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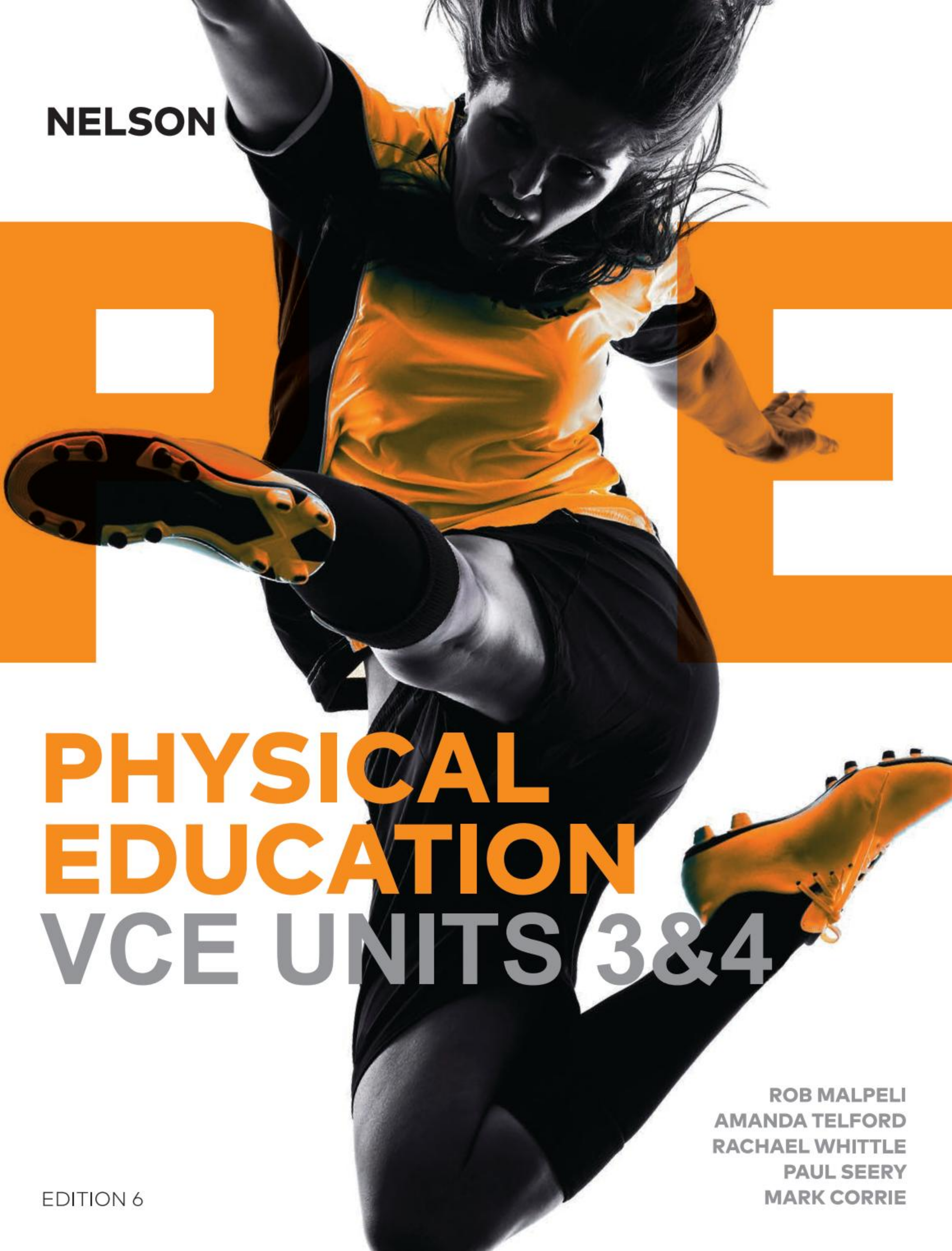

PHYSICAL EDUCATION
VCE UNITS 3&4

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EDITION 6

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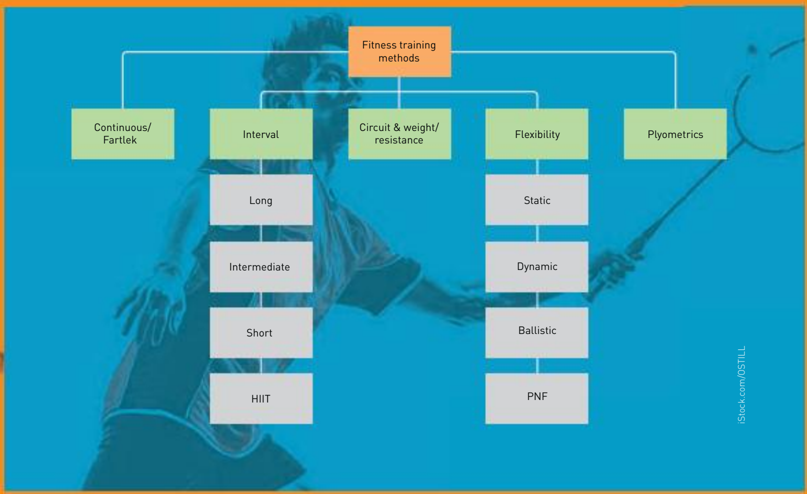
CONTENTS

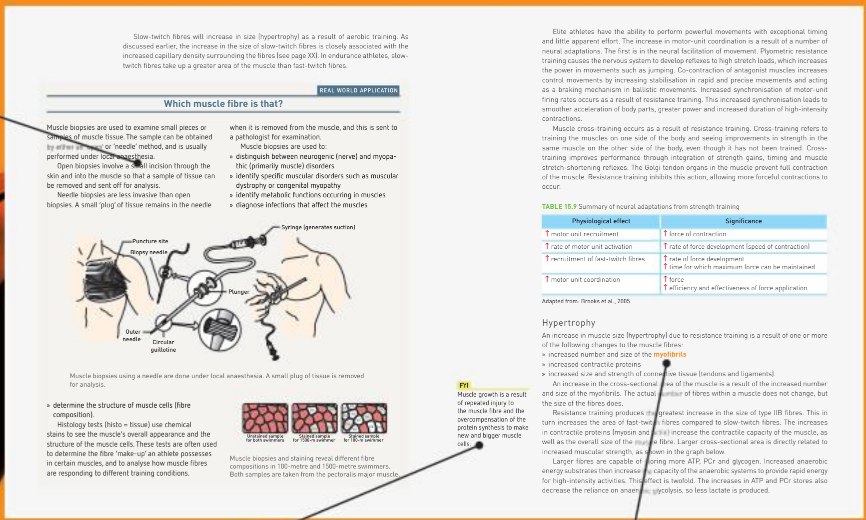
ABOUT THIS BOOK

This book has been completely rewritten to match the new Study Design, so we have taken the opportunity to include new research in the relevant areas. We have revised the content and features to provide a better, clearer, more user-friendly book.

Area of study pages list chapters. All VCAA Key knowledge and Key skills are explicitly covered within them. Each chapter opens with a flow chart providing an at-a-glance preview of what the chapter will cover.



IN EACH CHAPTER



Slow-twitch fibres will increase in size (hypertrophy) as a result of aerobic training. As discussed earlier, the increase in the size of slow-twitch fibres is closely associated with the increased capillary density surrounding the fibres (see page XX). In endurance athletes, slow-twitch fibres take up a greater area of the muscle than fast-twitch fibres.

REAL WORLD APPLICATION

Which muscle fibre is that?

Muscle biopsies are used to examine small pieces or samples of muscle tissue. The sample can be obtained by either an 'open' or 'needle' method, and is usually performed under local anaesthesia.

Open biopsies involve a small incision through the skin and into the muscle so that a sample of tissue can be removed and sent off for analysis.

Needle biopsies are less invasive than open biopsies. A small 'plug' of tissue remains in the needle when it is removed from the muscle, and this is sent to a pathologist for examination.

Muscle biopsies are used to:

» distinguish between neurogenic (nerve) and myopathic (primarily muscle) disorders
» identify specific muscular disorders such as muscular dystrophy or congenital myopathy
» identify metabolic functions occurring in muscles
» diagnose infections that affect the muscles
» determine the structure of muscle cells (fibre composition).

Puncture site
Biopsy needle
Syringe (generates suction)
Plunger
Outer needle
Circular guillotine

Muscle biopsies using a needle are done under local anaesthesia. A small plug of tissue is removed for analysis.

Histology tests (histo = tissue) use chemical stains to see the muscle's overall appearance and the structure of the muscle cells. These tests are often used to determine the fibre 'make-up' an athlete possesses in certain muscles, and to analyse how muscle fibres are responding to different training conditions.

Unstained sample for both swimmers
Stained sample for 1500-m swimmer
Stained sample for 100-m swimmer

Muscle biopsies and staining reveal different fibre compositions in 100-metre and 1500-metre swimmers. Both samples are taken from the pectoralis major muscle.

FYI
Muscle growth is a result of repeated injury to the muscle fibre and the overcompensation of the protein synthesis to make new and bigger muscle cells.

