the final intensity or oxygen uptake value at which the blood lactate concentration is relatively stable (i.e. the blood lactate steady state). The advantage of having a higher LIP is that the aerobic system can produce energy at a faster rate, so there is less reliance on the anaerobic glycolysis system until higher exercise intensities are reached. Consequently, lactate and **hydrogen ion** accumulation are delayed. Put simply, this means that the athlete can work at higher intensities for longer periods without feeling fatigued due to hydrogen ion accumulation. At exercise intensities beyond the LIP, blood lactate concentration increases exponentially and is associated with a rapid onset of fatigue due to the increased contribution from anaerobic pathways to meet the ATP demands of exercise. The greater the exercise intensity above the inflection point, the more rapid the onset of fatigue. LIP also coincides with a number of other changes within the body, such as a surge in adrenaline, recruitment of fast-twitch muscle fibres to facilitate the speed/power output, and a decline in the rate at which enzymes can oxidise fatty acids and pyruvate in the mitochondria.

As seen in figure 14.19, the LIP is the point of inflection on the curve of blood lactate versus exercise intensity (running speed) above which the rate of lactate production exceeds removal and blood lactate concentrations continue to increase disproportionally with increasing exercise intensity (running speed). There is a right shift on the graph for a trained athlete with a higher LIP.

hydrogen ion the presence of these ions makes the muscle acidic and will eventually fatigue muscle function

FIGURE 14.19 Training effects on blood lactate level in relation to running speeds



Source: Adapted from http://www.sport-fitness-advisor.com/lactate-threshold-training.html

Aerobic training at an intensity near the LIP is appropriate for an untrained individual, but a higher intensity is necessary for endurance-trained athletes. An athlete's LIP can be delayed until higher intensities without any variations to their VO_2 max. This is due to an increased aerobic metabolism at these higher intensities, as a result of greater mitochondrial mass and an increased ability to oxidise fat and carbohydrates in response to aerobic training.

Where maximal oxygen uptake (VO_2 max) is equivalent between athletes, LIP is more likely to distinguish the performances of middle- and long-distance athletes. LIP is often expressed as a percentage of an athlete's VO_2 max or maximum heart rate (MHR). An elite endurance athlete will reach their LIP at 80–90 per cent VO_2 max or 85 per cent MHR.

EXAM TIP

Be able to:

- define LIP
- identify the LIP on a graph
- explain why lactate accumulates beyond the LIP
- describe the impact of exercise intensities beyond the LIP on fatigue
- distinguish the differences in LIP between trained and untrained athletes
- discuss how training can improve the LIP.

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PRACTICAL ACTIVITY VO_2 max and LIP chronic adaptations to aerobic training

Goal

To be able to explain how VO_2 max and LIP chronic adaptations to aerobic training lead to improved performance.

Instructions

1. Form teams of 6–8 participants. You will be participating in a long interval Paarlauf relay (a form of continuous relay in which each participant runs several times).
2. Each team's participants must space themselves evenly around the boundary of an oval. One member of each team starts with a baton.
3. The first runner for each team runs to the second runner, hands over the baton and waits at this point. The second runner runs to the third runner, hands over the baton and waits, and so on around the oval. When the baton gets back to the first runner, they run again and the relay continues.
4. Teams continue running, passing the baton, until time is called (whistle blown) after 6–8 minutes.
5. The winning team is the one that has run the furthest distance when time is called.
6. Make sure to cool down appropriately.

Primary data/Reflection

- Gather feedback from the participants in relation to how they felt during the Paarlauf relay and how hard they worked (their rate of perceived exertion (RPE)) using a scale from 1 to 10, where:
  1 to 3 = very light
  4 to 6 = somewhat hard
  7 to 8 = very hard
  9 to 10 = extremely strenuous
- Optional: record the heart rate data of some of the participants at similar intervals throughout the session.

Questions

1. Discuss how participating in this type of training session 3 times a week for 8 weeks would increase VO_2 max.
2. Evaluate whether you think the intensity of the Paarlauf relay would improve LIP.
3. Outline how having a high VO_2 max and LIP would benefit a marathon runner.
4. Outline how two marathon runners who have recorded the same VO_2 max (mL/kg/min) might complete a marathon with different times.

14.6 Activity

14.6 Quick quiz on | **14.6 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3, 7	4, 5	1, 6, 8

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TEST your understanding

1. **Explain** the physiological aspects that combine to determine a person's VO_2 maximum.
2. **Identify** the approximate maximum oxygen uptake values of three different types of Australian sportspeople.
3. **Define** the term *lactate inflection point* and **outline** at what percentage of maximum heart rate the LIP generally occurs in elite athletes.

APPLY your understanding

4. **Discuss** how each of the three systems (cardiovascular, respiratory and muscular) contribute to an athlete's VO_2 maximum.
5. **Discuss** why VO_2 maximum is measured in millilitres of oxygen per kilogram of body weight.
6. **Explain** how one specific aerobic adaptation for each system would lead to an improvement to an athlete's VO_2 maximum.
7. **Describe** how aerobic training can improve an athlete's LIP.
8. **Identify** the type of athlete who would benefit from having an improved LIP and **explain** how having a higher LIP would improve that particular athlete's performance.

14.6 Exam questions

Question 1 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.6;* © ACHPER

A chronic adaptation which may contribute to an improvement to an endurance athlete's LIP would be

A. an increased tolerance to metabolic by products.
B. an increased number and density of mitochondria.
C. a decreased resting heart rate.
D. a decreased systolic blood pressure.

Question 2 (1 mark)

Source: *VCE 2017, Physical Education Exam, Section A, Q.2;* © VCAA

An improvement in the lactate inflection point (LIP) of an endurance athlete can be attributed to

A. insufficient oxygen supply.
B. an increase in lactate tolerance.
C. lactate production exceeding lactate removal.
D. an increase in the ability of the muscle fibres to oxidise fats and carbohydrates.

Question 3 (5 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.2.b,c;* © VCAA

Elite road cyclists can have a VO_2 maximum score of over 80 ml/kg/min. This is considered a relative oxygen consumption value.

a. **Explain** why a relative oxygen consumption value is more relevant for an elite cyclist compared with absolute oxygen consumption value. **(2 marks)**
b. **Identify** and **describe one** chronic adaptation of the cardiovascular system to training and **explain** how this would lead to a higher VO_2 maximum. **(3 marks)**

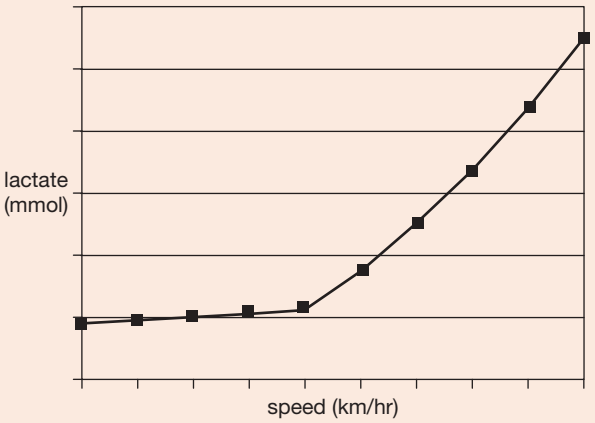
Question 4 (4 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.9.g,h;* © VCAA

Emily is a well-trained recreational runner who is training to complete the 10 km run at the Melbourne Marathon Festival. She hopes to complete the run in 35 minutes. To prepare for the run, she has completed a 12-week training program. Below is an example of a typical training session that Emily would complete.

Running around the athletics track for 6 × 4-minute repetitions with 2 minutes' rest between repetitions at 75–85% HR max.

The graph below illustrates Emily's lactate levels measured throughout one of her training sessions in week 1.



Draw on the graph the expected change to Emily's lactate concentration for the same training session completed in week 12. **(1 mark)**

Discuss one adaptation of the muscular system to aerobic training that could improve Emily's lactate inflection point and **explain** how this would enhance her performance in the 10 km Melbourne Marathon Festival run. **(3 marks)**

Question 5 (4 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.4.c,d;* © VCAA

a. **Explain** how an improved lactate inflection point (LIP) would be an advantage for a distance runner. **(2 marks)**
b. **Describe** how an increase in the oxidative enzymes leads to an improved LIP. **(2 marks)**

More exam questions are available in your learnON title.

14.7 Chronic adaptations to anaerobic training: muscular

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular system to aerobic, anaerobic and resistance training that produce improvements in: – speed and force of muscular contraction – lactate tolerance.	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

As previously mentioned, anaerobic training effects are best developed through short and intermediate interval training, plyometric training, circuit training and resistance (strength and power) training. The greatest adaptations occur at the muscular system level.

myofibrils small fibres that run through each muscle fibre

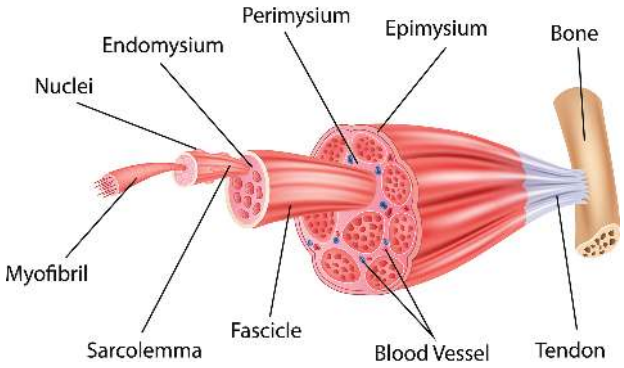
14.7.1 Muscular hypertrophy

Anaerobic training can lead to significant enlargement of muscle fibres (mainly Type 2A and 2B fast-twitch fibres), resulting in muscular hypertrophy (see figure 14.20). This hypertrophy occurs as a result of an increased size and number of **myofibrils** per muscle fibre (see figure 14.21) and increased amounts of myosin and actin myofilaments. Muscular hypertrophy is more pronounced in males than females due to greater levels of testosterone in men.

FIGURE 14.20 This female athlete's chronic responses to anaerobic resistance training have led to muscular hypertrophy.



FIGURE 14.21 Structure of skeletal muscles

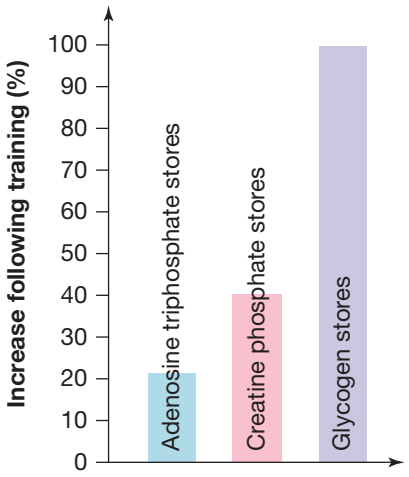


Muscle hypertrophy involves an increase in the cross-sectional area of muscle fibers, which leads to an enhanced force-generating capacity, a greater power output and an increased speed of contraction.

14.7.2 Fuel stores and enzymes

Muscular hypertrophy is accompanied by increased muscular stores of ATP and creatine phosphate (CP) (see figure 14.22). This increases the capacity of the ATP–CP system, allowing for faster resynthesis of ATP for high-intensity activities.

FIGURE 14.22 Effects of anaerobic training on muscular stores of ATP, CP and glycogen



There is also an increase in the enzymes required to break down and resynthesise ATP: specifically, ATPase, which is responsible for breaking down ATP to form ADP and release energy for muscular contraction, and creatine kinase, which initiates the breakdown of CP and provides the energy to resynthesise ATP at a fast rate. This increases the capacity of the ATP–CP system, allowing greater energy release and faster restoration of ATP. This benefits the athlete in activities that require speed, strength and power.

14.7.3 Increased glycolytic capacity

Enhanced muscular storage of glycogen and increases in the levels of glycolytic enzymes are also adaptations accompanying anaerobic training (see figure 14.22). The increase in glycogen synthase promotes the conversion of glucose into glycogen, which facilitates the storage of glycogen in the muscles. The muscles also become more efficient at using the glycogen for ATP resynthesis. Consequently, the capacity of the anaerobic glycolysis/non-oxidative system to produce energy is enhanced.

14.7.4 Motor unit recruitment

The ability of the nerve axons to innervate (supply) their corresponding muscle fibres increases as a result of anaerobic training. The greater the number of **motor units** that can be recruited, the greater the strength and power that can be produced by a muscle.

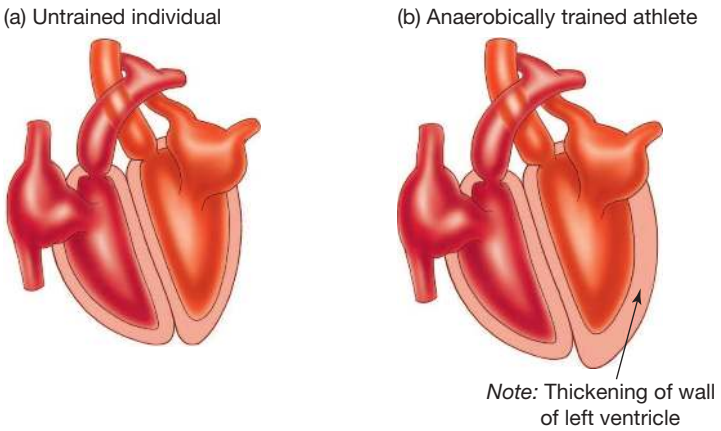
motor unit consists of one motor neuron and all of the muscle fibres that it innervates

14.7.5 Cardiac hypertrophy

Sustained anaerobic training results in the hypertrophy (enlargement) of the heart muscle itself. However, rather than increasing the size, and therefore volume, of the ventricular chambers, which occurs after prolonged

aerobic training, anaerobic training produces an increase in the thickness of the ventricular walls (see figure 14.23). While little or no change in stroke volume occurs, a more forceful contraction takes place and hence a more forceful ejection of blood from the heart.

FIGURE 14.23 Effects of anaerobic training on cardiac hypertrophy. Following intense sustained anaerobic training, the thickness of the ventricular wall increases, particularly in the left ventricle, but there is no increase in the volume of the ventricular cavity.



14.7.6 Increase in lactate tolerance

buffering capacity the ability of the muscle cell buffers to resist changes in pH (acidity)

When an athlete is working anaerobically, this means they are working above their LIP and are producing lactate at a faster rate than it can be removed. The body learns to tolerate the increased levels of lactate and H^+ ions and increases its **buffering capacity**. Anaerobic training increases the ability of the muscles to buffer (neutralise) the acid that accumulates from the production of hydrogen ions during an exercise bout. Buffers such as bicarbonate and muscle phosphates combine with the hydrogen ions to neutralise the increases in acidity. The increase in lactate tolerance delays the onset of fatigue and allows an athlete to continue to generate ATP anaerobically, which occurs at a faster rate and allows them to work at a higher intensity. At the end of their performance, they will have high lactate levels.

Any athlete that requires a significant contribution from the anaerobic glycolysis system, such as a 400 metre or 800 metre runner, will benefit from having an improved lactate tolerance.

TABLE 14.5 Summary of chronic adaptations to anaerobic training: muscular

	Adaptation to anaerobic training		
Muscular hypertrophy	Increase		
Fuel stores			
• ATP	Increase		
• CP	Increase		
• Glycogen	Increase		
Enzymes			
• ATPase	Increase		
• Creatine kinase	Increase		
• Glycogen synthase	Increase		
	Rest	**Submaximal exercise**	**Maximal exercise**
Motor unit recruitment	N/A	Increase	Increase
Speed and force of muscular contraction	N/A	Increase	Increase
Lactate tolerance	N/A	Increase	Increase

14.7.7 Chronic adaptations to training: athlete comparison — anaerobic and aerobic

FIGURE 14.24 Kristina's chronic anaerobic adaptations allow her to generate a greater amount of pedalling speed, force and power output.

Athlete: Kristina Clonan
Competition: 2023 Cycling World Championships
Event: 500-metre time trial
Time: 33.004 seconds

Chronic adaptations: anaerobic

Muscular

- increased muscle hypertrophy
- increased ATP, CP and glycogen fuel storage
- increase in ATPase and creatine kinase enzymes
- increase in motor unit recruitment
- increased neuromuscular functioning
- increased speed and force of muscular contraction
- increased lactate tolerance

Result: Achieving faster speeds and quicker times



FIGURE 14.25 Jazz's chronic aerobic adaptations allow her to more efficiently resynthesise ATP aerobically and improve her economy in the swim, bike and running legs.