Elite athletes have the ability to perform powerful movements with exceptional timing and little apparent effort. The increase in motor-unit coordination is a result of a number of neural adaptations. The first is in the neural facilitation of movement. Plyometric resistance training causes the nervous system to develop reflexes to high stretch loads, which increases the power in movements such as jumping. Co-contraction of antagonist muscles increases control movements by increasing stabilisation in rapid and precise movements and acting as a braking mechanism in ballistic movements. Increased synchronisation of motor-unit firing rates occurs as a result of resistance training. This increased synchronisation leads to smoother acceleration of body parts, greater power and increased duration of high-intensity contractions.

Muscle cross-training occurs as a result of resistance training. Cross-training refers to training the muscles on one side of the body and seeing improvements in strength in the same muscle on the other side of the body, even though it has not been trained. Cross-training improves performance through integration of strength gains, timing and muscle stretch-shortening reflexes. The Golgi tendon organs in the muscle prevent full contraction of the muscle. Resistance training inhibits this action, allowing more forceful contractions to occur.

TABLE 15.9 Summary of neural adaptations from strength training

Physiological effect	Significance
↑ motor unit recruitment	↑ force of contraction
↑ rate of motor unit activation	↑ rate of force development (speed of contraction)
↑ recruitment of fast-twitch fibres	↑ rate of force development ↑ time for which maximum force can be maintained
↑ motor unit coordination	↑ force ↑ efficiency and effectiveness of force application

Adapted from: Brooks et al., 2005

Hypertrophy

An increase in muscle size (hypertrophy) due to resistance training is a result of one or more of the following changes to the muscle fibres:

» increased number and size of the **myofibrils**
» increased contractile proteins
» increased size and strength of connective tissue (tendons and ligaments).

An increase in the cross-sectional area of the muscle is a result of the increased number and size of the myofibrils. The actual number of fibres within a muscle does not change, but the size of the fibres does.

Resistance training produces the greatest increase in the size of type IIB fibres. This in turn increases the area of fast-twitch fibres compared to slow-twitch fibres. The increases in contractile proteins (myosin and actin) increase the contractile capacity of the muscle, as well as the overall size of the muscle fibre. Larger cross-sectional area is directly related to increased muscular strength, as shown in the graph below.

Larger fibres are capable of storing more ATP, PCr and glycogen. Increased anaerobic energy substrates then increase the capacity of the anaerobic systems to provide rapid energy for high-intensity activities. This effect is twofold. The increases in ATP and PCr stores also decrease the reliance on anaerobic glycolysis, so less lactate is produced.

Real world applications include articles and interviews throughout the chapters. Some of the print interviews are also longer video clips (watch for the video icon).

FYI snippets are sprinkled through the book to keep you awake! They are not part of the Study Design key knowledge, however.

Glossary definitions appear in the NelsonNetBook. Otherwise, go to the Glossary pages at the end of the book (pp. 393–398).

There are several types of activities within the chapters: Chapter Check-up, Laboratory, QuickVid, Data/Text analysis, Investigation and Practical activity. These activities help you develop key skills, think about the content topics, or summarise and consolidate the material you have just completed. They are supplemented by the *Nelson Physical Education VCE Units 3&4 Peak Performance* workbook activities.

QUICKVID

This video clip explains clearly how muscles contract using the sliding filament theory. Go to http://vcepe34.nelsonnet.com.au and find this page.

DATA ANALYSIS
THE 100-METRE SPRINT

Analysis of speed variation during short sprints such as the 100- and 200-metre sprints can provide coaches with useful performance information.

Key performance indicators for sprints are:

- time taken to achieve maximum speed
- maximum speed
- length of time that maximum speed is maintained
- difference between maximum speed and speed at the finish.

Usain Bolt ran the 100-metre sprint in a world-record time of 9.58 seconds at the IAAF World Championships in 2009. Table 4.2 shows the times for each 10-metre split. From this data, his average speeds (in km/h) were calculated and are graphed on the following page.

TABLE 4.2 Usain Bolt's times in the 100-metre sprint in 2009

Distance (m)	Time (s)	Split times
10	1.89	1.89
20	2.88	0.99
30	3.78	0.90
40	4.64	0.86
50	5.47	0.83
60	6.29	0.82
70	7.10	0.81
80	7.92	0.82
90	8.75	0.83
100	9.58	0.83

QUICKVID

You can watch Bolt's record-breaking run via http://vcepe34.nelsonnet.com.au

Weblink

INVESTIGATION
DEBATE: FREE WEIGHTS VERSUS EXERCISE MACHINES

Weight training can be performed using free weights (dumbbells, barbells and the like) or highly sophisticated equipment such as Cybex, Nautilus and Hydra-gym equipment. There are advantages and disadvantages for each.

Using a range of resources, including the internet, research the advantages and disadvantages of free weights compared with weight-training machines. Summarise your findings in a table and provide a conclusive statement. If time permits, debate the pros and cons in class.

PRACTICAL ACTIVITY

Complete either a fartlek or long-interval training session (or both!). The training type could include running, swimming, cycling, rowing or using gym apparatus aimed at developing aerobic power such as a cross-trainer or stationary bike.

CHAPTER CHECK-UP

1 What role does potassium play in muscular contractions, and what happens when it is reduced via high sweat rates?
2 For each of the following events or training conditions, clearly identify the depletion of one major fuel that contributes to fatigue.
  a 100-metre sprint (track event <10 seconds)
  b 100-metre swim (approximately 50 seconds)
  c Australian Rules football match (rover covering 18 km)
  d Short-interval training (work = 60 seconds, rest = 120 seconds)
  e Triathlon (approximately 4.5 hours)
  f Swimming the English Channel (18 hours)
3 Discuss two disadvantages associated with switching from carbohydrates to fats as the main fuel source in any endurance performance lasting longer than three hours.
4 How does the accumulation of H^+ resulting from intermediate interval sprinting contribute to decreased muscle force?
5 How might an athlete avoid hyperthermia if they were about to compete in their first Oxfam Trailwalker 100-kilometre event?

LABORATORY
MOMENTUM OF THE HUMAN BODY

AIM

To investigate the amount of momentum the human body possesses

EQUIPMENT

Two witch's hats, line-marking equipment

METHOD

1 Set up the witch's hats 15 metres apart, on a flat surface suitable for sprinting.
2 Mark a distance 1 metre beyond the end of the 15 metres, as shown below.

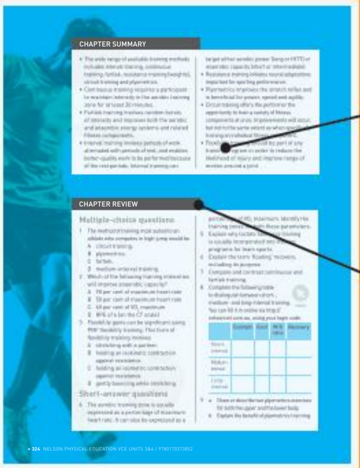
3 Perform the following activities. At the end of each trial, try to stop within the 1-metre end zone.
   - Jog 15 metres at about 50 per cent of maximum pace.
   - Run 15 metres at 75 per cent of maximum pace.
   - Sprint 15 metres at maximum pace.

DISCUSSION

1 In which of the sprints, if any, were you able to stop within the end zone?
2 Explain why it is more difficult to stop when sprinting than when jogging or running.
3 100-metre sprinters often continue running through after the conclusion of the race, whereas marathon runners generally come to a stop as they cross the finish line. Explain, in terms of momentum, why athletes in these two events finish their races so differently.

There are no direct weblinks printed in the book, as URLs change often. Instead, there is a single weblink (http://vcepe34.nelsonnet.com.au) to a website that will give you direct access to all the weblinks in the book. That is, you will not need to use your login code to access the weblinks. A web icon will alert you to web-based video clips.

Weblink



Each chapter concludes with a dot-point summary of the relevant key knowledge covered.

Chapter revision questions are exam-style, with multiple-choice, short-answer and some extended-response questions. Answers are in the back of this book, where relevant.

ON THE NELSONNET WEBSITE

The NelsonNet student website has:

- short video clips
- some templates (scaffolds) of forms, tables and questionnaires for you to fill out online
- some extension material
- revision cards that can be downloaded onto your smart phone.

Complex concepts are explained by the authors in short video clips, located on your student website.

Visit http://nelsonnet.com.au and enter your login code from the back of this book to access the website.

We hope you have fun using and learning from this book!

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UNIT 3

ANALYSIS OF MOVEMENT AND ENERGY PRODUCTION

AREA OF STUDY 1

HOW ARE MOVEMENT SKILLS IMPROVED?

CHAPTER 1

CHARACTERISTICS OF SKILLS AND STAGES OF LEARNING

Key knowledge

- 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
- practice strategies to improve movement skills including amount, distribution (massed and distributed) and variability (blocked and random)
- feedback including type (intrinsic, augmented, knowledge of results and knowledge of performance) and frequency

Key skills

- analyse and classify movement skills
- participate in, observe and record the characteristics of different types of practice strategies
- perform, observe, analyse, and report on the role of feedback in improving performance through practical-based activities

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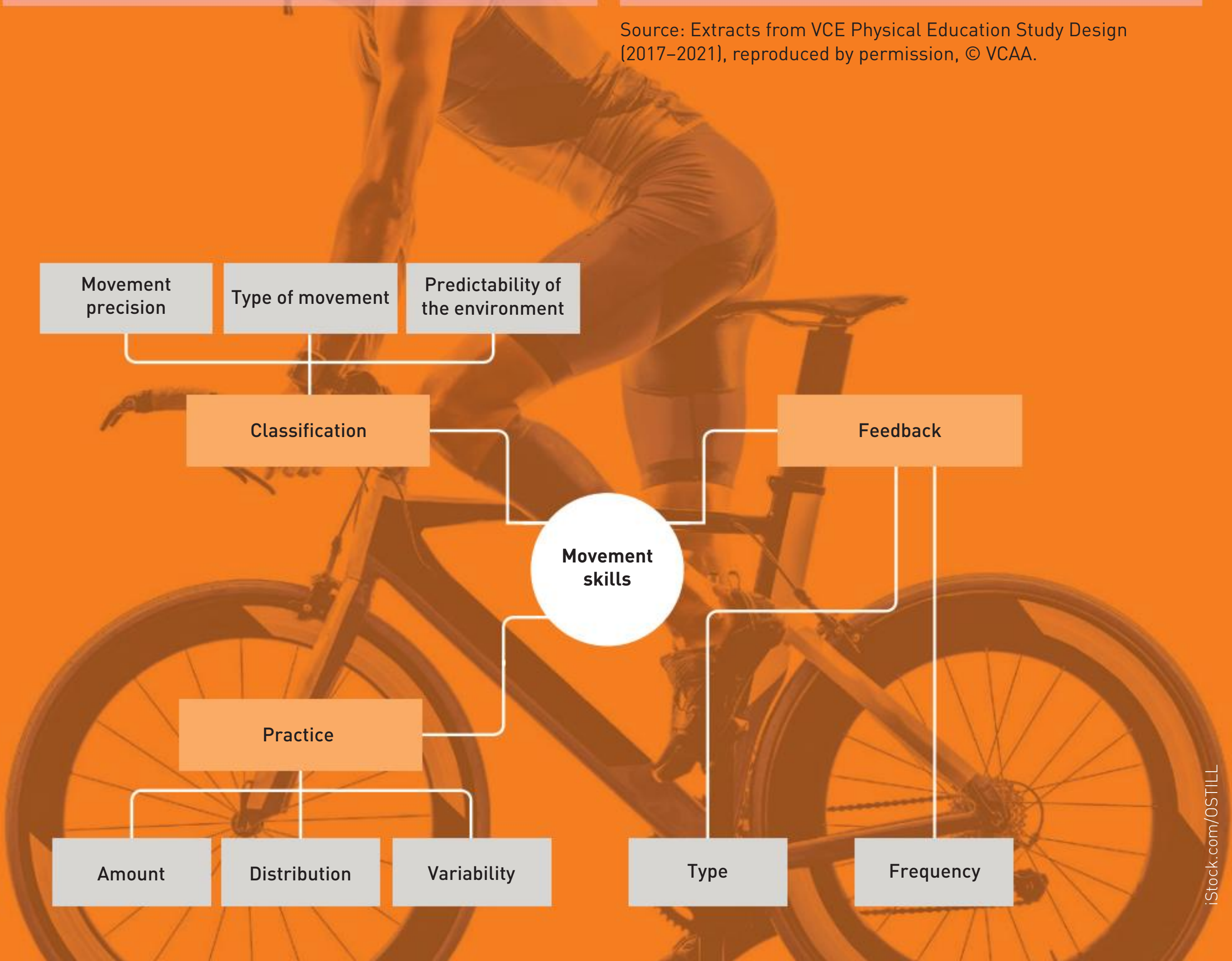

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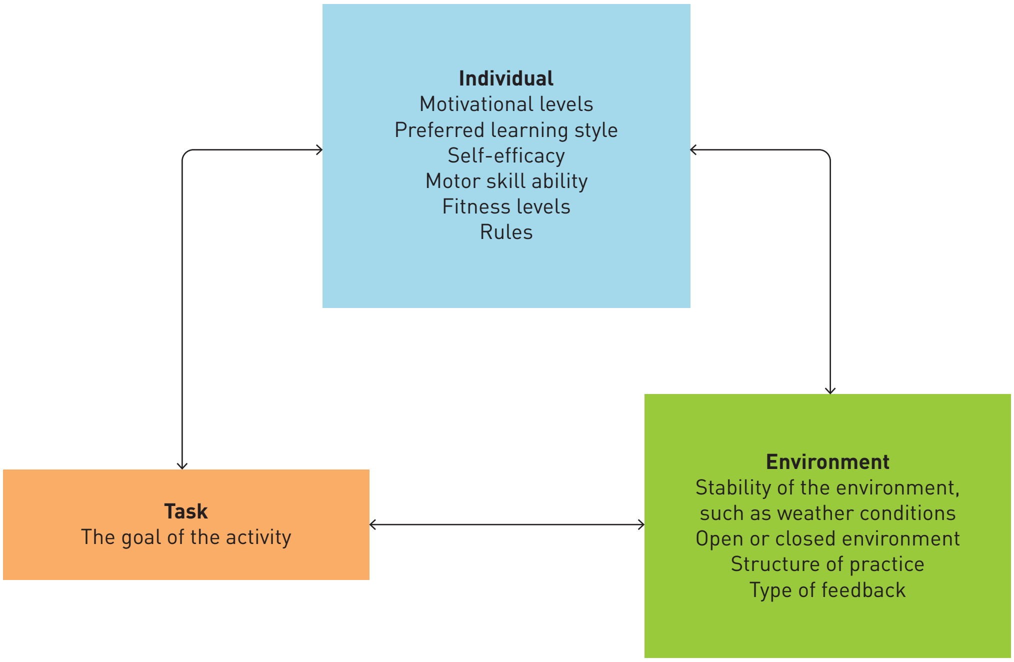
INTRODUCTION

This chapter looks at skill acquisition, examining skill learning principles and optimal practice environments. While many of the topics will be looked at separately, there is a dynamic connection between the individual, the environment and the task (such as the skill to be developed), as shown in the constraints model diagram below. A coach can develop a well-structured training session, but if the individual is not motivated, their learning, in this setting, will be compromised. This will be covered in greater detail in chapter 2.



Constraints model of skills acquisition

WHAT IS A SKILL?

A skill can be defined as the ability to do something well. Someone who successfully learns a foreign language is displaying good language skills. In sporting endeavours, the focus is on motor skills, such as a tennis serve, volleyball spike or hockey push.

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Motor skills in volleyball and hockey

FYI

It is important to distinguish between ability and skill. Ability is generally a stable, persistent trait that is difficult to change. It is the key variable in the learning of a motor skill.

Motor skill has been defined by experts as: 'a voluntary, goal-directed activity that we learn through practice and experience. Motor skills are a special form of skill that require movement of the body or limbs to achieve the goal.' (Spittle, 2013)

Motor skills are 'activities or tasks that require voluntary head, body and/or limb movement to achieve a goal'. (Magill, 2014)

CLASSIFYING MOVEMENT SKILLS

Skills can be classified according to their characteristics. This helps us understand the demands of the skill. It can also help coaches assess performance, plan skill development sessions and provide the performer with appropriate feedback.

Movement skills are often categorised under:

» movement precision
» type of movement
» predictability of the environment.

Because skills can be placed into more than one category, they are usually shown on a continuum.

Movement precision

Movement skills can be classified according to the precision of the movement and the size of musculature required, as:

» gross motor skills
» fine motor skills.

Gross motor skills

Gross motor skills involve the recruitment of large muscle groups. There is less emphasis on precision. Examples include running and swimming.

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Fine motor skills and gross motor skills.

Fine motor skills

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

Type of movement

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

» discrete motor skills
» serial motor skills.
» continuous motor skills

Discrete motor skills

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

Serial motor skills

Sometimes several discrete skills are performed in a sequence, such as in a gymnastics floor routine. This combination of discrete skills is classified as a **serial motor skill**.

Continuous motor skills

Continuous motor skills have no definite beginning or end point, and include activities such as walking and running. Sometimes beginning and end points are assigned, such as in a 100-metre running race, but the actual motor skill is continuous in nature.

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Examples of discrete, serial and continuous motor skills (left to right): a netball pass is a discrete skill; a gymnastics floor routine is a serial skill; running is a continuous skill.

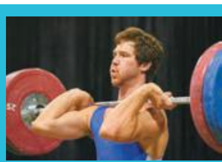
Predictability of the environment

This classification of motor skills is best represented as a continuum, with closed motor skills at one end and open motor skills at the other.

Closed motor skills

Motor skills can also be classified according to the extent to which they are influenced by environmental factors. **Closed motor skills** are those where the performer has the greatest control over the performance environment. This relates to external factors such as the weather, playing surface and opposition. An example of a closed motor skill would be an indoor individual diving routine. In this situation, the diver determines the routine they will perform and when their dive will commence, and is not affected by weather conditions.