Athlete: Jazz Hedgeland
Competition: 2023 World Triathlon
Time: 01:56:11 (total)
Swim: 00:20:09
Bike: 00:58:17
Run: 00:36:00

Chronic adaptations: arobic

Respiratory
- increased max. ventilation (TV x RF)
- increased pulmonary diffusion

Muscular
- increase in a VO_2 difference
- increase in size and number of mitochondria
- increase in myoglobin content/stores
- increased fuel stores (glycogen and triglycerides)
- increase in oxidative enzymes
- fibre type adaptation

Cardiovascular
- increased volume of left ventricle
- increased capillarisation (heart and skeletal muscle)
- increased stroke volume
- decreased resting HR and submax. HR
- increased max. Q
- decreased blood pressure
- increased blood volume

All three systems
- increased VO_2 max.
- increased LIP

Result: Competing in each leg at higher intensities for longer and producing a faster triathlon time overall



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PRACTICAL ACTIVITY Muscular chronic adaptations to anaerobic training

Goal

To be able to explain how the muscular system chronic adaptations to anaerobic training lead to improved performance.

Equipment

- 3-kilogram, 4-kilogram and 5-kilogram medicine balls

Instructions

1. Warm up appropriately.
2. Complete the power medicine ball workout for golfers using the **My favourite medicine ball exercises for golf power** weblink found in the Resources panel. (Remember, you do not need to pick the heaviest ball – less is more.)
3. Record your number of reps, rest time and sets.
4. Complete an appropriate cool down.

Primary data/Reflection

TABLE 1 Reps, rest time and sets for developing power

Exercise	Reps	Rest time	Sets
1. Medicine ball slam			
2. Medicine ball split stance slam			
3. Medicine ball hip toss (side on)			
4. Medicine ball hop toss (front on)			
5. Medicine ball shot put throw			
6. Medicine ball knee chest pass			

Questions

1. List the anaerobic muscular adaptations that would occur for an athlete undertaking this type of training session 2 × week for 6 weeks.
2. Discuss how each of the anaerobic muscular adaptations you listed in question 1 would contribute to improved performance for a golfer.

on Resources

Weblink My favourite medicine ball exercises for golf power

14.7 Activity

14.7 Quick quiz on | **14.7 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
2, 3, 4, 5, 6	1, 7	8, 9

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TEST your understanding

1. **Complete** the following table by indicating whether the physiological parameters have increased, decreased or remained unchanged as a result of involvement in a long-term anaerobic training program.

Physiological parameter	At rest	During submaximal exercise	During maximal exercise
Muscular hypertrophy			
Muscular fuel stores (ATP and CP)			
ATPase and creatine kinase enzymes			

Glycolytic capacity			
Motor unit recruitment			
Cardiac hypertrophy			
Lactate tolerance			

2. **Name** the training methods that develop chronic anaerobic adaptations in muscle tissue.
3. **Identify** three types of athlete who are most likely to benefit from chronic adaptations as a result of participating in an anaerobic training program.
4. **Outline** the role of the enzymes ATPase and creatine kinase.
5. **Explain** the benefit of having a larger muscular storage of ATP, CP and glycogen.
6. **Outline** what is meant by the buffering capacity of a muscle.

APPLY your understanding

7. a. **Outline** three chronic adaptations that may occur at the muscular level as a result of involvement in an anaerobic training program of at least 6 weeks' duration.
   b. **Discuss** how these adaptations can lead to improved performance.
8. An athlete participates in the following training program over a period of 6 weeks.

Session 1:	5 × 100-metre runs, each taking 14 seconds
	5 × 80-metre runs, each taking 12 seconds
	Work-to-rest ratio of 1:3
Session 2:	5 × 60-metre runs, each taking 9 seconds
	5 × 40-metre runs, each taking 7 seconds
	Work-to-rest ratio of 1:5

   The athlete notices a reduction in time taken to complete each of the runs as the weeks progress. **Identify** and **explain** the chronic adaptations that have occurred to allow the athlete to run faster.
9. Involvement in a long-term anaerobic training program (i.e. intermediate interval training) may result in an increase in an athlete's lactate tolerance.
   a. **Identify** chronic adaptations to training that help to bring about this improvement in an athlete's lactate tolerance.
   b. **Explain** the advantages of a higher lactate tolerance for both athletes who perform anaerobic exercise (i.e. sprinters) and those who perform aerobic exercise (i.e. long distance runners).

14.7 Exam questions

Question 1 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.15;* © VCAA

A 400 m runner undertakes an intermediate interval training program.

Identify the most likely chronic adaptation that will result from this training.

A. increased mitochondria
B. increased stroke volume
C. increased lactate tolerance
D. increased lactate inflection point

Question 2 (1 mark)

Source: *VCE 2015, Physical Education Exam, Section A, Q.12;* © VCAA

Training anaerobically can lead to a significant increase in the body's

A. oxidative enzymes.
B. lactate inflection point (LIP).
C. capillarisation of skeletal muscles.
D. ability to buffer the metabolic by-product build-up.

Question 3 (3 marks)

Source: *VCE 2022, Physical Education Exam, Section B, Q.14.d;* © VCAA

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.

Question 4 (3 marks)

Source: *VCE 2023, Physical Education Exam, Section B, Q.15.d;* © VCAA

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.

Question 5 (3 marks)

Source: *VCE 2016, Physical Education Exam, Section B, Q.8.c;* © VCAA

Physiological data from two athletes is shown in the table below.

	Athlete 1	Athlete 2
VO_2 max	63 mL/kg/min	52 mL/kg/min
Type II muscle fibres (gastrocnemius)	24%	75%
Type I muscle fibres (gastrocnemius)	76%	25%
Leg press I repetition maximum (RM)	220 kg	300 kg

Based on the data, **justify** which athlete is likely to perform better in 100 m and 200 m sprint events.

More exam questions are available in your learnON title.

14.8 Chronic adaptations to resistance training: neuromuscular

Key knowledge	Key skill
• chronic adaptations of the cardiovascular, respiratory, and muscular systems to aerobic, anaerobic and resistance training that produce improvements in: – speed and force of muscular contraction	• explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

As with any training, the resulting adaptations are specific to the type of training undertaken. Power and strength resistance training will induce anaerobic training adaptations; likewise, local muscular endurance resistance training will induce some aerobic training adaptations. With any type of long-term training, adaptations occur in the neuromuscular system; however, significant specific neuromuscular adaptations occur with resistance training.

The neuromuscular system is very responsive to training. The increases in strength depend on the type of resistance training and the muscle groups trained, and the intensity of the resistance training affects the scale of the adaptations.

on Resources

Weblink Neuromuscular synapse

14.8.1 Increase in muscle size and change in muscle structure

Resistance training increases the strength and size of a muscle. Increases in the cross-sectional area of a muscle are the result of an increase in the cross-sectional area of each individual fibre within the muscle. The hypertrophy of each fibre is due to an increase in the total quantity of actin and myosin protein filaments, the size and number of myofibrils and also the amount of connective tissue that surrounds the muscle.

While most research suggests that individual fibre hypertrophy is the major reason for whole-muscle hypertrophy, some research suggests that **fibre hyperplasia** — an increase in the number of fibres — may also be a contributing factor to an increase in muscle size. However, it remains unresolved whether fibre hyperplasia contributes to increases in whole-muscle hypertrophy.

14.8.2 Muscle fibre type adaptations

Each single motor unit (see figure 14.26) contains only one type of muscle fibre (fast or slow twitch). Resistance training will cause certain types of muscle fibre adaptations based on the specificity of the program. Research shows that type 2 fast-twitch fibres show greater increases in size, particularly with higher loads, than do type 1 slow-twitch fibres. This may be explained by the fact that there is a greater need to recruit more muscle fibres to produce the required force. The **size principle** suggests that all motor unit types would be recruited to lift heavy loads and, therefore, there is a greater involvement of the type 2 fast-twitch fibres, which would explain why they hypertrophy to a greater relative amount.

fibre hyperplasia an increase in the number of fibres within a muscle

size principle the principle by which motor units are recruited in order of their size from smallest to largest

A combination of adaptations that occur to both the muscular and neural systems explains the increased strength gained from resistance training (see figure 14.27). In the absence of hypertrophy (an increase in muscular size), the neural adaptations play a critical role in the increased force production of a muscle that results from resistance training.

FIGURE 14.26 An example of a motor unit showing the motor neuron and the muscle fibres it innervates

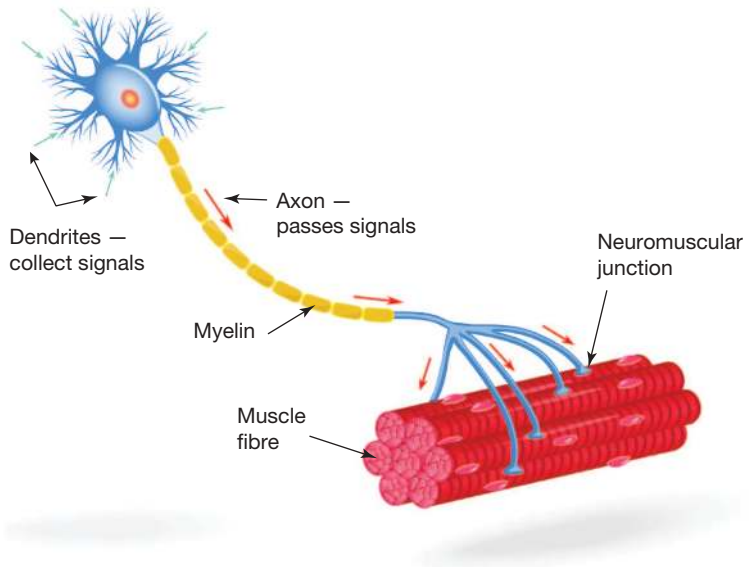
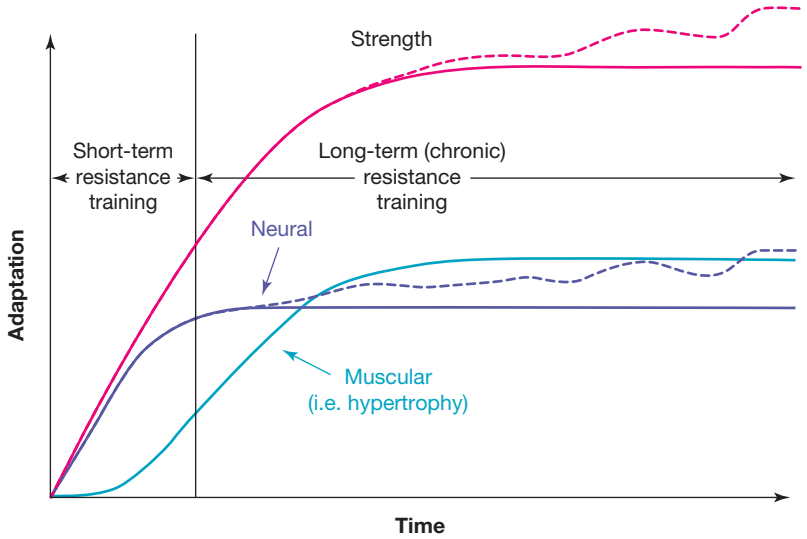


FIGURE 14.27 The contributions of neural and muscular training adaptations to increasing strength. Improvements in neuromuscular function explain the increase in strength in the early stages of training and, once the neural adaptations are maximised, further strength improvements are explained by the continued increase in the hypertrophy of a muscle.



One important aspect of the strength gains that result from resistance training, particularly in the early stages of a program, are the neural adaptations. These include an increase in the synchronisation and recruitment of additional motor units, an increase in the firing rate (rate coding) of motor units and a reduction in inhibitory signals.

14.8.3 Increased synchronisation of motor units

Motor units are not generally recruited at the same time. The 'size principle' states that motor units are recruited in order of their size from smallest to largest. Resistance training makes a number of different motor units able to fire at the same time. There is also an improved ability to recruit larger motor units that require a larger stimulus to activate and comprise the largest number of muscle fibres. The ability to recruit more motor units at the same time and to stimulate larger motor units earlier creates a more powerful muscular contraction with greater force application.

14.8.4 Increase in the firing rate (rate coding) of motor units

The combination of motor unit recruitment and the firing rate, or **rate coding**, of motor units is known as the 'neural drive'. Limited research suggests that more efficient motor unit recruitment due to resistance training may, in turn, increase the frequency of stimulation of a given motor unit. An increase in rate coding increases the rate of force development or how quickly a muscle can contract maximally, rather than increasing the force. This is beneficial for rapid ballistic movements where maximal force is required in a very short period.

rate coding refers to the frequency of impulses sent to a muscle

agonist the prime mover of the muscle action. It causes the movement to occur.

antagonist a muscle that works in opposition to the agonist muscle

synergist a muscle that stabilises movements to and maintains control within the desired range of motion

14.8.5 A reduction in inhibitory signals

The role of the inhibitory mechanisms that exist in the neuromuscular system (e.g. the Golgi tendon organs) is to provide an important protective reflex that limits the excessive generation of force within a muscle. This protective reflex is essential in preventing the muscles from exerting a force that is greater than they can tolerate. Resistance training can gradually override or reduce the inhibitory mechanisms and allow for greater force production within a muscle group. The improved coordination of the **agonists**, **antagonists** and **synergists** is thought to allow for a reduced inhibitory effect.

TABLE 14.6 Summary of chronic adaptations to resistance training: neuromuscular

	Adaptation to anaerobic training
Muscle size and structure	Increase
Synchronisation of motor units	Increase
Firing rate of motor units	Increase
Inhibitory signals	Decrease

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PRACTICAL ACTIVITY Neuromuscular chronic adaptations to resistance training

Goal

To be able to explain how the neuromuscular system chronic adaptations to resistance training lead to improved performance.

Instructions

1. Design a strength resistance training session that would be suitable for rugby players, and guide your class group through the session.
2. Make sure that your session includes the appropriate variables required to train strength and that you target your session at a level that is suitable for all participants.
3. Include an appropriate warm up and cool down.

Primary data/Reflection

TABLE 1 Weights/resistance training session

	Exercise 1	Exercise 2	Exercise 3	Exercise 4	Exercise 5	Exercise 6
Load %RM						
Repetitions						
Sets						
Rest/Recovery						
Contraction speed/ Tempo						

Questions

1. List the neuromuscular adaptations that would occur for an athlete undertaking this type of training session 3 × week for 6 weeks.
2. Discuss how each of the neuromuscular adaptations you listed in question 1 would contribute to improved performance for a rugby player.

EXAM TIP

To explain a chronic adaptation well, follow this general four-step structure:
1. Define the adaptation.
2. Indicate the change (increase, decrease or no change).
3. Outline the role of the chronic adaptation.
4. Discuss how it will improve performance.

14.8 Activity

14.8 Quick quiz on | **14.8 Exercise**

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 5, 6, 9	2, 3, 8	7

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TEST your understanding

1. **Outline** how resistance training affects the size and structure of muscles.
2. **Compare** and **contrast** the difference between fast- and slow-twitch responses to resistance training.
3. **Sketch** a motor unit.
4. **Identify** how the size principle is changed by resistance training.
5. **List** the neural adaptations that account for increases in strength when hypertrophy is not present.
6. **Outline** the role of the Golgi tendon organs.

APPLY your understanding

7. **Explain** how an increase in the synchronisation of motor units can improve strength.
8. **Discuss** the benefit of increased rate coding of motor units. **Explain** for which type of actions this adaptation would be advantageous.
9. **Describe** how resistance training can affect the inhibitory signals within a muscle.

14.8 Exam questions

Question 1 (4 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section B, Q.5.c;* © ACHPER

Outlined in the table below are muscle biopsies taken from four athletes to identify whether they were suited to discus throwing. The results are outlined in the table below.