PRECISION OF MOVEMENT



Shutterstock.com/mavo

Gross

Large muscles
Force/power

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Fine

Small muscles
Precision

Weight-lifting | Pole vault | Playing chess

ORGANISATION OF THE SKILL

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Discrete

Clear beginning and end
One distinct movement
Short duration

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Serial

Several discrete actions
Linked together
Specific order

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Continuous

Arbitrary beginning and end
Repetitive movements
Longer in duration

Throwing | Serving in tennis | Running

Catching | Dance routine | Swimming

STABILITY OF ENVIRONMENT

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Closed

Stable, predictable environment
Self-paced

Alamy Stock Photo/Jeremy Hogan

Open

Variable and unpredictable environment
Externally paced
Movement adapted to environment

Throwing a dart | Pitching in softball | Tackling in rugby

Playing billiards | Handball in AFL | Digging in volleyball

Open motor skills

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

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Closed (left) and open (right) motor skills. Which performer has more control over their environment?

Fundamental movement skills

Fundamental movement (motor) skills are foundation skills that provide the basis for the development of more sport-specific movement skills. Most skills used in sports are advanced versions of fundamental movement skills. For example, throwing in cricket and softball, the baseball pitch, tennis serve, javelin throw and netball shoulder pass are all advanced forms of the overhand throw (see photos below).

Fundamental movement skills are classified as:

» stability skills involving balance and control of the body
» locomotor skills that enable us to move through space, such as walking and running
» manipulative skills involving the control of an object, such as throwing catching, striking and kicking.

It is essential that fundamental movement skills are introduced to children at a young age (in early primary school). Without grounding in these fundamental skills, the transition into more sport-specific skills will be extremely difficult. Children who do not have the opportunity to master fundamental movement skills are less likely to participate in structured sport later in life.

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All of these actions are advanced forms of the overhand throw.

CHAPTER CHECK-UP

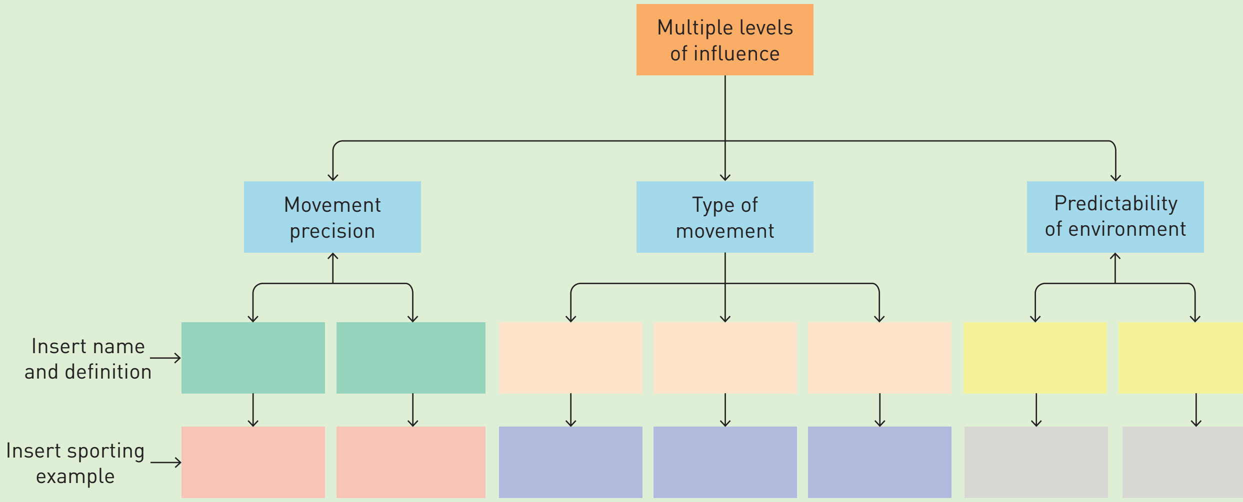
1 List five motor skills that are used in a sport of your choice.

2 'Highly developed motor skills are vital to sporting success.' Do you agree or disagree with this statement? Choose three of the skills you listed in question 1, and for each, discuss how a high level of skill development will bring about successful performance.

3 Use the online scaffold to complete the diagram below, or redraw it. To find the online scaffold, go to http://www.nelsonnet.com.au and use your login code.

Scaffold

4 Use a Venn diagram to present the similarities and differences between the three classification methods of motor skills.



STAGES OF LEARNING

All sportspeople progress through different stages of learning. Understanding the developmental needs of players, from beginners through to elite performers, and the most appropriate type of feedback to give at each stage, means practice can be tailored specifically to enhance the learning process.

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Ben Simmons in action

Australia's Ben Simmons was the number one pick in the 2016 US National Basketball Association (NBA) draft. There is no doubt that Ben's genetic characteristics predispose him to performing well in basketball. However, they only give Ben the potential to become an elite basketball player. Just like everyone else commencing a sport, he would have started playing basketball as a beginner.

There are several models that categorise motor skill learning into distinct stages. The most recognised and widely used model was proposed by Paul Fitts and Michael Posner in 1967. Fitts and Posner divided learning into three distinct stages (see the skill learning continuum on page 10):

» cognitive (beginner)
» associative (intermediate)
» autonomous (advanced/elite).

Cognitive stage

In the cognitive stage the beginner is mentally trying to comprehend the movement requirements of the motor skill: what needs to be done. In an appropriate and encouraging environment, beginners will ask lots of questions. Their attention will be on movement production and their performance will be inconsistent, with stiff and unrelaxed movements.

Beginners are often aware of what is wrong, but are not sure how to correct the problem – they have not yet developed their error detection and correction abilities. They may lack confidence, but they will show rapid improvement.

Practice will be discussed later in the chapter, but it is worth noting that blocked practice (repetitive practice of the same task) is preferable in the early stages of learning. It is also preferable to remove unpredictability by designing drills that are performed in a more closed environment. Given the large attention demands of this stage, instruction should be short and to the point.

Associative stage

In the associative stage, also termed the 'practice stage', the performer is beginning to refine their technique/ movement pattern. They are more consistent and make fewer errors. The demands on attention when performing the motor skill are decreasing, allowing the performer to focus on external stimuli such as the effects of spin on a ball, or the positioning of the opposition. The performer is now able to detect the cause of some errors and can develop strategies to eliminate them.

In this stage performance variability is decreasing and improvements are more gradual. The performer is more focused on how to perform the particular motor skill, and is able to cope with more practical coaching experiences.

Not all learners advance through this stage to the autonomous stage.

Autonomous stage

By the time the autonomous stage is reached, the skill is largely automatic; the performer no longer consciously thinks about the skill. This means their focus can be directed elsewhere. For example, an elite basketball player can focus on calling plays while dribbling up the court.

The performer has developed anticipation. They can detect their own errors and correct them, and performance variables are very small.

Good coaching, such as offering precise feedback, is still very relevant for performers in this stage.

Getty Images Jamie Squire

Alamy Stock Photo/epa european pressphoto agency b.v.

Sally Pearson (left) and Cameron McEvoy (right) are sportspeople who have progressed to the autonomous stage.

Skill learning continuum

As with all skill learning models, it is impossible to distinguish exactly when a performer moves from one stage to the next. Fitts and Posner's three-stage model should be viewed as a continuum.

Cognitive stage 'What is to be done?' → **Associative stage** Refining technique → **Autonomous stage** Focus is on strategy and tactics

The skill learning continuum

A performer can be in different stages of learning for different skills within the same sport. For example, a hockey player may have excellent hitting skills but lack control in dribbling the ball.

PRACTICAL ACTIVITY

EXPERIENCING THE THREE STAGES OF LEARNING

It's easy to forget what it was like to be a beginner. To experience moving through the three stages of learning, begin practising a new skill, such as making an origami crane. You can find instructions by clicking on the link at http://vcepe34.nelsonnet.com.au.

Weblink

There are a variety of other activities that could be substituted, such as throwing a ball with your non-preferred hand, or attempting to master a hula hoop.

As you work through this activity, reflect on what you are experiencing:

» What is your learning focused on?

» How are you trying to understand the skill?

» How did you practise the skill?

» Were you successful in performing the skill?

» How did you measure success?

» What difficulties did you encounter when trying to move from the cognitive to the associative stage?

» What did you find beneficial in enhancing this new skill development?

CHAPTER CHECK-UP

1 Why should motor skill learning be viewed as a continuum?

2 Distinguish between a beginner and someone more likely to be in the associative stage.

3 Distinguish between someone in the associative stage and someone in the autonomous stage.

4 Draw and complete the table below. For each of the three stages (cognitive, associative and autonomous) add at least two more key summary points.

Cognitive	Associative	Autonomous
(What is to be done?)	(Refining technique)	(Focus on strategy and tactics)
» Understanding the skill » »	» Refining the movement pattern » »	» Automatic performance » »

5 **Extension task**: 40 years ago it was rare to find modified sports for children. These days there are a variety of modified sports available for children (tee ball, Kanga cricket, AFL Auskick, etc.). Investigate a modified sport of your choice.

a What are the main modifications to your chosen sport?

b How will these modifications help to increase participation in the sport?

c How will these modifications help to improve the beginner's performance?

d At what age do you believe it is appropriate for children to begin non-modified sporting competition? Give reasons for your answer.

QUICKVID

Go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 11 is a video interview with Associate Professor Michael Spittle from Victoria University.

Video

PRACTICE STRATEGIES

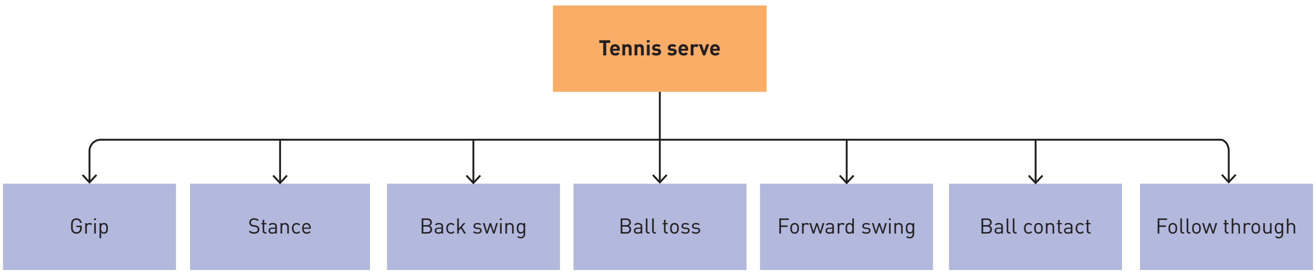
'Practice makes perfect' was the catch-cry of all coaches 40 years ago. But practice alone doesn't guarantee that the performer will improve. Learning will only be optimised when practice takes into consideration the individual, the task and the environment.

There are several factors that need to be considered when choosing practice methods, such as:

» part and whole practice
» amount
» distribution (massed or distributed)
» variability (blocked or random).

Part and whole practice

All motor skills can be broken down into subcomponents or segments. A tennis serve is a good example of this.



Breaking a skill into segments can be very useful for beginners, who may become overwhelmed by a complex task. When the beginner is able to achieve quick success with these smaller segments of the task, this can help to maintain, or even increase, motivational levels.

Choosing a practice type

When deciding whether to practice a task in parts or as a whole, two factors need to be considered: task complexity and task organisation.

Task complexity

As shown in the example of the tennis serve, when the motor skill has several components, it may be appropriate to break the task into segments. However, task organisation also needs to be considered before a decision is made.

Task organisation

Task organisation refers to how dependent each segment is on the previous segment. Not all tasks can be successfully broken down into individual segments. For example, a cartwheel in gymnastics would lose its rhythm if part practice were applied. Similarly, motor skills such as a volleyball spike, which are also highly dependent on the application of the stretch reflex, are not helped by part practice.

Amount of practice

The amount of practice is a critical learning variable. During the cognitive early stages of learning, significant gains in performance can be seen in proportion to the amount of practice. Similar to the law of diminishing returns (discussed in chapter 12, page 297), as a performer moves into the associative and possibly autonomous stages, their rate of improvement will slow.

Given the positive relationship between practice and improvement, it is important for coaches to maximise practice sessions. 'Time on task' is an important consideration for any coach planning a practice session aimed at skill development.

Practice distribution

Practice distribution refers to the scheduling of practice sessions. The first consideration is the availability of the participants. Once this has been established, the frequency and length of sessions can be determined.

Distributed practice

Distributed practice involves shorter but more frequent training sessions. More time is also allocated to rest between tasks during the session. This model is generally adopted by full-time professional teams. Research has shown that this type of practice scheduling creates a better learning environment.

Massed practice

Massed practice involves less frequent training sessions that last for a longer period of time. Rest intervals between tasks are also shorter than in distributed practice. Most non-professional team sports use this method because they need to schedule training around the varied work, school and family commitments of team members. Physical and psychological fatigue is more likely to result from massed practice.

Practice variability

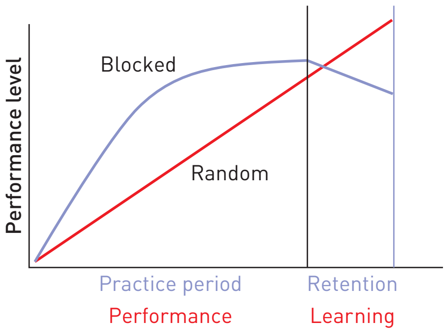
In most training sessions several skills will be practised. For example, during a tennis training session participants may practise forehands, backhands and volleying. The coach then needs to decide whether it is best to practise one of these skills for a set number of repetitions (blocked practice) before moving to the next skill, or to mix the skills up (random practice) during the training session.

Blocked practice

Blocked practice involves practising the same skill continuously without changing to a different task. Each skill is practised in a block, in isolation from other skills, before moving on to the next skill. Examples include continuously practising a netball chest pass for 15 minutes, or performing 50 basketball free throws in a row.

Blocked practice is an appropriate strategy for beginners who are trying to understand and reproduce the movement action. In this situation, the environment should be kept as stable as possible, reducing the impact of factors such as wind, uneven surfaces etc.

If a skill such as a volleyball spike would usually be performed in a more open environment, then it is best to remove the inconsistencies of a random setting by removing factors such as opposition, and perhaps have someone feed volleyballs at an appropriate height for spiking. This more closed environment should enable the beginner to quickly replicate the basic foundations of the movement pattern.



Blocked vs random practice

Random practice

Random practice is the varied sequencing of different motor skills in the same training session. So in volleyball, it is not performing five spikes, then five digs, then five sets, which would still be blocked practice. Random practice could be dig, set, dig, spike, spike, set, dig, set, spike, dig, dig, set, spike, spike, set!

Random practice is suitable for performers in the associative and autonomous stages. There are several studies that support this practice regime. In a study by Farrow and Maschette, blocked practice led to better performance during training. However, greater learning, via a delayed retention test, was seen in the group under the random practice regime (see the graph at left).

LABORATORY

BLOCKED PRACTICE: NON-DOMINANT HAND

AIM

To investigate whether motor skill development results from blocked practice

EQUIPMENT

One frisbee per pair of students

METHOD

1 In pairs, stand 10 metres apart.
2 Do not practise before commencement of trials. All participants must use their non-dominant hand.

 Set A
 - Each person attempts to pass the frisbee to their partner.
 - The receiver is not allowed to move their feet to assist in catching the frisbee.
 - Every successful catch scores 1 point.
 - Attempt 10 throws each.
 - Record your score.
 - Practise an additional 30 throws each from the same distance.

 Set B
 - Repeat the procedure in set A.

3 Record your result.

RESULTS

1 Calculate your score for sets A and B.
2 Calculate the class score for each set. Work out the class average for each set.

DISCUSSION

1 Why was your non-dominant hand chosen for this activity?
2 Compare your results for both sets.
3 Compare the class average for sets A and B.
4 Why was blocked practice chosen in this activity?
5 Discuss one individual factor that affected this activity.
6 Discuss one environmental factor that affected this activity.

Transfer of practice

Designing a training session can be a challenge. There never seems to be enough time to devote to all the areas that a coach or performer would like to address. There may also be a diverse range of skills that need to be addressed in a properly constructed training session.

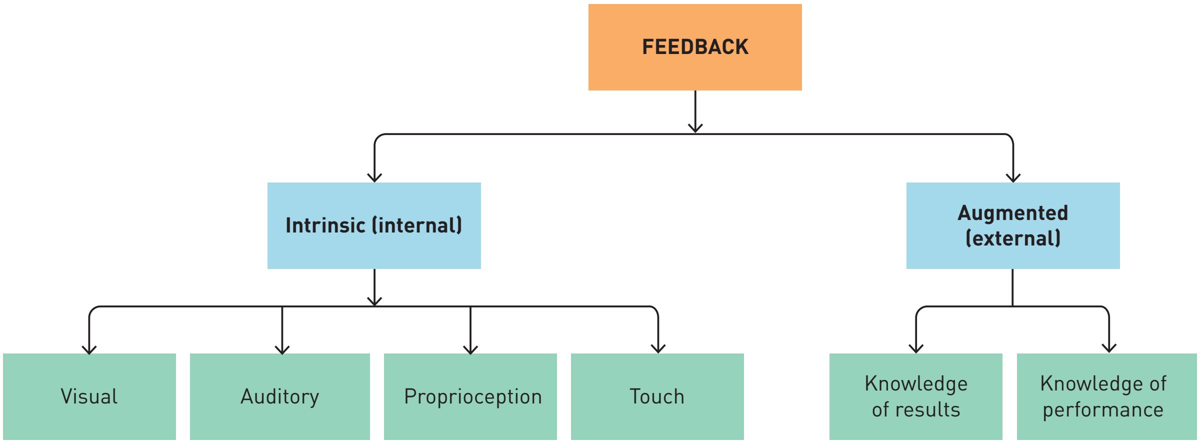
Practice that closely resembles the game will result in a greater transfer of skills from training to game. However, constant 'practice games' will not necessarily result in skill development transfer. Repetitive 'full-on' practice games can lead to boredom, decreased motivation and increased risk of injury.

Beginners may benefit more from reducing some of the environmental factors that would usually be present in a game, such as the opposition. For example, in basketball it may be beneficial for a beginner to practise dribbling without the pressure of a defender, and then gradually introduce passive defence as the beginner gains confidence.