Muscle biopsy of the gastrocnemius for four discus throwers

Athlete	Fast-twitch fibre concentration	Mitochondrial mass	Myosin – ATPase activity
Henry	moderate	intermediate	high
Jordan	moderate	high	low
Luke	low	intermediate	low
Ben	high	low	high

a. **Identify** which athlete would be most likely to be successful as a discus thrower. **(1 mark)**
b. Use the data above to **justify** your selection in part a. **(3 marks)**

Question 2 (3 marks)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Q.8.a,b;* © ACHPER

Australian athletes have won numerous medals at recent International elite snow sport competitions in events such as the snowboard half pipe and aerial skiing. In these events, athletes perform multiple somersaults, tricks and twists. Points are awarded for air, form, and landing.

These events typically have a duration of 5 to 25 seconds. Athletes train to improve muscular power. These athletes also prefer not to have large muscle mass but prefer to stay lean to maximize their flight time in the air. Their training focuses on neuromuscular adaptations.

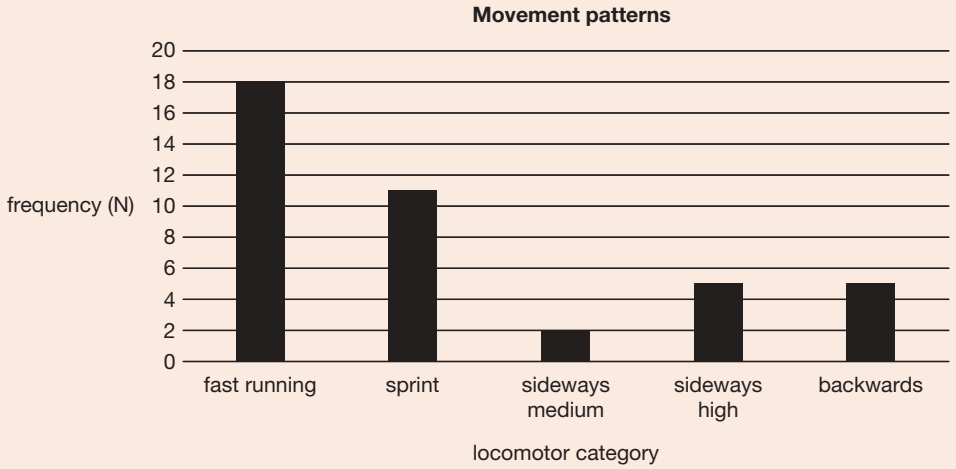
a. **Identify** a training method these athletes are likely to undertake to build muscular power. **(1 mark)**
b. **Name two** neuromuscular adaptations these athletes would develop as a result of the training method identified in part a. **(2 marks)**

Question 3 (3 marks)

Source: *VCE 2018, Physical Education Exam, Section B, Q.1;* © VCAA

A coach collected data on one player during a 60-minute recreational European handball match.

The data is presented in the following graph and table.



Source: Data and ideas from SCA Povos et al., 'Physical and Physiological demands of recreational team handball for adult untrained men', *Biomed Research International*, 2017, p. 5

Skill-frequency table

throws	20
jumps	27
changes of direction	13

i. **Identify one** muscular adaptation that a European handball player would develop after undertaking a plyometric training program. **(1 mark)**

ii. **Outline** how this muscular adaptation would improve the performance of the European handball player. **(2 marks)**

Question 4 (marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.6;* © VCAA

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

(continued)

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
RPE — rate of perceived exertion
reps — repetitions
mins — minutes
s — seconds

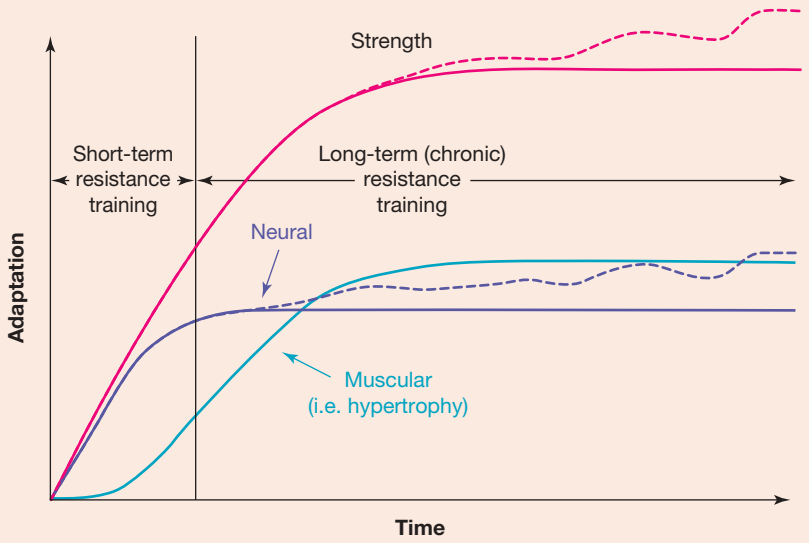
Explain how an increase in the firing rate of motor units would aid Noah's performance in track cycling.

Question 5 (4 marks)

Source: Adapted from *VCE 2015, Physical Education Exam, Section B, Q.14.d,e;* © VCAA

When an individual takes up resistance training for the first time, strength gains are made without the muscle gaining size (hypertrophy).

Relative contribution of neural and muscular adaptations to the improvement in strength



a. Using the information provided in the graph above, **explain**, physiologically, why strength gains can be made without the muscle gaining size. **(2 marks)**
b. Other than muscular hypertrophy, **identify** one chronic adaptation to the muscular system that occurs as a result of anaerobic training. **Explain** the benefit of this change to the athlete. **(2 marks)**

More exam questions are available in your learnON title.

14.9 Key skills

Key skill

- explain how the chronic adaptations of the cardiovascular, respiratory and muscular systems to training lead to improved performance

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

14.9.1 Tell me

To address this key skill, it is important to:

- describe how each of the adaptations to the cardiovascular system leads to improved performance of aerobic activities
- describe how each of the adaptations to the respiratory system leads to improved performance of aerobic activities
- describe how each of the adaptations to the muscular system leads to improved performance of aerobic and anaerobic activities
- explain the specific adaptations that occur from undertaking aerobic, anaerobic and resistance training.

14.9.2 Show me

Practice question (4 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: Adapted from *ACHPER 2021, Trial Exam Units 3 & 4, Section B, Q.10.b;* © ACHPER

Most elite swimmers train ten or more sessions per week with training that is specific to the energy systems they are targeting.

Contrast the chronic muscular adaptations to training for a 50-metre swimmer and a 1500-metre swimmer, and **explain** why each swimmer needs to develop different *adaptations* to ensure *successful* performance in their event. (4 marks)



Decode the question

Strategies to decode the question

- **Identify the action words:**
  Contrast — show how things are different
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *training*, *50-metre swimmer comparison with 1500-metre swimmer and successful performance*
- **Key concepts** — energy systems, chronic muscular adaptations
- **Marking scheme** — 6 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response and marking scheme

The *adaptations* will differ because the physiological requirements of the events differ. The 50-metre swimmer will develop an increased number of contractile proteins, which will enable more forceful muscular contractions. This will assist the 50-metre swimmer to apply *more force* during each stroke to enable them to swim at a *faster velocity*, which is necessary in a 50-metre event. The 1500-metre swimmer will develop a greater capillary density at the muscle site, which will allow greater amounts of oxygen to be delivered to their working muscles. This will assist them to produce greater amounts of *aerobic energy*, aiding their performance by letting them *swim faster aerobically*, at a *higher intensity*.

Award 1 mark for identifying the chronic muscular adaptation for a 50-metre swimmer.

Award 1 mark for explaining how this adaptation ensures the 50-metre swimmer's success in their event.

Award 1 mark for identifying the chronic muscular adaptation for a 1500-metre swimmer.

Award 1 mark for explaining how this adaptation ensures the 1500-metre swimmer's success in their event.

14.9.3 Let me do it

Question 1 (3 marks)

Source: *VCE 2019, Physical Education Exam, Section B, Q.3.c;* © VCAA

In a study, elite-level male sprint and distance runners' blood lactate levels were assessed under different conditions. The runners had been training for three months and were in the middle of their competitive season. The following data was collected.

Distance		Sprint runners	Distance runners
		Blood lactate (mmol/L)	Blood lactate (mmol/L)
400 m	baseline	1.3	1.3
	post-exercise	6.6	4.1
1600 m	baseline	1.4	1.5
	post-exercise	14.5	8.8

Data: TJ Canfield & KA Gabel, 'Blood lactate, heart rate, and rating of perceived exertion in collegiate sprint, middle distance, and long distance runners after 400 and 1600 meter runs', *International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering*, vol. 7, no. 8, 2013, p. 479

Referencing the data and using your understanding of anaerobic chronic adaptations, **explain** the differences in the sprint and distance runners' blood lactate levels.





14.10 Review

Hey students! Now that it's time to revise this topic, go online to:

Review your results

Watch teacher-led videos

Practise exam questions

Find all this and MORE in jacPLUS



14.10.1 Summary

- Long-term responses that develop over a period of time (usually a minimum of 6 weeks) when training is repeated regularly are referred to as chronic adaptations to training. The combined effect of all chronic adaptations is known as the training effect.
- Chronic adaptations to training may occur in the cardiovascular, respiratory and muscular systems. The result of these physiological adaptations is an improvement in performance.
- Chronic adaptations to training are dependent on:
  - the type and method of training
  - the frequency, duration/time and intensity of training
  - the individual athlete's capacities and genetic make-up.
- Aerobic (endurance) training adaptations (see table 14.6) lead to more efficient delivery of larger quantities of oxygen to working muscles and an improved economy. Specifically, the cardiovascular system increases blood flow and delivery of oxygen (transport) to the muscles, the respiratory system increases the amount of oxygen available (uptake), and the muscular system increases the amount of oxygen utilised for ATP resynthesis, increasing VO_2 max and the lactate inflection point (LIP).
- Aerobic training effects are developed through continuous, fartlek, long-interval, aerobically designed circuit, resistance (endurance) and high-intensity interval (HIIT) training.
- Anaerobic training adaptations (see table 14.7) lead to increased muscle size, enabling greater strength, power, speed and force of contraction, as well as changes at the cellular level that improve anaerobic energy production and lactate tolerance.
- Anaerobic training effects are best developed through short and intermediate interval training, plyometric training, circuit training and resistance (strength and power) training.
- Resistance training causes a range of neuromuscular adaptations to take place (see table 14.8), such as increased neural control, increased neuromuscular control and function, improved synchronicity of motor units and increased firing rate of motor units.

TABLE 14.7 Summary of chronic physiological adaptations to aerobic training

Respiratory	Explain the adaptation from aerobic training and how it affects performance
Increased alveolar surface area (increased pulmonary diffusion)	Aerobic training increases the surface area of the alveoli, which in turn increases pulmonary diffusion, allowing more oxygen to be extracted and transported to the working muscles for use.
Increased tidal volume	Aerobic training increases the amount of air inspired and expired by the lungs per breath. This allows for a greater amount of oxygen to be diffused into the surrounding alveoli capillaries and delivered to the working muscles.
Decreased resting and submaximal respiratory frequency	Aerobic training improves pulmonary function and capacity, which increases the extraction of oxygen from the alveoli to the surrounding capillaries. The diaphragm and intercostal muscles function more effectively with each breath.
Increased ventilation during maximal exercise	Aerobic training results in more efficient lung ventilation. Ventilation may be reduced slightly at rest and during submaximal exercise due to improved oxygen utilisation. At maximal workloads, ventilation is increased due to an increase in tidal volume and respiratory frequency. This allows for greater oxygen delivery to working muscles at maximum exercise intensities.

(continued)

TABLE 14.7 Summary of chronic physiological adaptations to aerobic training *(continued)*

Cardiovascular	Explain the adaptation from aerobic training and how it affects performance
Increased left ventricle size and volume (increased stroke volume)	Aerobic training results in cardiac hypertrophy. An increase in the size and volume of the left ventricle, in particular, occurs. This increases stroke volume and cardiac output, allowing a greater volume of blood to be ejected from the heart, thus providing more oxygen for the athlete to use.
Increased capillarisation of the heart muscle	Cardiac hypertrophy leads to an increase in the capillarisation of the heart muscle. The increased supply of blood and oxygen allows the heart to beat more strongly and efficiently during both exercise and rest.
Faster heart rate recovery rates	Increased heart rate recovery rates mean that the heart rate will return to resting levels in a shorter time. This is due to the greater efficiency of the cardiovascular system to produce energy aerobically.
Increased blood volume and haemoglobin levels	Red blood cells may increase in number and the haemoglobin content and oxygen-carrying capacity of the blood may rise. There is also an increased ratio of plasma in the blood cells, which reduces the viscosity of the blood, allowing it to flow smoothly through the blood vessels. This allows a greater amount of oxygen to be delivered to the muscles for use by the athlete.
Increased capillarisation of skeletal muscle	Aerobic training leads to increased capillarisation of skeletal muscle. Greater capillary supply means increased blood flow and greater surface area for gas diffusion to take place. Increasing the oxygen and nutrients in the muscles allows for more removal of by-products.
Decreased heart rate at rest and during submaximal workloads	A greater stroke volume results in the heart not having to beat as often to supply the required blood flow (and oxygen). Aerobic training also results in a slower increase in heart rate during exercise and a lower steady state, which is reached sooner.
Muscular	**Explain the adaptation from aerobic training and how it affects performance**
Increased size and number of mitochondria	Mitochondria are the sites of aerobic ATP resynthesis and where glycogen and triglyceride stores are oxidised. The greater the number and size of the mitochondria located within the muscle, the greater the ability to resynthesise ATP aerobically.
Increased myoglobin stores	Myoglobin is responsible for extracting oxygen from the red blood cells and delivering it to the mitochondria in the muscle cells. An increase in the number of myoglobin stores increases the amount of oxygen delivered to the mitochondria for energy production.
Increased fuel storage and oxidative enzymes	Aerobic training increases the muscular storage of glycogen and triglycerides in the slow-twitch muscle fibres and there is also an increase in the oxidative enzymes that are responsible for metabolising these fuel stores to produce ATP aerobically. This reduces reliance upon the anaerobic glycolysis system until higher intensities. Further, the increased levels of the enzymes associated with fat metabolism mean that an aerobically trained athlete is able to 'glycogen spare' more effectively and therefore work at higher intensities for longer.
Increased a-VO_2 difference	All of the above listed factors contribute to the body's ability to attract oxygen into the muscle cells and then use it to produce adenosine triphosphate (ATP) for muscle contraction. A measure of this is the difference in the amount of oxygen in the arterioles in comparison to the venules.
Increased muscle fibre adaptation	Some research has indicated that skeletal muscle type 2A fast-twitch fibres can take on some of the characteristics of slow-twitch fibres as an adaptation to aerobic training. This would allow for a greater ability to generate ATP aerobically with fewer fatiguing factors.

All three systems: cardiovascular, respiratory and muscular	Explain the adaptation from aerobic training and how it affects performance
Increased VO_2 max	An increase in the maximum oxygen uptake (VO_2 max) allows a greater amount of oxygen to be taken in by the respiratory system, transported by the cardiovascular system and utilised by the muscular system to produce ATP, improving the economy of the athlete.
Increased lactate inflection point	The lactate inflection point (LIP) represents the highest intensity point at which there is a balance between lactate production and removal from the blood. The advantage of having a higher LIP is that the anaerobic glycolysis system doesn't contribute as much until higher exercise intensities are reached. This means that the athlete can work at higher intensities for longer before fatiguing hydrogen ions begin to accumulate.

TABLE 14.8 Summary of chronic physiological adaptations to anaerobic training

Muscular	Explain the adaptation from anaerobic training and how it affects performance
Muscular hypertrophy	Muscle fibre size increases due to an increase in the size and number of myofibrils and the protein filaments actin and myosin. This increase in muscle size allows for a greater production of strength and power.
Increased muscular stores of ATP and CP	Increased muscular stores of ATP and creatine phosphate increases the capacity of the ATP–CP system, allowing for faster resynthesis of ATP for high-intensity activities.
Increase in ATPase and creatine kinase enzymes	ATPase is responsible for breaking down ATP to form ADP, releasing energy for muscular contraction. Creatine kinase initiates the breakdown of CP, which provides the energy to resynthesise ATP at a fast rate.
Increased glycolytic capacity	Increased muscular storage of glycogen and, consequently, increased levels of glycolytic enzymes, enhance the capacity of the anaerobic glycolysis system to produce energy.
Increase in the number of motor units recruited	An increase in the number of nerve axons and their corresponding muscle fibres increases the power and strength of muscular contractions.
Increased lactate tolerance	There is an increase in the ability of the muscles to buffer (neutralise) the acid that accumulates from the production of hydrogen ions during an exercise bout. The increase in lactate tolerance prevents the onset of fatigue and allows an athlete to continue to generate ATP anaerobically, which occurs at a faster rate and allows the athlete to work at a higher intensity. High lactate levels are produced at the end of the performance.

TABLE 14.9 Summary of chronic physiological adaptations to resistance training

Neuromuscular	Explain the adaptation from resistance training and how it affects performance
Increase in the cross-sectional area of a muscle (muscle hypertrophy)	There is an increase in the total quantity of actin and myosin protein filaments, the size and number of myofibrils and the amount of connective tissue that surrounds the muscle. This allows the muscle to create more strength and power with each contraction.
Increased synchronisation of motor units	There is an improved ability for different motor units to fire at the same time and to recruit larger motor units that require a larger stimulus to activate. This creates a more powerful muscular contraction.
Increase in the firing rate (rate coding) of motor units	An increase in the frequency of stimulation of a given motor unit (rate coding) increases the rate of force development or how quickly a muscle can contract maximally. This is beneficial for rapid ballistic movements where maximal force is required in a very short period of time.
A reduction in inhibitory signals	The improved coordination of agonists, antagonists and synergists is thought to allow for a reduced inhibitory effect. This allows for greater force production within the muscle group.

14.10.2 Key terms

absolute VO_2 max a measurement of the total amount of oxygen consumed in L/min
agonist the prime mover of the muscle action. It causes the movement to occur.
antagonist a muscle that works in opposition to the agonist muscle
arteriovenous oxygen difference (a-VO_2 diff) a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.
buffering capacity the ability of the muscle cell buffers to resist changes in pH (acidity)
capillarisation an increase in the capillary density and blood flow to skeletal or cardiac muscle as a result of aerobic training
cardiac hypertrophy an enlargement of the heart muscle as a result of training
cardiac output ($\dot{Q}$) the amount of blood ejected from the left ventricle of the heart per minute. $\dot{Q}$ = heart rate (HR) × stroke volume (SV).
chronic adaptations the body's long-term responses of the cardiovascular, respiratory and muscular systems that develop over a period of time when training is repeated regularly
diastolic blood pressure the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.
economy the quantity of oxygen (mL/kg/min) required to generate movement at any given speed or intensity
fibre hyperplasia an increase in the number of fibres within a muscle
glycogen sparing the process whereby glycogen stores are not used as early in an exercise bout due to the increased ability to use triglycerides to produce energy. This delays depletion of glycogen stores, and thereby delays the time to exhaustion.
haemoglobin a substance in the blood that transports oxygen around the body
hydrogen ion the presence of these ions makes the muscle acidic and will eventually fatigue muscle function
hypertension high blood pressure
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.
maximum oxygen uptake (VO_2 max) the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production
mitochondria cell structures (organelles) that serve as the power generators of the cell, converting nutrients into ATP in the presence of oxygen (aerobically)

motor unit consists of one motor neuron and all of the muscle fibres that it innervates
muscular hypertrophy an increase in the cross-sectional size of a muscle
myofibrils small fibres that run through each muscle fibre
myoglobin an oxygen-binding protein in skeletal muscle cells that attracts oxygen from the bloodstream and shuttles it to the mitochondria in the muscles for aerobic energy production
oxidative enzymes enzymes that, with the use of oxygen, speed up the breakdown of nutrients to resynthesise ATP
pulmonary diffusion the movement of oxygen and carbon dioxide from areas of high concentration to areas of low concentration between the alveoli and the surrounding capillaries
rate coding refers to the frequency of impulses sent to a muscle
relative VO_2 max a measurement that takes into account body weight and is given in mL/kg/min
respiratory frequency (RF) the amount of times a person breathes in and out each minute
resting heart rate the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult
size principle the principle by which motor units are recruited in order of their size from smallest to largest
stroke volume the amount of blood ejected from the left ventricle with each beat (contraction) of the heart
synergist a muscle that stabilises movements to and maintains control within the desired range of motion
systolic blood pressure the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure value
tidal volume (TV) the amount of air inspired and expired by the lungs per breath
type 1 slow-twitch oxidative fibres contain large and numerous mitochondria, high levels of myoglobin and a high capillary density. They are very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolism.
type 2A fast-twitch oxidative fibres red fibres; have a very high capacity for generating ATP by oxidative metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.
type 2B fast-twitch glycolytic fibres white fibers; are geared to generate ATP by anaerobic metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and fatigue easily.
ventilation the amount of air inspired or expired per minute by the lungs. Ventilation (V) = respiratory frequency (RF) × tidal volume (TV)

14.10 Exam questions

14.10 Section A – Multiple choice questions

Question 1 (1 mark)

Source: *ACHPER 2020, Trial Exam Units 3 & 4, Section A, Q.15;* © ACHPER

Below is an example of a 6-week training program.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	continuous	HIIT		fartlek		interval – long	
2		fartlek		continuous		HIIT	
3	continuous	HIIT		interval – long		Fartlek	
4	fartlek		HIIT		continuous	interval – long	
5	continuous	HIIT		interval – long		interval – long	
6		HIIT	interval – long		continuous		interval – long

Which of the following adaptations would occur as a result of participating in this program?

A. increase size and number of myofibrils
B. increase in ATPase
C. increase in oxidative enzyme activity
D. decreased lactate inflection point.

Question 2 (1 mark)

Source: *ACHPER 2021, Trial Exam Units 3 & 4, Section A, Q.7;* © ACHPER

A chronic adaptation which may lead to an increase in an athlete's LIP would be increased

A. ATPase enzyme activity.
B. mitochondrial density.
C. tolerance to metabolic by–products.
D. connective tissue.

Question 3 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section A, Q.13;* © ACHPER

The greatest muscular adaptation to short interval training would be

A. increased lactate tolerance.
B. increased myosin ATPase.
C. decreased CP stores.
D. increased glycogen stores.

Question 4 (1 mark)

Source: *ACHPER 2018, Trial Exam Units 3 & 4, Section A, Q.5;* © ACHPER

Psychological benefits of aerobic training include

A. increased oxidative enzymes, decreased ventilation at rest and decreased heart rate at rest.
B. increased stress levels, decreased depression and decreased anxiety.
C. increased stroke volume at rest, decreased total lung volume at rest and decreased capillary density at rest.
D. increased self-esteem, decreased depression and decreased anxiety.

Question 5 (1 mark)

Source: *VCE 2023, Physical Education Exam, Section A, Q.11;* © VCAA

Which one of the following adaptations is an example of a vascular chronic adaptation?

A. an increase in alveoli surface area
B. an increase in oxidative enzymes
C. an increase in red blood cells
D. an increase in stroke volume

Question 6 (1 mark)

Source: *ACHPER 2022, Trial Exam Units 3 & 4, Section B, Q.8;* © ACHPER

Regarding fast twitch fibres, which of the following adaptations could occur as a result of the 6-week, short interval running training program shown below, which is undertaken three times per week?

Distance	Intensity	Rest between repetitions	Rest between sets	Repetitions	Sets
20 meters	Maximal 100%	30 seconds	3 minutes	6	4

A. increased alveoli surface area and increased pulmonary diffusion
B. increased stroke volume and decreased resting heart rate
C. increased phosphocreatine stores and increased contractile proteins
D. increased triglyceride stores and increased pulmonary diffusion

Question 7 (1 mark)

Source: *VCE 2019, Physical Education Exam, Section A, Q.11;* © VCAA

In which one of the following sports is having a high mitochondrial mass most likely to provide an advantage to an athlete in a competition?

A. long-distance swimming
B. lawn bowls
C. gymnastics
D. karate

Question 8 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.6;* © VCAA

Which one of the following adaptations would be observed in the respiratory system after 12 weeks of fartlek training three times per week?

A. maintained lung volumes
B. increased haemoglobin levels
C. decreased alveolar surface area
D. increased ventilation at maximal intensity

Question 9 (1 mark)

Source: *VCE 2020, Physical Education Exam, Section A, Q.7;* © VCAA

A high jumper has been taking part in a resistance training program. They have recently improved their performance by 10 cm.

Which one of the following adaptations may have contributed to this increase?

A. increased ATPase
B. increased lactate tolerance
C. increased glycolytic enzymes
D. increased muscle glycogen stores

Question 10 (1 mark)

Source: *VCE 2022, Physical Education Exam, Section A, Q.3; © VCAA*

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.

14.10 Section B – Short answer questions

Question 1 (2 marks)

Source: *VCE 2020, Physical Education Exam, Section B, Q.1;* © VCAA

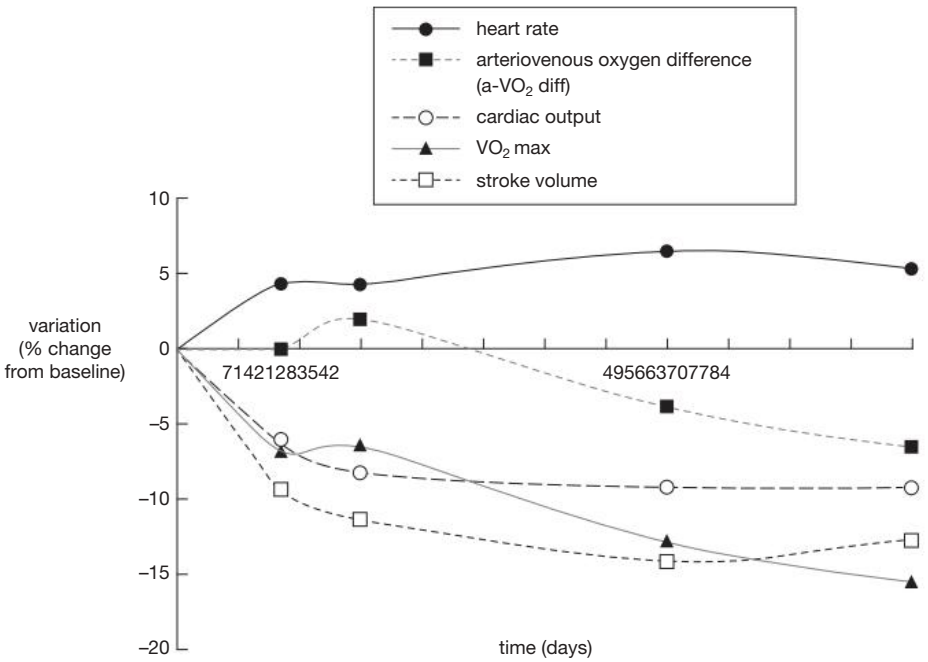
Below is an example of a high-intensity interval training (HIIT) program.

Frequency	Intensity	Work period	Recovery period	Type	Repetitions
3 × per week	80–90% VO_2 max	4 min	1–3 min	running	4–6

a. i. **List two** chronic adaptations that occur as a result of using the HIIT method. **(1 mark)**
ii. **Explain** how **one** of the chronic adaptations listed in **part a.i.** can improve running performance. **(1 mark)**

Question 2 (3 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.4.d;* © VCAA



Source: L Bosquet & I Mujika, 2012, 'Detraining', in I Mujika (ed.), *Endurance training: science and practice,* Figure 10.1, p. 102

Use the data in the graph to **explain** the relationship between VO_2 max, cardiac output and a-VO_2 diff, and their effect on aerobic capacity.

Question 3 (2 marks)

Source: *VCE 2017, Physical Education Exam, Section B, Q.13.b;* © VCAA

The Australian Football League (AFL) carries out a series of fitness tests at its annual draft camp to help clubs determine who is the best young talent. The Brisbane Lions selected Jarrod Berry after he performed very well at the draft camp. His results were as follows:

- 4th overall in the 6 × 30 m sprint test – 24.99 s
- 1st overall in the 20 m shuttle run – level 15.1
- 1st overall in the 3 km time trial – 9.46 min

Data: AFL news, 'Top-10 results from 2016 NAB AFL Draft Combine', 9 October 2016, www.afl.com.au

The six 30 m sprints are run at 20 s intervals. The sprints are started at 0 s, 20 s, 40 s, 1 min, 1 min 20 s and 1 min 40 s.

What is the advantage for Berry of having a high aerobic capacity in the 6 × 30 m sprint test?

Question 4 (7 marks)

Source: Adapted from *ACHPER 2014, Trial Exam Units 3 & 4, Section B, Q.11;* © ACHPER

Caitlin Sargent from Queensland ran the fastest 400 m by an Australian female athlete in 2013.

She completed the race in a time of 52.16 seconds. Caitlin would include interval training as part of her training routine. As a result of her training, she would expect to develop an increase in glycolytic enzymes, an increase in contractile proteins and an increased tolerance to hydrogen ions.

a. Which of the following interval sessions would be most likely to bring about these adaptations? Please circle the most appropriate session — either A, B or C. **(1 mark)**

	Sets	Repetition number	Distance (metres)	Time (seconds)	Recovery (seconds)
A	3	8	30	4	30
B	3	5	150	20	60
C	3	5	600	120	120

b. **Complete** the table below to **describe** how an increase in each factor can lead to improved performance in the 400 m by Caitlin. **(6 marks)**

	Role in improving performance in the 400 m event
Glycolytic enzymes	
Contractile proteins	
Tolerance to hydrogen ions	

Question 5 (8 marks)

Source: Adapted from *ACHPER 2013, Trial Exam Units 3 & 4, Section B, Q.8;* © ACHPER

The lactate inflection point (LIP) and lactate tolerance are terms related to exercise science. With specific reference to these parameters, **complete** the following table.

	Lactate inflection point	**Lactate tolerance**
Definition		
Appropriate training method to achieve improvement		
Event likely to benefit from this parameter		
Outline how improvement in this parameter will benefit performance		

Continue to build your exam skills

Access the Unit 4 Area of Study 2 Review at the end of Topic 14. This includes:

- Practice extended response
- Practice examination
- Practice school-assessed coursework.

AREA OF STUDY 2 How is training implemented effectively to improve fitness?

OUTCOME 2

On completion of this unit, the student should be able to participate in a variety of training methods; design and evaluate training programs; and explain performance improvements that occur due to chronic adaptations, depending on the type of training undertaken.

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

REVIEW CONTENT SEQUENCE

U4 AOS2 Extended response — Build your exam skills
U4 AOS2 Practice examination online only
U4 AOS2 Practice school-assessed coursework online only

U4 AOS2 Extended response — Build your exam skills

Tell me

To address these questions, it is important to remember:

- physiological refers to the body's responses to physical activity, specifically the chronic aerobic and anaerobic adaptations to training
- a clear link is needed between the adaptations and the resulting improvements to performance.

Show me

Practice question (8 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

The women's 15-kilometre skiathlon competition in cross-country skiing at the 2022 Winter Olympics was won by Therese Johaug of Norway in a time of 44:13.7, while Jonna Sundling of Sweden recorded a time of 3:09.68 to become the Olympic champion of the women's sprint cross-country skiing competition.

By applying your understanding of physiological principles for *improving performance*, **compare** the two athletes. Your response should **discuss**:

- suitable training methods that each athlete could include in their training programs
- the difference between *lactate inflection point (LIP)* and *lactate tolerance*
- which athlete would benefit the most from having an improved *LIP* and which would benefit the most from having an improved *lactate tolerance*.

Provide a **recommendation** on how Therese and Jonna could monitor their training and **explain** why this is important.

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Compare — recognise similarities and differences and their significance

Discussion — present a clear, considered and balanced argument
Recommendation — put forward a suitable option
Explain — provide detail to show the relationship between concepts

- **Key terminology** — *improving performance*, *lactate inflection point (LIP)*, *lactate tolerance*
- **Key concepts** — physiological principles, training methods, training programs
- **Marking scheme** — 8 marks – always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response

Due to the duration of the 15-kilometre skiathlon competition in cross-country skiing with a time of *44:13.7 minutes*, the training methods that Therese needs to adopt should be aerobic in nature (e.g. *continuous, fartlek and/or long interval training methods*). These will allow Therese to develop aerobic chronic adaptations (increased VO_2 max and LIP), enhancing her performance through an increased ability to *produce ATP aerobically* and an improved economy, *leading to a faster time*. Therese will benefit from having a higher LIP, as this means that she will be able to work at *higher intensities for longer periods without fatiguing hydrogen ion accumulation*. There will also be an *increase in the oxidative enzymes* that are responsible for metabolising fuel stores to produce ATP aerobically. This means Therese will be *less reliant* on the anaerobic glycolysis system until higher intensities.