Performers in the associative or autonomous stages of motor skill development will benefit most from practice that resembles some component of the game. Team-orientated strategies and tactics can be introduced at this level. These can be introduced in a more closed environment before opening the drill up to more closely resemble a game situation, enhancing the transfer of practice to game. These concepts will be discussed in greater detail in chapter 2.

FEEDBACK

Feedback is the information that a performer receives about the outcome of a task they have performed. It is a critical part of skill development. Feedback can be classified as either intrinsic (internal) or augmented (external), as shown below.



Types of feedback

Types of feedback

Intrinsic feedback

Intrinsic feedback is when performers use their own senses to assess performance, including visual, auditory, **proprioception** and touch.

This feedback is always available to the performer if they understand the goal of the task. For example, when executing a tennis serve, the performer can see whether the ball goes into the desired area of the court; they can hear the sound made by the ball hitting the racquet; tactile senses allow the performer to feel their grip on the racquet; and proprioceptors provide feedback on body positioning.

Augmented feedback

Augmented, or external, feedback can greatly enhance a performer's own internal feedback system. In the tennis serve example, a coach can provide external feedback on how to correctly grip the racquet. This gives the performer a reference point for their internal feedback system.

Augmented feedback can occur during or after a performance. If the feedback occurs during the activity, it is called concurrent feedback. An example could be a coach giving a triathlete their split times during the run or cycle phase of the triathlon. Terminal feedback is provided after the performance, such as a coach telling a tennis player to toss the ball higher after a serve.

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A coach giving feedback to players is an example of augmented feedback.

External/augmented feedback can be further classified as either knowledge of results or knowledge of performance.

Knowledge of results

Knowledge of results refers to specific feedback about the outcome of the task, as opposed to feedback relating to performance characteristics. This feedback is particularly beneficial for learners trying to develop new skills. For a learner trying to develop a topspin tennis serve, for example, the coach could give feedback on the amount of topspin achieved on each serve. This will enable the learner to align intrinsic feedback to the goal of the task.

As the task outcome improves and their own internal feedback system develops, the learner will become less reliant on results feedback. Knowledge of results feedback can sometimes become annoying to performers who are able to analyse their own outcome results.

Knowledge of performance

Knowledge of performance relates to the characteristics of performing a task, as opposed to the specific outcome of the task. A tennis coach may tell their student to increase the height of the ball toss when serving in order to achieve greater topspin, or to tuck tighter in a dive to increase rotational speed.

Knowledge of performance results are generally delivered after the task has been completed. This feedback can take several forms depending on the aim, from a few simple coaching 'cues' to reviewing video footage. Learning styles should be taken into consideration when delivering external feedback.

Feedback and equipment

Equipment has long been used to enhance feedback. The stopwatch is an obvious example. More recently there has been an ever-increasing amount of computer software available to help coaches display and deliver feedback. This includes computer analysis software as well as the myriad of smart technology available, such as iPads and smart phones, that can video record for future playback.

How to deliver feedback

External feedback can serve three purposes:

1 fixing errors as a result of either knowledge of results or knowledge of performance
2 motivation through feedback that shows progress
3 reinforcement through positive feedback (e.g. 'You've got the ball toss right').

Most feedback from coaches will be verbal, regardless of learning style. Feedback should be clear, precise and limited in the information it offers. Overly complicated feedback will only confuse the performer.

All learners respond well to positive reinforcement. One very effective strategy for offering feedback is the 'see if you can' approach. In this strategy, a coach offers the learner a motivating comment first (e.g. 'Serves are looking good'), then positive reinforcement (e.g. 'Good backswing'), before offering the learner a cue to fixing an error (e.g. 'See if you can throw the ball a little higher in the ball toss'). In any communication it is important that the learner views feedback as genuine. This is particularly important when offering positive reinforcement.

Finally, it is important to monitor how much feedback is given. Although beginners need a lot of feedback, they should not be allowed to develop an overdependence on it.

PRACTICAL ACTIVITY

FRISBEE GOLF

EQUIPMENT

- one frisbee per person
- a pen
- something to record scores on for every 3–4 students

GAME DESIGN

1 Place seven cones in a row, each about 60–80 metres from the next
2 Beginning at the first cone, attempt to use as few throws as possible to arrive at the second cone, which has been 'reached' when it is hit with your frisbee.
3 Continue this process until you have reached all six cones.

DISCUSSION

Reflect on your own performance.

1 Discuss the factors that you would need to consider in order to implement an effective practice schedule to help improve your score.
2 In your discussion, compare and contrast this with other coaching experiences that you have had.

Feedback frequency

There is no definitive rule regarding how often a coach should provide feedback during a skill development session. What we do know, however, is that the frequency of feedback should be reduced as a performer moves through the stages of learning (cognitive, associative and autonomous).

When a learner is in the cognitive stage, they will initially have limited ability to detect and correct errors, and will develop the skill more quickly with frequent augmented feedback. As the skill starts to progress, the learner needs to develop their own ability to detect errors. Coach feedback is still important, but it should not be given as frequently, enabling the performer to develop their own error detection abilities.

REAL WORLD APPLICATION

Professor Damian Farrow, Victoria University

Courtesy of Victoria University

Professor Damian Farrow is one of Australia's leading experts in the fields of motor learning and skill development.

When you were at the AIS, how were you involved in establishing the skill acquisition department?

While coaches need to be able to apply all facets of sports science, such as biomechanics and physiology, I think skill acquisition has an even closer connection to coaching. It wasn't until it was recognised that a coach could no longer keep pace with all the developments in the field of skill acquisition that the AIS decided to appoint someone with specific knowledge in this area.

How did you help develop the elite athletes at the AIS?

We helped coaches plan their skill practice sessions, asking them to consider the latest recommendations emerging from research if we felt it may assist their athletes. We also tested athletes' skill levels in a variety of specific capacities. For instance, we tested netball players' decision-making skills, ability to read the play, reactive agility and ability to pass under pressure (called a dual-tasking test). We also questioned the athletes on their preferred learning style and provided a summary to the coach so that they could adjust their communication style accordingly.

What is one piece of advice you could give aspiring sportspeople?

The most consistent feature I have seen in all elite athletes is their capacity to challenge themselves in skill practice sessions. They invent ways to make practice just that bit more difficult. For example, Don Bradman was famous for practising his cricket batting by trying to hit a golf ball with a cricket stump by bouncing it off a corrugated iron water tank. Similarly, rugby league's Andrew and Matty Johns used to put the ball in a bucket of soapy water before practising catching and passing.

What is one piece of advice you could give aspiring young coaches?

Don't search for a recipe book of skill drills for your sport. Develop a skills coaching framework like the constraints model on page 3 of this chapter and then use your imagination to develop the correct drills/games for your players. Skill learning is a dynamic process so don't over-assess how your athletes are progressing – make a longer term assessment, as it's likely to be far more reliable. We all develop our skills at different rates and to judge an athlete as lacking skill early in their career may be unfair and limit what they achieve.

Video

QUICKVID

Go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 18 is a video interview with Professor Damian Farrow, discussing skill acquisition.

CHAPTER SUMMARY

- Motor skills can be classified in several ways, including by movement precision, type of movement and predictability of the environment.
- Fundamental movement skills are the foundation skills that provide the basis for the development of more sport-specific motor skills.
- Motor skills and training sessions are often discussed in terms of the open–closed skills continuum. The less predictable the environment becomes (i.e. active opposition), the more 'open' the skill is on the continuum.
- When performers are learning a skill, they move through different developmental stages: cognitive (beginner), associative (intermediate) and autonomous (advanced).
- There are several practice modalities to enhance skill development, including blocked and random practice, whole and part practice, and massed and distributed practice.
- A greater transfer of skills from training to a game situation will result from practice that more closely resembles the game.
- Feedback is the information the performer receives about the outcome of a task. Feedback can be internal or from an external source.
- Internal feedback is received from the performer's own senses, including visual, auditory, proprioception and touch.
- External feedback consists of both knowledge of results and knowledge of performance.
- Knowledge of results is specific feedback about the outcome of the task and is particularly beneficial for beginners trying to develop new skills.
- Knowledge of performance feedback is focused on the characteristics of the task.
- Feedback should also include positive reinforcement.

CHAPTER REVIEW

Multiple-choice questions

1 Fine motor skills involve the recruitment of
   A large muscle groups.
   B smaller muscles associated with precision.
   C all muscle groups for maximal performance.
   D large muscle groups for a short period of time.

2 The most recognised method of categorising motor skill learning was developed by Fitts and Posner. Under their system, learning is divided into three stages. These stages are
   A beginner, intermediate and master coach.
   B cognitive, intermediate and associative.
   C cognitive, associative and autonomous.
   D associative, autonomous and progressive.

3 Distributed practice involves
   A longer but less frequent training sessions.
   B shorter but more frequent training sessions.
   C shorter and less frequent training sessions.
   D longer and more frequent training sessions.