In comparison, for the women's sprint cross-country skiing competition, Jonna would benefit more from anaerobic training methods (e.g. *intermediate interval training*) to give her *greater force production, power output, speed, and lactate tolerance* for her event. This will help Jonna improve on her *3:09.68 hour time* because an increase in lactate tolerance will prevent the *onset of fatigue* and allow Jonna to continue to generate ATP anaerobically (at a faster rate) for longer and *work at a higher intensity*, producing *high lactate levels* at the end of the event.

Both Therese and Jonna could monitor their training by keeping a *training diary*, in which they can record both *objective and subjective training information* and also incorporate information from a *digital tool or wearable technology*, such as a smart watch. By recording, monitoring and evaluating their physiological (e.g. heart rate, responses), psychological (e.g. motivational levels) and sociological (e.g. temperature and weather conditions) data in this way, they receive feedback on the *effectiveness of their training program*. This can help them to ensure they are achieving the chronic adaptations and goals set by their programs, and to make any adjustments that may be required.

Marking guide

High range response	• A thorough comparison of the specific physiological principles for improving performance for both athletes • Demonstrates an extensive understanding of suitable training methods for each athlete • Clear and accurate knowledge of the difference between LIP and lactate tolerance • Highly proficient comparison and justification about which athlete would benefit from having an improved LIP or lactate tolerance • How the athletes can monitor their training and why this is important is comprehensively explained • Highly appropriate terminology and sophisticated prose • Relevant and specific examples from the stimulus are included to support responses

Mid range response	• A generalised comparison of the physiological principles for improving performance for both athletes. • Demonstrates an acceptable understanding of suitable training methods for each athlete. • Shows some comparison between which athlete would benefit from having an improved LIP or lactate tolerance • Shows a basic awareness of how the athletes can monitor their training and outlines why this is important. • Some use of appropriate terminology • Relevant examples from the stimulus are provided to support responses
Low range response	• A limited comparison of the physiological principles for improving performance for both athletes • Demonstrates minimal knowledge of the concepts • Unstructured response • Limited use of appropriate terminology

Let me do it

Extended response questions

learn on

Question 1 (10 marks)

Source: Adapted from *VCE 2019, Physical Education Exam, Section B, Q.6*; © VCAA

Noah, an 18-year-old student, wants to improve his sprinting ability in track cycling (500–1000-metre 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

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 RPE — rate of perceived exertion	reps — repetitions mins — minutes	s — seconds

By applying your understanding of the principles for improving performance, reference the following aspects in relation to Noah's training program. Use specific examples from the training program data to support your response.

- Recommend the type of stretches that Noah should include in his warm up.
- Outline whether progression has been applied correctly.
- Discuss the application of the FITT principles (frequency, intensity, time and type) to evaluate the effectiveness of this training program to improve sprint performance for track cycling.
- Outline how an increase in the firing rate of motor units would aid Noah's performance in track cycling.
- Provide a recommendation for how Noah can monitor his training and explain why this is important.

Question 2 (10 marks)

Pickleball is a paddle sport that combines elements of tennis, badminton and table tennis. It is a fun and accessible sport suitable for players of all ages and skill levels and is typically played on a badminton-sized court with a slightly modified tennis net. Pickleball is both fun and challenging, with a combination of long rallies and a blend of soft and rapid-fire shots. The best athlete must earn their points not purely by athleticism, power and speed, but also through the use of positioning, patience, tactics and touch. Mitch Hargreaves, a 25-year-old from Sydney, won the 2023 men's singles at the World Pickleball Championships in Bali, and 36-year-old Gold Coast mother-of-two Sarah Burr has become Australia's most accomplished female player of the sport.



Traditionally, pickleball games are played to 11 points, and a team must win by at least two points. Points are scored only by the serving team. A match usually consists of the best of three games. The duration of a match will vary. On average, a single game will last between 10 and 30 minutes; however, a match may last up to 90 minutes.

By applying your understanding of improving performance to compete successfully, discuss how to plan and implement an effective training program for pickleball.

Your response should include the following:

- a recommended training method to be undertaken
- application of the principles of
  - specificity
  - intensity
  - time/duration
  - progression/overload
  - frequency
- the components of a training session.

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UNIT 4

AREA OF STUDY 3

Integrated movement experiences

OUTCOME 2

On completion of this unit, the student should be able to integrate theory and practice that enables them to analyse the interrelationships between skill acquisition, biomechanics, energy production and training, and the impacts these have on performance.

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TOPIC SEQUENCE

15 Integrated movement experience 688

UNIT 4 AREA OF STUDY 3 REVIEW

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15 Integrated movement experience

15.1 Overview

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LEARNING SEQUENCE

15.1 Overview
15.2 Case study — Dick Fosbury
15.3 Preparing for your SAC
15.4 Key skills
15.5 Review

15.1.1 Introduction

In this topic, you will not learn any new content; instead, you will apply the knowledge that you have already learned throughout the subject to refine your understanding of how the different aspects covered in the course combine to produce optimal sporting performance.

Optimal sporting performance is the culmination of the many concepts that we have studied throughout the course, all harmoniously contributing to the performance of an athlete or sporting team.

To facilitate optimal performance, an athlete or coach must use their knowledge of biomechanics, skill acquisition, energy systems, acute responses, fatigue and recovery, training programs, chronic adaptations, psychological and dietary strategies and so on, and apply this to their own specific needs within their sport. If they get this application right, improvements will occur and the goals that the athlete is trying to achieve can be met — and in some cases, exceeded!

FIGURE 15.1 Interrelationships exist between all the concepts covered. It is now time to demonstrate those connections.



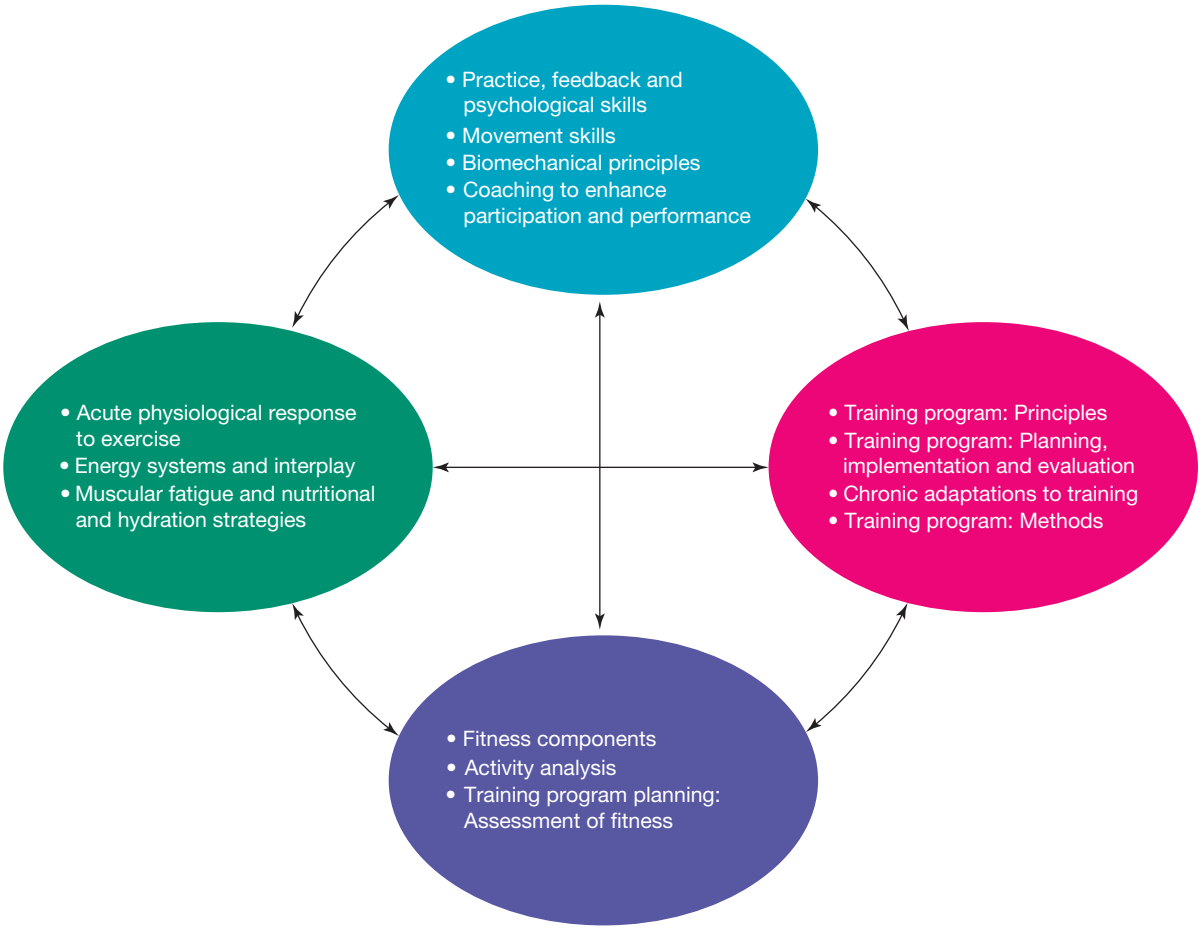
This topic provides an opportunity to investigate, from a participatory perspective, the interrelationships between the various concepts covered in Units 3 and 4, thereby promoting deeper understanding.

15.1.2 Key knowledge and Key skills

Key knowledge	Key skills
• the integration of theory and practice utilised in and through participation in practical activity • interdisciplinary learning that connects knowledge related to skill acquisition, biomechanics, energy production and training and the impacts these have on performance	• reflect on primary data from participation in a practical activity • use primary data to demonstrate integration of theory and practice • analyse interrelationships between skill acquisition, biomechanics, energy production and training knowledge for the practical activity completed in consideration of/in relation to the impacts these have on performance between movement skills or performers

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15.1.3 Topic preview



15.2 Case study — Dick Fosbury

Let us look at an example to explain how many areas of sports science may contribute to optimal sports performance.

Dick Fosbury was an American high jumper credited with changing the sport forever by introducing the revolutionary backwards jumping style that became known as the 'Fosbury flop'.

Fosbury competed for Oregan State University's track and field team and was an average high jumper. He had access to top coaches who ensured his muscular power was developed in the gym using resistance training three times a week as well as plyometrics for neuromuscular improvements specific for the jump event. In the beginning, his coaches, who offered augmented feedback, were refining his straddle technique because this was the accepted technique at the time.

Fosbury's training was distributed throughout the week with rests between. This accommodated for the explosive training of his ATP–CP system, which requires higher intensities and therefore longer recovery times between sessions. Over time, his fast-twitch muscle fibres hypertrophied (increased in size), he developed larger fuel stores of CP and ATP, and his muscular contractions became faster and more forceful than ever due to these chronic adaptations.

However, despite all his training and chronic adaptations, Fosbury was not a world-class high jumper until he switched to the backward jumping style. Initially, his coaches were sceptical because the style was different; however, as he refined the backward flop, Fosbury got better results — in time, qualifying for the 1968 Olympics in Mexico City.

On day 1 of the Olympics, his technique was seen as a novelty by the crowd and fellow competitors, but he cleared all heights. Fosbury's iron-willed belief in the efficacy of his new technique based on the biomechanical principle of centre of mass meant that he persisted the next day despite criticism from the international coaches who watched on and mocked him.

On day 2, Fosbury changed the sport of high jump forever, jumping 2.24 meters to break the US and Olympic records and win the Olympic gold medal. In the years that followed, every Olympic athlete would adopt the Fosbury flop technique as standard for the sport.

This sporting example perfectly illustrates the important role that the different parts of our Unit 3 and 4 course can play in the development of an athlete. Let us break it down a little for you.

FIGURE 15.2 Dick Fosbury changed the sport of high jump by clearing great heights backwards.



15.2.1 Unit 3 knowledge required by Fosbury's coaches

Skill acquisition

Fosbury needed to learn a new skill (the backwards jump, or Fosbury flop) after having trained a completely different skill (the straddle jump) for most of his life. This probably meant that he went from the autonomous stage for the straddle jump to the cognitive stage for the Fosbury flop. It would have taken quite a lot of practice to move through the stages of learning to become autonomous in this new technique.

In order to fast track his progress, his coaches developed a distributed practice regime and provided him with specific augmented feedback. This feedback involved knowledge of performance on the quality of his jumps, and from this they devised training sessions to correct any errors that they saw during the observation and evaluation stage of their qualitative movement analysis (e.g. hitting the bar with his legs, which is quite common with this technique).

Biomechanics

The genius of the Fosbury flop is that it allows the athlete to bend their back around the bar at the peak, causing the athlete's body to clear the bar while their centre of gravity travels under the bar (see figure 15.3). This is a biomechanical concept that Fosbury didn't understand at the time; it would only be understood by biomechanists following Fosbury's Olympic performance.

FIGURE 15.3 In the Fosbury flop, as the athlete bends their back over the bar, their centre of gravity travels under the bar, allowing them to clear higher jumps. This differs from the straddle jump, where the centre of gravity of the athlete has to travel over the bar.



The straddle jump used by his competitors has now been proven to be an inferior technique to gain maximum height, angle and speed of release in the high jump event. However, it was the development of the high jump mat that made the new technique possible. High jumpers previously had to land on sand, a far less forgiving surface than a soft mat. The biomechanical principles of impulse and force reception were critical to the new

technique and therefore the improvement in performance in the high jump. Imagine having to land on your back in a sandpit! All that force, received over such a short time, would have caused many injuries.

Speaking of forces, all of Newton's Laws are applicable during the Fosbury flop.

- Newton's First Law of inertia says that the high jumper must apply a force on the ground in order to overcome their mass and change their motion to jump vertically. The greater the jumper's mass, the more force required.
- Newton's Second Law of acceleration says that for the same mass, if the jumper applies a greater force on the ground, then they will accelerate vertically faster and therefore jump higher.
- Newton's Third Law of action/reaction tells us that when a jumper applies a force on the ground, the ground applies a reaction force on them that is equal and opposite, launching them into the air.

Energy systems

An understanding of the energy systems required for high jumping was critical when developing a training program, training sessions and recovery strategies for Fosbury. The high jump is a maximal intensity, short-duration event and, therefore, the ATP–CP system would be the greatest contributor during his jumps. This system needed to be highly developed and required the most training. Due to high jump's maximal intensity, Fosbury's training sessions needed to include large amounts of passive recovery so that the fuel creatine phosphate could be replenished between jumps.

Acute responses

During each jump, some acute responses that Fosbury would have experienced were decreased creatine phosphate stores, increased enzyme activity and increased motor unit recruitment. These are all muscular acute responses; because the high jump is an anaerobic sport that does not rely on oxygen availability for energy production, there would have been few respiratory or cardiovascular acute responses relevant to his performance. Indeed, Fosbury would have been in oxygen deficit for all of his jumps (i.e. oxygen demand exceeded oxygen supply), and between jumps during his passive recovery, he would have sat down to use excess oxygen to replenish his creatine phosphate.

15.2.2 Unit 4 knowledge required by Fosbury's coaches

Training programs

A knowledge of the fitness components required for high jump and how to fitness test and train each of those fitness components using the correct training methods and training principles was paramount to Fosbury's improvement.

His coaches needed to work on his muscular power and flexibility alongside his new technique during training sessions. To perform the Fosbury flop successfully requires great flexibility of the back, hips and shoulders, so training methods such as dynamic and PNF flexibility training may have been used to increase range of motion and avoid injury. An understanding of resistance training would also have been beneficial, including the exercises targeting muscle groups specific to the requirements of high jump, and how to follow the guidelines for muscular power training using the correct weights (percentage of repetition max) and repetition ranges. Plyometrics training would also have helped Fosbury, allowing him to experience chronic adaptations, particularly at a muscular level and in his fast-twitch fibres. Such adaptations as hypertrophy, increased fuel stores of ATP and creatine phosphate, and increased motor unit recruitment would have allowed him to spring powerfully and high into the air to clear the bar at the Olympic record height of 2.24 meters.