Short-answer questions

4 Why is knowledge of results important feedback for beginners?

5 Distinguish between random and blocked practice, using a sporting example to highlight your answer.

6 Justify a circumstance under which part practice may be appropriate.

7 Use a Venn diagram to compare and contrast the three stages of motor skill learning.

CHAPTER 2

IMPROVING SKILLS

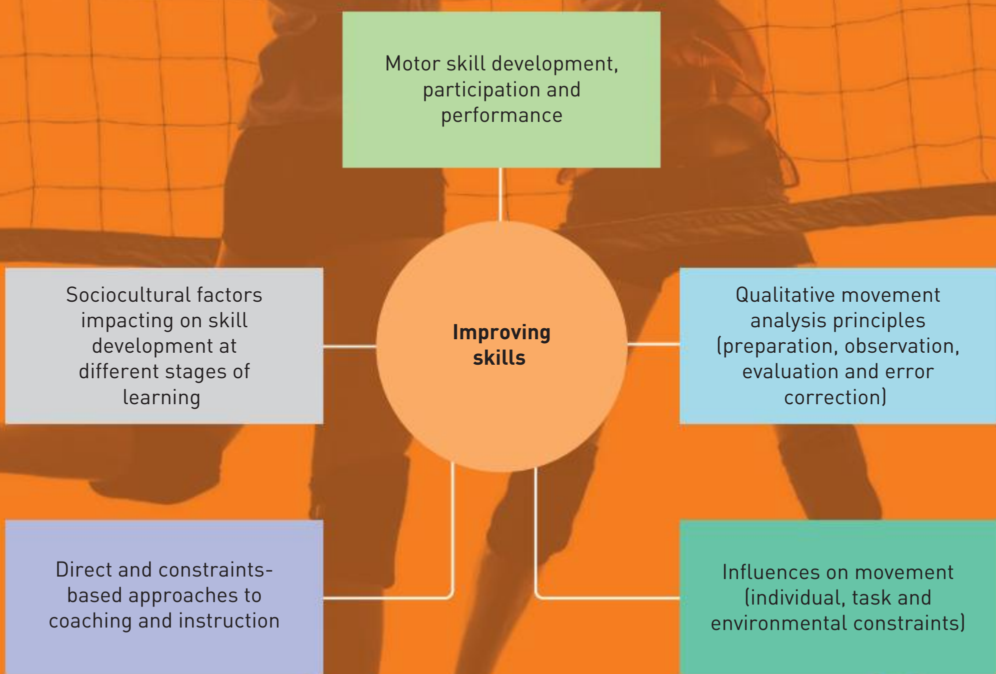
Key knowledge

- the link between motor skill development and participation and performance
- influences on movement including individual, task and environmental constraints on motor skill development
- qualitative movement analysis principles (preparation, observation, evaluation and error correction)
- direct and constraints-based approaches to coaching and instruction
- sociocultural factors that have an effect on skill development, and the characteristics of the three stages of learning (cognitive, associative and autonomous)

Key skills

- explain and apply theories of learning to practical coaching situations
- explain sociocultural factors that influence movement skill development at different stages of learning
- analyse individual, task and environmental factors influencing movement skill development
- analyse the link between motor skill development and participation and performance

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



iStock.com/OSTILL

THE LINK BETWEEN MOTOR SKILL DEVELOPMENT, PARTICIPATION AND PERFORMANCE

A young person who is unable to competently throw, kick or catch is unlikely to participate in physical activities and sports that require these skills. We know from research that young people with better developed motor skills may find it easier to be active and engage in more physical activity (PA) than those with less developed motor skills. Motor skills (known as movement skills) generally do not develop naturally, as discussed in chapter 1. The period when it is critical to develop motor skills is childhood. Basic motor skills are typically classified as:

» object control skills (e.g. catching and throwing)
» locomotor skills (e.g. running and jumping)
» stability skills (e.g. balancing and twisting).

Source: Gallahue et al., 2011; Ulrich, 2000

The fundamental movement skills (FMS) lay the foundations for the development and refinement of more complex sport-specific skills. These determine the level of performance a person can achieve when playing sport. Not only is the development of motor skills positively associated with participation in physical activity and performance, but FMS competency also has implications for individual health, positively affecting physical activity and cardiorespiratory fitness. FMS competency has an inverse relationship with weight. Ideally, children should have mastered all basic motor skills by Year 4, however research examining the skills competency of young people indicates that fewer than half of Australian children in Year 6 have mastered the kick, sprint run, overhand throw or the vertical jump.

In general, boys are more proficient in performing object control skills, such as catching and throwing, are more active and fitter, and have a higher perceived competence than girls. Unfortunately, because many Australian children are not proficient in many of the basic motor skills, they have little success performing the more complex sport-specific skills that feature heavily within secondary school physical education and sport programs. Although physical education programs in primary and secondary schools have the potential to help students develop their motor skills, barriers, such as funding and staff availability, may limit the effectiveness of these programs.

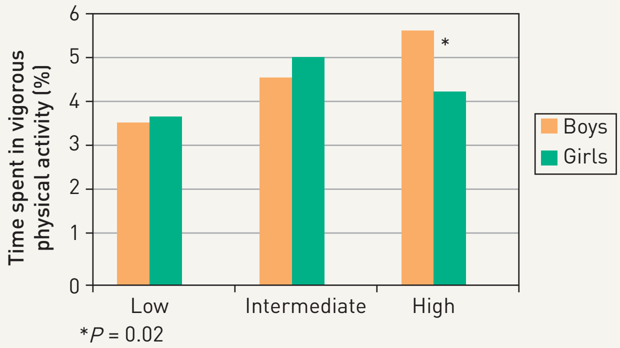
REAL WORLD APPLICATION

CHAMPS

A study of four-year-old children (preschoolers) in the Children's Activity and Movement in Preschool Study (CHAMPS) examined the association between motor skill proficiency and physical activity levels, assessed using an accelerometer. Data was expressed as a percentage of time spent in sedentary, light, moderate-to-vigorous PA (MVPA), and vigorous PA (VPA).

The findings indicated that children with better-developed motor skills were more active in terms of both MVPA and VPA – (see graph on next page) than their less-skilled classmates. Children classified in the highest grouping for locomotor skills spent significantly less time engaged in sedentary activity than children in other, less skilled groups. These differences were not observed in relation to the mastery of object control skills.

>



Motor skill performance by sex (four-year-olds)

Source: Williams et al., 2012

Questions

1. Describe the association between motor skill level (locomotor skills) and physical activity level.
2. Discuss whether this association varies by sex.
3. Explain why you think there was significant association between locomotor skills and physical activity levels but not between object control skills and physical activity.
4. What implications do you think these findings have for primary teachers?

QUALITATIVE MOVEMENT ANALYSIS PRINCIPLES

Qualitative movement analysis is used to improve human movement. The four main principles of qualitative movement analysis are: preparation, observation, evaluation and error correction. Qualitative movement analysis is used by a variety of professionals, including:

» teachers
» coaches
» dance instructors
» athletic trainers
» sports medicine practitioners
» physical therapists
» fitness instructors
» biomechanists (see chapter 3 for an explanation of a biomechanical qualitative analysis).

Qualitative movement analysis is sometimes referred to as:

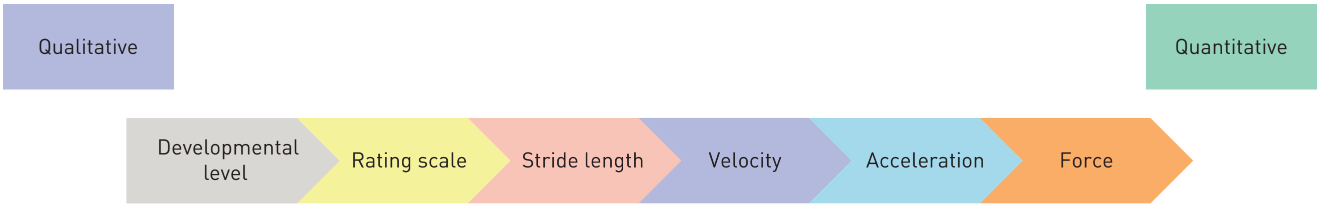
» qualitative movement diagnosis (QMD)
» error detection
» skill analysis
» movement analysis
» diagnosis
» observation
» eyeballing
» observational assessment
» systematic observation
» clinical diagnosis.

Qualitative movement diagnosis (QMD), the most widely used of the above terms, is the assessment of human movement technique, with the aim of providing appropriate intervention to improve performance.

Qualitative movement can be analysed for many purposes, including:

» diagnosis of strengths and weaknesses of players or teams
» to obtain a final result or rank in competition
» for talent identification or team selection
» to predict future performance results.

The diagram on page 24 illustrates a continuum of human movement assessment. Notice that all assessments of human movement fall somewhere along the continuum from qualitative to quantitative. Table 2.1 summarises the features of assessment towards each end of the spectrum.