Interestingly, Fosbury did not make the US Olympic Team for the 1972 Munich Olympics. Following his 1968 victory, most athletes adopted the Fosbury flop, quickly perfected it and surpassed Fosbury's Olympic performance. Many of them were superior athletes in other areas important for high jumping, such as muscular power, flexibility and anaerobic capacity, and once they added his biomechanically superior technique, Fosbury was unable to match them. Fosbury and his flop is truly an example of many different disciplines within sports science contributing harmoniously at just the right time to produce an extraordinary sporting performance.

15.2 Activity

15.2 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 4	2, 3	5, 6

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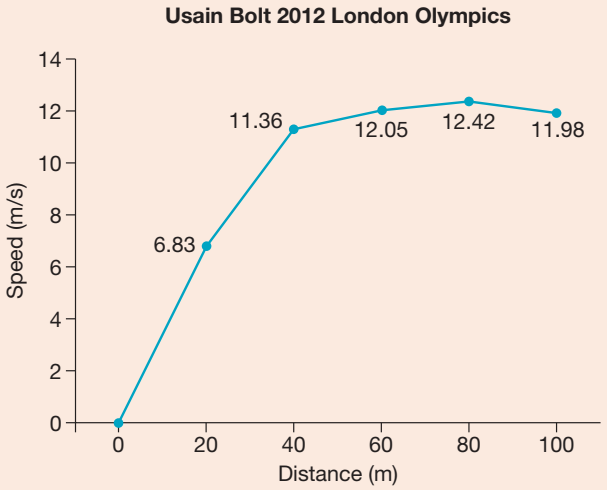


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APPLY your understanding

Use the following information to answer questions 1–2.



1. The graph depicts the 20-metre split speeds for Usain Bolt during the 2012 Olympic final in which he won gold.
   Identify one split on the graph where Usain experienced positive acceleration and **discuss** one acute response to exercise that enabled this.
2. **Identify** one split on the graph where Usain experienced negative acceleration and use your knowledge of energy system interplay and fatigue mechanisms to suggest the cause of negative acceleration.
3. Jamaican runners such as Usain Bolt have dominated track sprinting in both the women's and men's events in recent times. Using your understanding of biological factors such as muscle fibre type and two sociocultural factors, **suggest** a possible explanation for this domination.

Use the following information to answer questions 4–6.



Claudia Hollingsworth is a young Australian middle distance runner competing in the 800-metre and 1500-metre events. At 18 years old, Claudia has the third fastest 800-metre time by an Australian woman of 1 minute 58:81 seconds and she hopes to compete at the 2024 Paris Olympics in both events.

4. **Discuss** the major energy systems and fitness components required to be successful in both the 800-metre and 1500-metre events.
5. **Explain** why having a high lactate inflection point (LIP) is important for Claudia's events and **identify** two chronic adaptations that contribute to an improved LIP.
6. Lactate tolerance would also be important for Claudia to train. **Define** *lactate tolerance*, **describe** how Claudia could best train to improve it and **explain** how an increased lactate tolerance would impact her performance in both events. In your answer you must **identify** one training method and apply the FITT training principles (frequency, intensity, time and type).

15.3 Preparing for your SAC

Key knowledge	Key skills
• the integration of theory and practice utilised in and through participation in practical activity • interdisciplinary learning that connects knowledge related to skill acquisition, biomechanics, energy production and training and the impacts these have on performance	• reflect on primary data from participation in a practical activity • use primary data to demonstrate integration of theory and practice • analyse interrelationships between skill acquisition, biomechanics, energy production and training knowledge for the practical activity completed in consideration of/in relation to the impacts these have on performance between movement skills or performers

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In your SAC, which is worth 25 marks out of 110 for Unit 4, you will be asked to reflect on your participation in:

- a practical activity focusing on a particular movement skill, the performance of which can be compared to another individual completing the same skill **or**
- a practical activity focusing on comparing your participation in two different movement skills.

15.3.1 Primary data

In this area of study, you must use **primary data** as part of your written report. Primary data can include a video or photographs of your performance, or it could include actual data collected during the performance, such as heart rates, lactate levels, heights jumped and/or distances thrown. The data should be recorded in a **reflective folio**.

The findings from the practical activity will be assessed as an **extended response** where you will answer a prompt(s) using the evidence recorded in your reflective folio. The response will demonstrate integrated application of the selected key knowledge and the key skills noted below in the SAC examples. You will also be given time to complete a concept map that clearly shows the interrelated content applicable to the practical activity.

primary data may include numerical data, visual evidence or written observations taken from involvement in practical activities

reflective folio a summary of observations and experiences gained from a practical activity and the theoretical links developed or identified through the activity

15.3.2 Reflective folio

As mentioned, you will have to record your practical session in a reflective folio so that you can draw on this information during your SAC. Below is a template for collating relevant information.

Reflective folio

Sociological data (Context)	
Date of session	
Time of session	
Partner/s (if applicable)	
Venue	
Environmental conditions	
Goal	
Psychological data	
Motivation 0 = Not at all motivated, 5 = Highly motivated	**0 1 2 3 4 5** **Comments:**
Readiness to train 0 = Not feeling it, 5 = Ready	**0 1 2 3 4 5** **Comments:**
Stress 0 = None, 5 = High	**0 1 2 3 4 5** **Comments:**
Quality of sleep 0 = Restless, 5 = Very restful	**0 1 2 3 4 5** **Comments:**
Hours of sleep	
Physiological data	
Energy levels 0 = Lazy and lethargic, 5 = Out of your skin	**0 1 2 3 4 5** **Comments:**
Muscle soreness 0 = Very sore, 5 = Feeling great	**0 1 2 3 4 5** **Comments:**
Health rating 0 = Illness, 5 = Fit and healthy	**0 1 2 3 4 5** **Comments:**
Nutrition and hydration 0 = Poor, 5 = Excellent care taken	**0 1 2 3 4 5** **Comments:**
Components of training session	
Warm up • General phase • Dynamic flex • Sport-specific	400-metre jog followed by 5 × 20-metre strides at 7 RPE Activation activities (dynamic stretches), including hamstring sweeps, open/close gates, A skips, high knees and butt kicks
Conditioning phase • Type of activity • Duration of activity • Intensity of activity	High jump competition 3 × jumps, 10 seconds in duration each High intensity
Primary data • Include results • Attach photos if relevant • Observations made	We recorded our best jumps below: Junhui – 1 m 28 cm Michael – 1 m 05 cm Amalia – 1 m 44 cm Kate – 1 m 22 cm
Reflection • How did it feel? • Did you enjoy the activity? • Any success or challenges experienced	The high jump competition was fun, but challenging and frustrating at times. Coordinating the jump and movement of my body over the bar was difficult and I knocked the bar a number of times.

(continued)

(continued)

Reflective folio	
Cool down • General phase • Dynamic flex • Sport-specific	400-metre jog followed by static stretches, such as toe touches, calf stretch and quad stretch
Teacher/class discussion	Mr Lawrence told us that the Olympic champions, Mutaz Essa Barshim from Qatar and Gianmarco Tamberi of Italy, jumped 2 m 37 cm in 2021. He mentioned that they must train muscular power to be able to produce so much force and that they would be in the autonomous stage so are coordinated to summate more force with timing. As for us, Amalia is a member of the local athletics club and trains for high jump and she was really skilled compared to the rest of the class. Mr Lawrence said she must have lots of fast-twitch muscle fibres.

Notes: *(any interrelationship that exists between skill acquisition, biomechanics, energy production and training)*

SAC EXAMPLE 1

A practical activity focusing on a particular movement skill, the performance of which can be compared to another individual completing the same skill

During a practical class, you hold a high jump competition among the members of your class following an adequate warm up. Each class member must use the Fosbury flop technique for each attempt and will record their results in their reflective folio. Each jumper should also have their technique digitally recorded and ensure a still photo is taken of them as they clear the bar. This must be included in the reflective folio and compared to an image of an elite jumper.

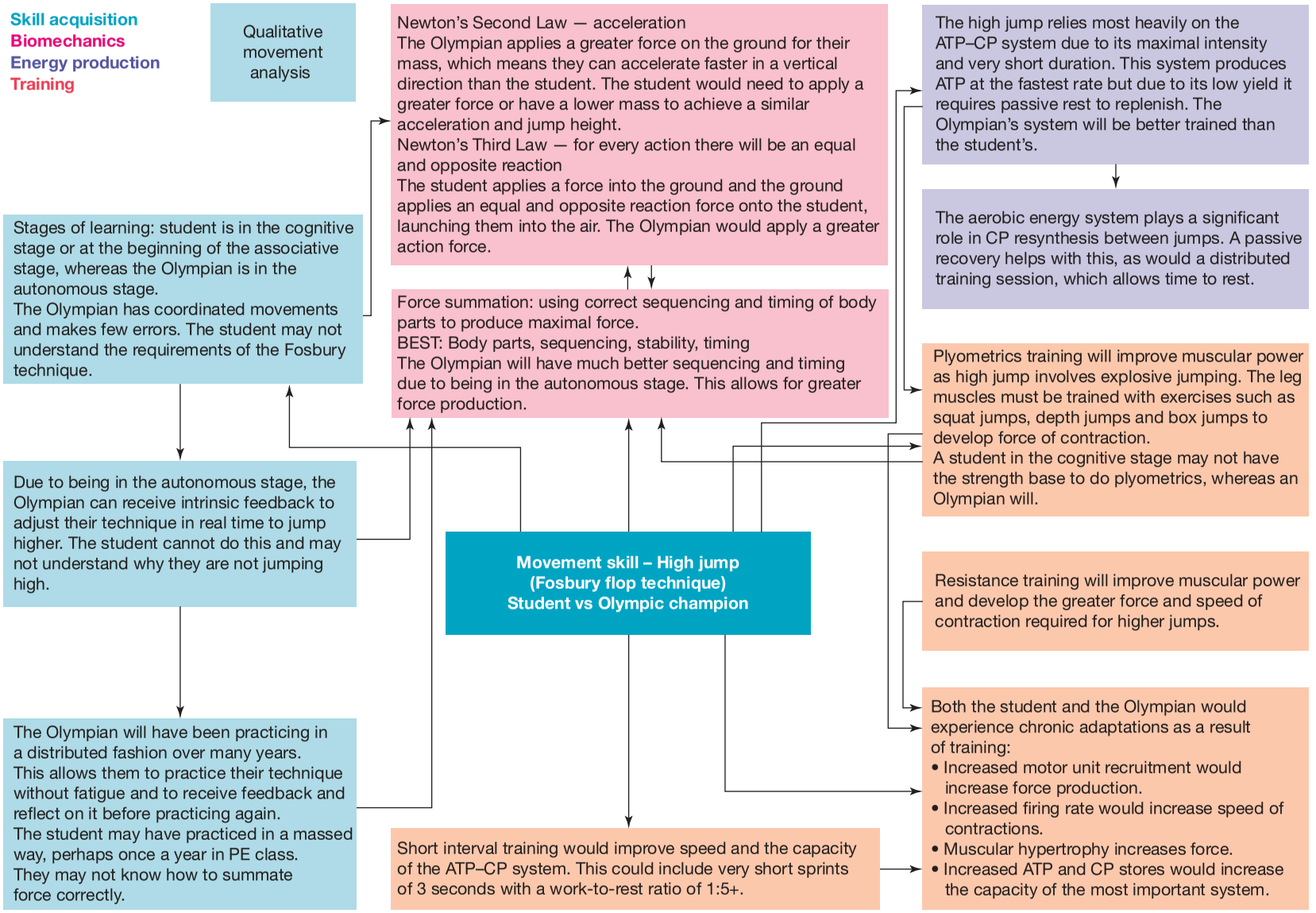
Your **written report** will analyse the **interrelationship** between skill acquisition, biomechanics, energy production and training by comparing your participation in the practical activity (high jump) with the elite performance of either of the two current Olympic champions: Mutaz Essa Barshim from Qatar or Gianmarco Tamberi of Italy (see figure 15.4).

FIGURE 15.4 Mutaz Essa Barshim from Qatar and Gianmarco Tamberi of Italy cleared 2.37 meters to share Gold at the Tokyo 2020 Olympics.



The first part of your SAC will involve creating a concept map like the one in figure 15.5. This must be done in class after you receive an inquiry question from your teacher. Of course, you will already have formulated ideas in your reflective journal about the concepts that are likely to be relevant and the interrelationship of those concepts. This first section of your SAC should take approximately 20 minutes.

FIGURE 15.5 A concept map that shows the interrelationship between concepts related to high jump when comparing a student and Olympic champion.



The second part of your SAC will be responding to an extended response question that your teacher creates. Your response must clearly show both your understanding of the concepts your teacher has identified as well as the interrelationship between the concepts and how this culminates in the performance. This section should take approximately 30 minutes.

The inquiry question for this SAC could be:

Analyse the biophysical differences in the performance of the Fosbury flop high jump technique between you and one of the current Olympic champions. Use the findings to compare how skill acquisition, biomechanical, energy production and training concepts interrelate in influencing the two performances.

Concept map

Many students will find a visual tool such as a concept map valuable for exploring the interrelationship between concepts. The concept map in figure 15.5 is a good example of what you will need to create in the SAC. This kind of concept map is readily transferable to a multitude of events and sports. It provides specific details about the different concepts applicable to the sport or event, how these relate to other concepts and the application for athletes.

Written report

Introduction (100 words, approximately 20% of the report)

In your introduction, briefly describe the Fosbury flop high jump technique and any interrelationships that exist between skill acquisition, biomechanics, energy production, fitness and training as demonstrated through your high jump practical.

Body of the report (250 words, approximately 70% of the report)

Extended response question: In the body of your report, be sure to explain how the interrelationship between the following factors contributes to differences in performance in the high jump between you and one of the elite Olympic high jump champions:

- Stages of learning and practice distribution
- Newton's Laws and force summation
- Energy systems contributions
- Training methods and at least two muscular chronic adaptations.

Conclusion (50 words, approximately 10% of the report)

By referring to any concepts within skill acquisition (including coaching) and training to improve performance, suggest how your performance in high jump could be improved in the future.

SAC Example 1 — sample response

Introduction

During a PE class, we performed in a high jump competition against others in the class. The technique we used was the Fosbury flop, which required us to go over the bar backwards. The technique is quite difficult to coordinate, most of us hit the bar with either our legs or our backsides and my best result was 1.58 metres. We then watched the 2020 Tokyo Olympics final where the athletes jumped 2.37 metres. The two winners' techniques were far more advanced, as they were able to get their backsides much higher, flick their legs out of the way and apply more force on the ground.

Body

The student high jumper is in the associative stage of learning for the Fosbury flop as they had practiced the technique in PE class in Year 9 and 10, whereas the Olympic champion is in the autonomous stage. This means that the Olympic champion has more fluent, coordinated movements and their technique is able to summate forces more efficiently to produce a height of 2.37 metres compared to the student at 1.58 metres.

Force summation is the correct sequencing and timing of body parts to produce maximal force. The Olympic jumper can use as many body parts as possible in correct sequence using their heavier/slower body parts first (e.g. torso and hips) and their lighter/faster body parts last (e.g. their feet and toes). Each part moves only when the previous body part has reached maximal velocity. Increased force summation will mean greater force can be applied on the ground during the high jump and so the ground will apply a greater reaction force on the jumper, which launches them high into the air to clear the bar. This is Newton's Third Law of action/reaction. Distributed practice, where training is done frequently but with rests in between, is an advantage that the Olympian has over the student, who has only done massed practice. The student completed practice only twice over four years, which also means they will not have received much feedback and had time to act on it, in contrast to the Olympian. Distributed practice also enables the Olympic athlete to train without fatigue and to take breaks to replenish CP stores.

The ATP–CP system is the most important energy system for the high jump event. This is because the high jump is a maximal intensity but very short duration skill and the ATP–CP system produces ATP at the fastest rate. The aerobic system is also vital for the rest periods in between each jump so that CP stores can be replenished during a passive recovery.

The best training methods would be plyometrics and short interval training. Plyometrics are very specific because they replicate the jumping action and train muscular power. Exercises such as jump squats and box jumps would illicit chronic adaptations such as muscular hypertrophy, increased force production so that the jumper can summate more force and increased speed of contraction via an increased firing rate and increased motor unit recruitment. Due to being in the associative stage, the student may not be able to partake in plyometrics training due to not having a base level of strength yet, but the Olympian would benefit greatly. Short interval training of 3-second sprints at 95% MHR with a work-to-rest ratio of 1:5–10 would help to increase the capacity of the ATP–CP system for both the student and the Olympic champion. Increased ATP and CP fuel stores would allow greater speed into the bar and greater force production. If a jumper can apply more force on the ground, Newton's Second Law of acceleration ($F = m \times a$) states that for a given mass, the greater force will produce greater acceleration and therefore a greater height achieved over the bar. Both the student and the Olympian need to have as small a mass as possible while producing as much force as possible to achieve the fastest acceleration. This causes a greater height over the bar and better performance by the Olympian (2.37 metres compared to the 1.58 metres of the student).

Conclusion

In order to improve their performance, the student would need to engage in distributed practice frequently, with rest periods during which they receive feedback on their technique. Technique development should focus on improving force summation via correct timing and sequencing, and be combined with a plyometrics or resistance-training program aimed at increasing the force and speed of muscular contraction, and interval training to improve the capacity of the ATP–CP system. All of this would allow a greater force to be applied to the ground, potentially resulting in a higher jump.

SAC EXAMPLE 2

A practical activity focusing on comparing your participation in two different movement skills.

Written report

During a practical class, you and your classmates are to participate in two different athletic events, high jump and shotput, following an adequate warm up.

Each class member must do their best in both skills and will record their best results in their reflective folio. Each student should also have their techniques for both sports digitally recorded and have still photos taken of them performing both skills.

Your written report will analyse the interrelationship between skill acquisition, biomechanics, energy production and training in both sports and then compare any similarities and differences between the requirements of high jump and shotput.

FIGURE 15.6 Although high jump and shot-put are quite different movement skills, there are many interrelationships between their underpinning concepts.



Introduction (100 words, approximately 20% of the report)

In your introduction, briefly describe the techniques of the high jump and the shot-put, along with any similarities and differences between the performance of these skills that you have noted.

Body of the report (400 words, approximately 50% of the report)

Extended response question: In the body of your report, be sure to analyse the differences in your performance of the high jump as compared to the shot-put by referring to the interrelated concepts below:

- Stages of learning
- Projectile motion and force summation
- Fitness components
- Training methods

Would it be possible for one athlete to be an elite performer in both events at the same time? Why or why not?

Conclusion (150 words, approximately 15% of the report)

By referring to any concepts within skill acquisition, biomechanics and training to improve performance, suggest how your performance in high jump and shot-put could be improved in the future.

15.4 Key skills

Key skills

- reflect on primary data from participation in a practical activity
- use primary data to demonstrate integration of theory and practice
- analyse interrelationships between skill acquisition, biomechanics, energy production and training knowledge for the practical activity completed in consideration of/in relation to the impacts these have on performance between movement skills or performers.

Source: VCE Physical Education Study Design (2025–2029) extracts © VCAA; reproduced by permission

15.4.1 Tell me

- Question 11 of the 2023 VCAA Physical Education Examination gave insight into how you are expected to show understanding of the interrelationship of concepts in exam conditions.
- The question itself was familiar, but the answer required links to each of the interrelated concepts within each paragraph of the response.
- You must not simply address each dot point within the question stem, but interweave them throughout.

15.4.2 Show me

Practice question (8 marks)

KEY

- **green** identify the action word
- *purple* key terminology
- blue key concepts
- light orange marks/marking scheme

Source: *VCE 2023, Physical Education Exam, Section B, Q.11;* © VCAA

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 canoes 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 usage
- fitness components.

Decode the question

Strategies to decode the question

- **Identify the action words:**
  Explain — provide detail to show the relationship between concepts
- **Key terminology** — *interrelationship*, *successful performance*
- **Key concepts** — Newton's laws of motion, fuel usage, fitness components
- **Marking scheme** — 8 marks — always check the marking scheme for the depth of response required, linking to key information highlighted in the question.

Sample response

Jessica Fox was able to successfully win gold in the canoe slalom by using a combination of *muscular power, agility, speed* and *anaerobic capacity*. The canoe would *remain at rest* until Fox applies a *force* using her paddle, which allows her to move towards the first gate (Newton's First Law). CP would fuel this explosive movement, allowing Fox to use her *muscular power* to approach the gate as quickly as possible. As Fox's paddle *applies a force* on the water, the water would apply an equal and opposite reaction on the paddle (Newton's Third Law), allowing her to move through the course quickly.

Once Fox reaches the gate, she applies a force using her paddle to *change the motion of the canoe to slow it down* (Newton's First Law). In doing so, Fox uses her *agility* — the ability to change direction quickly in control. This is important so that she does not touch the gate but can still complete the course as quickly as possible.

As she leaves the first gate, she would use Newton's Second Law of motion to apply a force to the water to successfully *accelerate* towards the next gate. The greater the force Fox can apply, the greater the acceleration of the canoe because force = mass × acceleration. This allows Fox to use the *fitness component of speed* to get to each gate in the quickest time possible. As her CP stores start to *deplete,* Fox would use glycogen as a fuel and her *anaerobic capacity to resynthesise ATP anaerobically* so that she can continue to move her canoe quickly, helping to reduce her time.

As the course takes Fox 105.4 seconds to complete, glycogen will be the main fuel used through anaerobic and aerobic pathways, therefore requiring a combination of *aerobic power and anaerobic capacity*. By using a combination of *agility, muscular power, speed and anaerobic capacity*, Fox successfully paddles at the fastest pace possible to win the gold medal.

Marking guide

Marks for these types of questions would be allocated based on a rubric similar to the one shown in table 15.1.

TABLE 15.1 A rubric, similar to this one, is used to mark these types of questions.

High range response	• Ideas are well-organised and convey a clear message • Interrelationships among fitness components, fuels and Newton's laws are very clear and integrated throughout the response • Strong connection to the stimulus • Significant fitness components for canoeing are **comprehensively** discussed — at least two fitness components referenced correctly • Link between the fitness components, fuels and Newton's laws are thoroughly discussed
Mid range response	• Ideas are mostly organised • Some interrelationships among fitness components, fuels and Newton's laws are given, and an attempt to integrate them has been made • Stimulus is referred to more than once • Significant fitness components for canoeing are discussed • The fitness components, fuels and Newton's laws are discussed, but separately with few links
Low range response	• Ideas are discussed separately • Little of the stimulus is incorporated into the response • Some fitness components are discussed with an attempt to connect to the stimulus • Only some of the concepts of fitness components, fuels and Newton's laws are mentioned • There are inaccuracies in the answer

Success criteria: To perform in the top bracket, all of the below key words must be included:

- Newton's three laws: inertia, acceleration and action/reaction
- CP
- glycogen
- muscular power
- explosive intensity
- force
- speed, agility or anaerobic capacity.

Marks for this question are awarded based on:

- discussion of the interrelationships
- how well the stimulus material has been understood and connected to the response
- how the response has been structured
- how well the content of the study design has been understood
- how the stimulus material has been used to support the analysis of performance for the canoe slalom, integrating Newton's laws, fuel usage and fitness components.

EXAM TIP

If the question asks to show an interrelationship, you must not simply address each dot point within the question stem, but interweave them throughout.

15.4.3 Let me do it

Question 1 (8 marks)

Nicola Olyslagers (née McDermott) is an Australian high jumper who won a silver medal at the Tokyo Olympics in 2021. Nicola drew attention at these games for her routine of sitting down to write in her journal as she recovered between jumps.

Nicola is pushing for Gold in the Paris Olympics and has been utilising the help of coaches and biomechanists so that she can clear her personal best and Australian record height of 2.00 metres.

The high jump is a technical sport requiring multiple fitness components working together to gather horizontal velocity during the run up and then convert it into vertical velocity during the explosive take-off, to defy gravity and clear a rigid bar. High jumpers must do all of this by mastering a complicated technique that sees them launch backwards, contort their bodies and land on their backs on a soft mat to break their fall and avoid injury.

FIGURE 15.7 Nicola Olyslagers making notes during the high jump final at the Tokyo 2020 Olympic Games.



Explain how the interrelationship between the following factors would contribute to Nicola Olyslagers' successful performance in the high jump at the Paris 2024 Olympics:

- fitness components
- training methods
- the biomechanical concept of impulse
- energy systems and recovery.

15.5 Review

Hey students! Now that it's time to revise this topic, go online to:

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15.5.1 Summary

Case study — Dick Fosbury

- Many of the concepts covered in Units 3 and 4 can be applied to sports performance.
- The interrelationship between concepts within a sport must be demonstrated.

Preparing for your SAC

- Primary data has to be collected during practical activities so that it can be referenced.
- A reflective folio is a way to record the data collected during a practical activity.
- In the written report, you will be required to create a concept map to show the interrelationship between concepts.
- The introduction briefly describes the sport and the interrelationship between relevant concepts.
- The body of the report requires you to explain these interrelationships and aspects of the sport.
- The conclusion suggests how performance in the sport could be improved.

15.5.2 Key terms

primary data may include numerical data, visual evidence or written observations taken from involvement in practical activities
reflective folio a summary of observations and experiences gained from a practical activity and the theoretical links developed or identified through the activity

15.4 Exam questions

Question 1 (9 marks)

Source: Adapted from *VCE 2020, Physical Education Exam, Section B, Q.4;* © VCAA

Peta is a soccer coach who is applying her understanding of fitness components and training methods as well as 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 fitness component of muscular power, training methods and biomechanical principles, discuss the type of feedback and training that Peta can provide to the players to correct this error and refine their skill.

Your response should include reference to the interrelated concepts of:

- feedback
- practice variation
- force summation
- training methods.

Question 2 (9 marks)



A fast bowler in cricket can bowl balls at over 200 km/h. A fast bowler will complete a long run-up of around 20 metres at a fast speed then in the delivery stride they will leap up powerfully. Upon landing on their back foot, they turn side on to facilitate hip and shoulder rotation into the movement. The bowler will then plant their front foot behind the bowling crease to stabilise themselves and produce as much force as possible from the lower body. At the same time, the arm swings rapidly around the axis of the shoulder (the elbow cannot bend in a bowl) and the release of the ball is made from the fingers.

The objective is to bowl as fast as possible so that the batsman has minimal time to see and hit the ball and is more likely to be rushed into a shot that leads to them getting out.

Explain how the interrelationship between the following factors would contribute to a fast bowler bowling a ball that exceeds 200 km/h:

- energy systems
- training methods
- summation of momentum.

Question 3 (8 marks)

A gymnastics coach is teaching a young gymnast how to complete and hold a handstand during her floor routine. The gymnast is initially motivated to master this skill as quickly as possible. However, after a number of long 2-hour sessions focusing on just the one skill, her motivation quickly deteriorates, and her performance does not improve. The young girl begins to miss sessions due to muscle soreness and considers quitting gymnastics.



Explain the interrelationship between practice distribution, fatigue and recovery as well as the link between motor skill development, participation and performance, and suggest a more appropriate training regime for the young gymnast to follow to remain motivated.

Question 4 (9 marks)

Bryson De Chambeau is a big-swinging American golfer; he won the 2020 US Open Golf Championship. That year, Bryson hit his drives off the tee an average of 315 metres — almost 12 metres longer than the next closest player — and his longest tee shot was an amazing 357-metre drive.

In 2019, Bryson significantly altered his body shape through resistance training, as well as his swing and equipment, in order to maximise his driving distance for the 2020 season.

He gained 20 kilograms in muscle by working out each day and he learned to swing the longest golf driver on the tour (115 centimetres) to gain even more distance.



With reference to data in the stimulus, explain the interrelationship between altering body shape via resistance training and the impact that an increased club length might have on driving length.

In your answer be sure to show your understanding of the concepts of:

- levers and mechanical advantage
- angular momentum
- chronic muscular and neuromuscular adaptations.

Continue to build your exam skills

Access the Unit 4 Area of Study 3 Review at the end of Topic 15. This includes:

- Practice school-assessed coursework.

GLOSSARY

1 RM (1 repetition maximum) the maximum amount of force that can be generated in one maximal contraction. This is commonly used to measure strength.

absolute VO_2 max a measurement of the total amount of oxygen consumed in L/min

accelerometer an instrument for measuring the rate at which an athlete changes velocity

accuracy precision of measurements, observations, or actions

active recovery low-intensity (50–60 per cent of MHR) activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling

activity analysis the recording and analysis of movement and skill data from a game, sport or activity

acute responses the body's immediate, short-term responses that last only for the duration of the training or exercise session and for a short time afterwards (recovery)

adenosine diphosphate (ADP) a by-product that results when ATP breaks down and loses one of its phosphate groups, which are located at the end of the molecule

adenosine triphosphate (ATP) a high-energy molecule stored in muscle cells and other parts of the body. It is the energy currency for biological work.

aerobic energy system provides energy from the breakdown of carbohydrates and/or fats in the presence of oxygen

aerobic metabolism when ATP resynthesis occurs via energy pathways that require the presence of oxygen

aerobic power the maximum rate of energy production from the aerobic energy system (i.e. energy produced in the presence of oxygen)

aerobic system provides energy for the resynthesis of ATP through the breakdown of various energy fuels (mainly glycogen and triglycerides) through a series of chemical steps that require oxygen

agility a quick change in direction while maintaining balance

agonist the prime mover of the muscle action. It causes the movement to occur.

amino acids the building blocks of protein. Protein is broken down through the process of digestion into amino acids.

anaerobic capacity the total amount of energy obtainable from the anaerobic energy systems (the combined capacity of the ATP–CP system and the anaerobic glycolysis system)

anaerobic glycolysis energy system provides energy for the resynthesis of ATP through the breakdown of glycogen through a series of chemical steps that do not require oxygen

anaerobic metabolism when ATP resynthesis occurs via energy pathways that do not require the presence of oxygen

angular displacement the change of angle between the initial and final position

angular distance the angle between the initial and final position

angular motion takes place when a body moves along a circular path

angular speed the change in angular distance over time

angular velocity the change in angular displacement over time, which indicates how quickly an object rotates

antagonist a muscle that works in opposition to the agonist muscle

arousal the readiness an individual experiences when faced with a sporting situation or task

arteriovenous oxygen difference (a-VO_2 diff) a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.

associative (practice) stage of learning the second phase in the learning of a new skill, in which movement patterns become more refined and consistent through practice

ATP demand refers to how much ATP is required during an activity and the rate at which it is expended and, therefore, needs to be resynthesised

ATP–CP energy system provides energy for the resynthesis of ATP through the breakdown of creatine phosphate (CP) without oxygen being involved

augmented feedback information about a skill performance that comes from an external source
autonomous (automatic) stage of learning the final stage of learning in which the performer's skill execution is almost automatic and requires very little of their attention
balance the ability of the body to remain in a state of equilibrium while performing a desired task
barrier something or someone that has a negative effect on a person's movement skills
blocked practice a type of practice in which each skill component is practised repetitively as an independent block
blood pressure the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: systolic blood pressure and diastolic blood pressure.
buffering capacity the ability of the muscle cell buffers to resist changes in pH (acidity)
capillarisation an increase in the capillary density and blood flow to skeletal or cardiac muscle as a result of aerobic training
carbohydrate loading a nutritional strategy in which muscle glycogen stores are maximised prior to endurance events
carbohydrates naturally occurring compounds that consist of carbon, hydrogen and oxygen
carbohydration combining hydration and refuelling at the same time
cardiac hypertrophy an enlargement of the heart muscle as a result of training
cardiac output ($\dot{Q}$) the amount of blood ejected from the left ventricle of the heart per minute; $\dot{Q}$ = heart rate (HR) × stroke volume (SV)
centre of mass the position where the weight of the object is evenly distributed
choking when an athlete fails to perform effectively under pressure conditions
chronic adaptations the body's long-term responses of the cardiovascular, respiratory and muscular systems that develop over a period of time when training is repeated regularly
circuit training involves working at a variety of activity stations in sequence, training a number of fitness components at once
closed motor skills are performed in a predictable, self-paced environment with low inter-trial variability
cognitive (understanding) stage of learning the initial phase of learning of a motor skill where the emphasis is on conscious understanding of the task requirements
competition phase (in-season phase) the phase of training in which the emphasis is on maintaining the fitness and skill level developed during the preparatory phase, and further developing and refining strategies, tactics and game plans
concentration (or attention) the ability to focus on the task at hand and ignore distractions
continuous motor skills have no distinct beginning or end
continuous training involves continuous activity that lasts a minimum of 20 minutes at the required intensity using the aerobic energy system. It is submaximal and requires an intensity of 70–85 per cent of maximum heart rate. Also known as long, slow distance training.
cool down low-intensity activity completed at the end of an exercise bout that allows the body to recover by maintaining an elevated blood flow to the muscles and preventing venous pooling, gradually returning the body to its resting physiological state
coordination the ability to use different parts of the body together smoothly and efficiently
creatine phosphate (CP) a chemical compound found in muscle cells that is capable of storing and releasing energy that can be used to resynthesise ATP from ADP and Pi
creatine an organic substance that occurs naturally in humans and helps to supply energy to muscle
data collection the process of gathering information
dehydration the loss of too much fluid from the body
detraining a period of time when training is ceased or there is a reduction in training load beyond what is required for fitness to be maintained
diastolic blood pressure the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.
diminishing returns a principle that states that as a performer becomes more competent in their skill performance and progresses to the later stages of learning, there is a gradual reduction in the rate of improvement in skill performance in response to practice

discrete motor skills involve movements of brief duration that are easily defined by a distinct beginning and end

displacement the difference between the initial position and final position of an object

distance the length of space between two points

distributed practice a form of practice in which smaller practice time intervals are interspersed with rest periods. This applies equally to both the practice schedule and the individual practice session.

dynamic equilibrium the state in which a body is in motion with a constant velocity

eccentric force a force that is off-centre or not directly through an object's centre of mass

eccentric a contraction in which the muscle lengthens as it contracts

economy the quantity of oxygen (mL/kg/min) required to generate movement at any given speed or intensity

enabler something or someone that has a positive effect on a person's movement skills

excess post-exercise oxygen consumption (EPOC) the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest

explicit learning learning that takes place as a result of direct instruction, where the performer is told what to do and when to do it

fartlek training a type of training that works both the aerobic and anaerobic energy systems by interspersing continuous low/medium-intensity efforts with high-intensity efforts

fascia densely woven connective tissue that covers and bonds internal sections of the body

fatigue an exercise-induced reduction in the ability of muscles to produce force or power

fats (lipids) an essential component of a balanced diet; should comprise about 20–25 per cent of daily food intake

feedback frequency how often an external source (e.g. coach) provides feedback to the skill learner

feedback information concerning the performance and/or outcome of a movement skill, including information about errors and how to correct them

fibre hyperplasia an increase in the number of fibres within a muscle

fine motor skills delicate, precise movements that engage the use of small muscle groups

fitness conditioning phase the part of a training session that focuses on the development and/or maintenance of the specific fitness components, muscle groups and energy systems required for a particular sport or activity

flexibility the range of movement around a joint

force summation the correct timing and sequencing of body parts to produce maximal force

force the product of mass and acceleration

free fatty acids a broken-down, transportable form of fats

frequency the number of training sessions needed per week to ensure improvements are achieved in the desired fitness components and energy systems

fundamental movement skills (FMS) movement patterns that involve different body parts. They are the foundational movements for more specialised sport-specific skills.

gastrointestinal tolerance the ability to digest or fully metabolise a food/drink

general motion the combination of linear and angular motion

glucose the simplest form of carbohydrate and the basic ingredient for anaerobic and aerobic glycolysis

glycogen sparing the process whereby glycogen stores are not used as early in an exercise bout due to the increased ability to use triglycerides to produce energy. This delays depletion of glycogen stores, and thereby delays the time to exhaustion.

glycogen the storage form of glucose; a chemical fuel found in the muscles and in larger quantities in the liver

goal setting making plans to work towards achieving specific and beneficial objectives and results

GPS Global Positioning System. This technology uses satellites to identify position and movement.

gross motor skills movements involving the use of large muscle groups, resulting in a coordinated action

gyroscope a sensory device that explains the direction of gravity and determines the position of an athlete

haemoglobin a substance in the blood that transports oxygen around the body

heart rate (HR) the number of times the heart contracts or beats per minute

heart rate reserve the difference between resting heart rate and maximum heart rate

high-intensity interval training (HIIT) involves repeated work intervals that are relatively brief in duration, performed at a high level of intensity close to VO_2 maximum, followed by less intense recovery/rest intervals

hitting the wall a term used in endurance sports to describe the sudden feeling of extreme fatigue associated with the depletion of glycogen stores in the muscle and liver
homeostasis the ability of the body to maintain a stable internal environment
hydrogen ion the presence of these ions makes the muscle acidic and will eventually fatigue muscle function
hypertension high blood pressure
hyperthermia high body temperature caused by a failure of the heat-regulating mechanisms of the body
hypoglycaemia when blood sugar levels have dropped too low due to prolonged strenuous activity and depleted glycogen stores
implicit learning learning through doing. The participants learn through completing a task.
impulse the product of force and time
individuality a principle that suggests that individual responses to physical activity are highly varied
inertia the resistance of a body to a change in its state of motion
intensity the exertion level or how hard the training is being performed. It is commonly measured as a percentage of maximum heart rate (MHR), which is determined by beats per minute (bpm).
intermittent short periods of work followed by a period of rest
interplay of energy systems the energy systems simultaneously working together, but at different rates, to supply the ATP required for an activity
interval training consists of repeated periods of work followed by periods of rest or recovery
intrinsic feedback sensory information the learner receives directly from skill execution
isometric a contraction in which the muscle length remains the same as it contracts under tension
knowledge of performance feedback regarding how a skill is performed; assessing performance on the basis of process and skill technique
knowledge of results information about the outcome of skill performance; information regarding the relative success or failure in regard to the intended goal of the movement skill
lactate inflection point (LIP) the highest intensity point at which there is a balance between lactate production and removal from the blood. It represents a person's highest steady state intensity.
linear motion occurs either in a straight line or curved path
magnetometer a device that measures the direction and strength of magnetic fields
maintenance a principle that suggests that once a required level of fitness has been achieved, the level of effort to maintain that level of fitness is not as great as was required to achieve it
mass the quantity of matter found within a particular body
massed practice a form of practice in which there is little or no rest between repeat performances of a skill
maximum heart rate (MHR) the highest heart rate value achieved in an all-out effort to the point of exhaustion
maximum oxygen uptake (VO_2 max) the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production
metabolic by-product (or metabolite) a substance produced as a result of chemical reactions within the body associated with the production of energy for ATP resynthesis
metabolic equivalents (METs) a system for classifying exercise intensity. 1 MET is equal to resting levels.
mitochondria cell structures (organelles) that serve as the power generators of the cell, converting nutrients into ATP in the presence of oxygen (aerobically)
moment of inertia a measure of an object's resistance to change in its rate of rotation
momentum the product of mass and velocity; for example, a body with greater mass moving faster will have greater momentum than a lighter object moving slower
motion the change in position of a body in relation to time
motivation a reason for participating in an activity; a reason for practising.
motor unit consists of one motor neuron and all of the muscle fibres that it innervates
movement patterns the typical movements completed by a performer during a sport or activity
multifactorial involves or is dependent on several factors or causes
muscle protein synthesis the process of producing new muscle protein to maintain and build muscle
muscular endurance the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time
muscular hypertrophy an increase in the cross-sectional size of a muscle

muscular power the ability of a muscle or group of muscles to exert a maximum amount of force in the shortest period of time

muscular strength the peak force that a muscle can develop

myofascial release a massage technique that focuses on relieving pain in the thick connective tissue that support muscles (myofascial tissues)

myofibrils small fibres that run through each muscle fibre

myoglobin an oxygen-binding protein in skeletal muscle cells that attracts oxygen from the bloodstream and shuttles it to the mitochondria in the muscles for aerobic energy production

neuromuscular the connection between the nervous (neural) system and muscular system. Motor neurons transmit signals to muscular fibre/s, causing a muscle contraction.

Newton's First Law of Motion states that an object will stay at rest or continue to travel in the same direction at a constant velocity unless acted on by an unbalanced force

Newton's Second Law of Motion states that the rate of acceleration of a body is proportional to the force applied to it and in the direction in which the force is applied

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction

open motor skills are performed in a constantly changing, externally paced environment with high inter-trial variability

overtraining often caused by an overload of training volume and/or intensity, limiting recovery. It is characterised by a decline in an athlete's performance and an increase in their susceptibility to injury/illness.

oxidative enzymes enzymes that, with the use of oxygen, speed up the breakdown of nutrients to resynthesise ATP

oxygen deficit the state in which there is a discrepancy (shortfall) between oxygen supply and the oxygen needed to meet the energy requirements of the activity. The anaerobic pathways must supplement the energy demands of the activity.

oxygen uptake (VO_2) the amount of oxygen transported to, taken up by and used by the body for energy production

part practice learning smaller parts of a skill in isolation

passive recovery complete rest by standing, sitting or lying down to replenish CP at a faster rate

peaking refers to the planning of training so that an athlete reaches their optimum state of readiness to perform at a particular predetermined time

periodisation a systematic approach to training that involves dividing the training program into specific phases each with distinct goals, including the planned manipulation of training variables (volume, frequency and intensity)

pH a measure of the acidity or alkalinity of a substance

physiological perspective examination and understanding of the various bodily systems and functions that influence athletic performance

physiological training data provides information about the body's physical functioning in response to training

Pilates a type of exercise that involves a series of repetitive body movements that aim to improve your muscle strength, balance, flexibility and posture

plyometrics involves the use of the stretch-shortening muscle cycle to produce powerful and explosive movements

potential energy the capacity of the muscle to do work based on its position. This happens in the eccentric phase of contraction. The greater the stretch, the greater the capacity of the concentric muscle contraction.

practice distribution the ratio between time spent actively practising and time spent resting

preparatory phase (pre-season phase) the first phase of training within a yearly training program. The major objective of this phase of training is to provide a suitable fitness and skill base for the phases of training that follow.

primary data may include numerical data, visual evidence or written observations taken from involvement in practical activities

proprioception the body's ability to sense its location, movements and actions

protein an essential component of a balanced diet. Protein allows for muscle growth and repair, fights disease, assists in chemical reactions and transports materials

psychological perspective examination and understanding of the mental and emotional aspects that influence athletic performance, behaviour and experiences

psychological training data provides the athlete with an understanding of their mental readiness and mental capacity to train and perform. Includes recording the athlete's thoughts, feelings and cognitive characteristics that affect performance.

pulmonary diffusion the movement of oxygen and carbon dioxide from areas of high concentration to areas of low concentration between the alveoli and the surrounding capillaries

pyruvic acid (pyruvate) an intermediate product in the metabolism of carbohydrates, formed by the anaerobic metabolism of glucose

qualitative subjective in nature; thoughts, opinions and feelings (e.g. RPE)

quantitative objective in nature; expressed in numerical terms (e.g. heart rate)

random practice a form of practice that involves rehearsing a number of different skills in an unpredictable sequence

rate coding refers to the frequency of impulses sent to a muscle

rate refers to how quickly ATP is resynthesised

real time means that data is processed straight away and is available virtually immediately as a source of feedback

recovery the overcoming or reversal of the fatigue experienced as the result of participation in a training session or exercise bout, where body systems repair damaged tissue and replenish energy stores

reflective folio a summary of observations and experiences gained from a practical activity and the theoretical links developed or identified through the activity

relative VO_2 max a measurement that takes into account body weight and is given in mL/kg/min

reliability consistency and dependability of measurements, tests, or assessments used to evaluate

repetition maximum (RM) the maximum amount of weight that a person can lift in one muscular contraction

resistance training training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance

respiratory frequency (RF) the amount of times a person breathes in and out each minute

respiratory rate the number of breaths taken per minute

resting heart rate the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult

reversibility the fitness and/or performance loss after a period of detraining

RPE (rating of perceived exertion — Borg Scale) a subjective rating of how hard the athlete feels they are working. It is a numerical scale ranging from 6 to 20, with 6 being no feeling of exertion and 20 being extremely hard. A score of 13–14 is classified as moderate intensity, and 15–16 is classified as vigorous.

SAID stands for specific adaptations to imposed demands

self-confidence what an individual has when they believe that they can successfully perform a task and achieve their goal

serial motor skills a series or group of discrete skills strung together to create a more complicated, skilled action

size principle the principle by which motor units are recruited in order of their size from smallest to largest

skill development phase includes activities designed to develop and/or practise skills, game plans, tactics and strategies

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

sociological training data provides context about the broader social, cultural and environmental factors that contribute to an athlete's performance

somatic having an awareness and connection with your body. Comes from the Greek word *soma*, which means 'body'.

specificity the process of replicating the characteristics of physical activity in training to ensure it benefits performance

speed the rate of motion (distance/time)

sport-specific skills use a range of fundamental movement skills in a sequence

stability the degree to which a body resists changing its equilibrium
static equilibrium the state in which a body has zero velocity and zero acceleration. A body is in equilibrium when the sum of all forces and the sum of all movements acting on the body are zero
static stretches involve holding the end point of a stretch for up to 30 seconds
steady state the state in which oxygen supply equals oxygen demand so that virtually all the required ATP to maintain the current exercise intensity is being supplied aerobically.
stretch reflex occurs when an impulse is immediately sent to the spinal cord for a muscle to contract when it is stretched, to prevent overstretching
stroke volume (SV) the amount of blood ejected from the left ventricle with each beat (contraction) of the heart
synergist a muscle that stabilises movements to and maintains control within the desired range of motion
systolic blood pressure the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure values.
tapering a reduction in training that allows the athlete time for extra recovery and for their energy stores to be fully replenished
thermoregulation the processes the body uses to maintain its core internal temperature
tidal volume (TV) the amount of air inspired and expired by the lungs per breath
time/duration the length of a training session, the length of a work interval within a training session and/or the length of the overall training program
torque a force that is applied at a distance away from the centre of mass, that causes the object to rotate
training zone describes the intensity range that is required for specific adaptations to occur
transition phase (off-season phase) designed to provide the athlete with a break from the physiological and psychological demands of competition and training. The aim in this phase is for an athlete to remain reasonably active through participation in recreational and low-intensity activities.
triglycerides the stored form of fats found in adipose tissue and skeletal muscle
type 1 slow-twitch oxidative fibres contain large and numerous mitochondria, high levels of myoglobin and a high capillary density. They are very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolism.
type 2A fast-twitch oxidative fibres red fibres; have a very high capacity for generating ATP by oxidative metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.
type 2B fast-twitch glycolytic fibres white fibers; are geared to generate ATP by anaerobic metabolic processes. They split ATP at a very rapid rate, have a fast contraction velocity and fatigue easily.
validity the degree to which a test, measurement, or assessment tool accurately measures what it claims to measure
variability the amount of change and uncertainty in an environment or in the performance of a skill
variety providing different activities, formats and drills in training, while still addressing the aims of the training program. Its focus is to maintain the motivation levels of the performer and thereby optimise their fitness gains.
vasoconstriction the process where blood vessels narrow or constrict as a response to a decreased demand for oxygen delivery to muscle tissue
vasodilation the process whereby blood vessels increase their internal diameter as a response to an increased demand for oxygen delivery to muscle tissue
velocity the rate of the speed at which an object moves its position
venous pooling an accumulation of blood in the veins in inactive muscles following activity
ventilation the amount of air inspired or expired per minute by the lungs. Ventilation (V) = tidal volume (TV) × respiratory frequency (RF).
VO_2 max the maximum amount of oxygen per minute that can be taken in, transported and used by the body for aerobic energy production
volume the amount of work performed during a specific period
warm up activities and exercises undertaken at the beginning of a training session that are designed to prepare the body, both physiologically and psychologically, for the conditioning phase of the training session

weight/resistance training training that aims to build muscle strength, muscle power or local muscular endurance by exercising muscles or muscle groups against a resistance

whole practice learning all of the skill

work-to-rest ratio a summary of the time an athlete spends physically working compared to the time spent resting or recovering

yield the total amount of ATP that is resynthesised during an exercise bout or from a specific fuel within the bout

yoga a physical activity which focuses on building strength and flexibility through different poses and exercises

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