Sample continuum of human movement assessment for assessing running

Source: Knudson and Morrison, 2013

TABLE 2.1 Qualitative vs quantitative assessment of human movement

Towards the qualitative end	Towards the quantitative end
Involves non-numeric assessment of movement information or a judgement on the quality of performance	Involves some measurement of performance
As an example, qualitative statements about a baseballer's pitching could include comments from a coach or a TV commentator	As an example, quantitative data that could be collected about a baseballer's pitching would include a statistical breakdown of total pitches, strikes, balls, locations of pitch, radar measurement of ball speed
Used by most physical education teachers and coaches in everyday practice to diagnose and correct errors	The most quantitative assessments in sports science relate to biomechanics and exercise physiology, which are generally laboratory-based within university research settings or elite sport performance institutes, making them too expensive for everyday widespread use in teaching and coaching
Based on rich decision making and knowledge of the skills and demands of the given physical activity/sport	Still subject to qualitative factors and therefore doesn't guarantee validity
	Evaluating the time taken to complete a 50-metre sprint is at the qualitative end of the continuum

CHAPTER CHECK-UP

1 Identify five types of professionals who would use qualitative movement analysis to improve human movement.
2 Outline four purposes of quantitative movement analyses.
3 Describe three features of assessment towards the qualitative end of the assessment continuum.
4 Explain why quantitative analyses are not generally accessible in everyday contexts such as teaching or coaching.

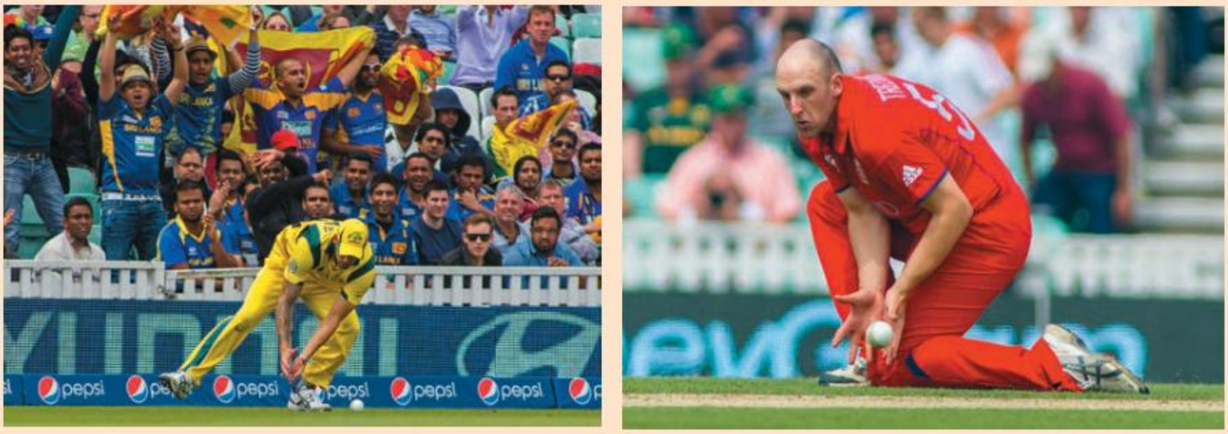
PRACTICAL ACTIVITY

VISUAL ANALYSIS: CLASS DISCUSSION

Look at the image on the next page of the cricketer about to let a ball through his legs while fielding. Qualitative movement diagnosis (QMD) would improve this player's learning outcomes.

>

Alamy Stock Photo/European Sports Photographic Agency



Alamy Stock Photo/European Sports Photographic Agency

Discuss the most appropriate feedback to encourage cricket fielders to avoid a ball going between their legs while fielding a ground ball.

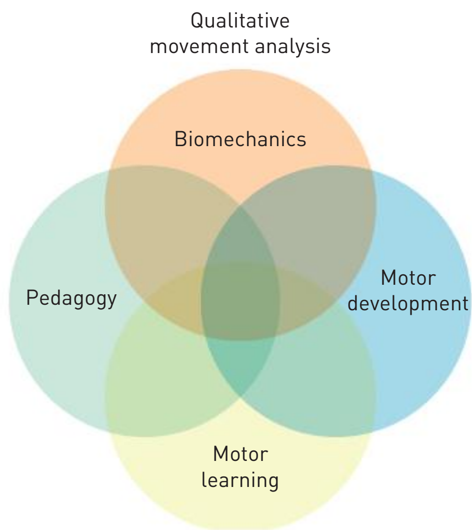
Refer to the image on the left above, of the cricketer fielding a ground ball that is likely to go between his legs. There are many reasons why a fielder may miss a ball. As part of the QMD process, a coach/teacher weighs up all of the possible reasons and decides on the most important factor to focus on for error correction.

A fielder may miss a ball because of:

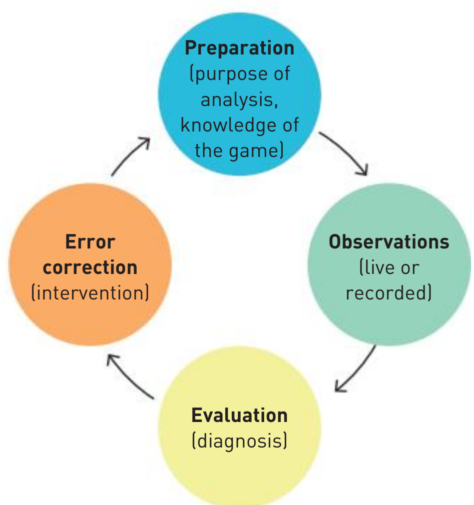
» poor vision to track the ball
» poor fielding technique
» environmental factors such as wind or sun
» the psychological pressure of a critical moment in the game
» the possibility that player didn't selectively attend to the most relevant information, and instead was looking at the batter running rather than seeing the ball into their hands.

A coach/teacher would weigh up whether the player makes this error frequently, and the size and direction of the errors, to determine what intervention or error correction strategy should be used. A coach needs cross-disciplinary knowledge to determine what factors are causing the problem. The Venn diagram (right) displays the interdisciplinary nature of qualitative movement analysis.

The principles of qualitative movement analysis are depicted in the diagram below right. Let's take a look at the key components within each of these principles: preparation, observation, evaluation and error correction.



Source: Knudson & Morrison, 2013



Principles of qualitative movement analysis

Preparation

Coaches need to develop an observation strategy, which must be based on a solid knowledge of the game and the characteristics of skilled performance relating to the skills of the sport. First, they need to determine the specific purpose of the analysis. Educators/instructors should utilise media technology as a valuable aid for observation and analysis, especially during game-like situations. There are numerous types of software, apps and technologies that can assist with capture and analysis of a range of movements. Coaches also need to determine which player will be observed and what the specific focus of the observation will be, and determine how progress will be tracked (e.g. number and timing of observations). Characteristics of skilled performance include:

- performs consistently at a very high level
- coordinated
- balanced
- flexible
- fit
- efficient in time and energy
- strong kinaesthetic sense
- good anticipation
- efficient technique
- sound mental approach.

Observations

Observations can be performed live and/or recorded digitally. Several factors can influence your ability to observe, including:

- accumulation of experience
- knowledge of the game and the skills required
- academic training
- technical training.

A range of variables could be observed before or during the game, such as:

- global dynamics of a team
- whether the team is completing **set plays** according to the game plan
- opponents' patterns of play
- behaviour of the opposing coach
- situational variables.

Several factors influence our capacity to observe and analyse players during a game, including:

- psycho-emotional aspects
- expectations
- referee errors.

The main limitation of observing the quality of a performance is subjectivity. For example, two different coaches, selectors or spectators could watch the same performance and have two very different perceptions about the quality of the performance.

Evaluation (diagnosis)

Evaluation is the third stage of qualitative movement analysis. The term 'evaluation' (and diagnosis) generally refers to a judgement of quality, and a determination of the value or amount of something. When evaluating human performance, the analyst essentially has to become a human movement detective or physician. They must decide first what the problem is; second, what is causing it; and third, how can it be addressed. Performance can be assessed either objectively (based on measures such as score and time) or subjectively, generally by employing qualitative approaches (based on perception and interpretation of observation or opinion). Most sports generally attempt to make the scoring/judging more objective via the development of criteria/rubrics that can be used to award scores. Table 2.2 summarises the use of objective and subjective performance measures.

Measurements can be made more objective by using electronic measurement devices/systems, e.g. electronic timing gates, timers (quantitative). However, this section focuses on qualitative movement analysis, which can be made more objective through the use of:

» checklists – these list the components and elements essential for the performance (e.g. style and technical performance)
» rating scales – a degree of difficulty sheet outlining a scoring/marking scale for movements
» criteria/rubrics outlining a set of rules, procedures or guidelines relating to assessment of the performance.

TABLE 2.2 Objective vs subjective measures of human movement

Objective performance measures	Subjective performance measures
Involve impartial measurement (without bias or prejudice)	Influenced by the observer's personal judgement of how skill/game was performed/played
Include measures of time (e.g. stopwatches or timing devices, gates)	Open to interpretation and opinion
Include distance measures (e.g. measuring tapes)	Often refer to quality and style of performance (e.g. scoring of dance and gymnastics)
Mean that performance appraisal is not subject to personal opinion or interpretation	Numerical scores can be applied

INVESTIGATION

1 Search online for a judging panel's commentary from a sport or physical activity such as dance, gymnastics, boxing, diving or dressage. It needs to be from during or after a performance, and should show highlights reflecting their feedback/comments. It could be based on a sports broadcast or even a television show.
2 Describe the physical activity/sport you observed.
3 Outline the type of scoring system used to judge the performance.

Weblink

Tests need to be valid and reliable

Ideally, when we qualitatively analyse skills, we use a valid and reliable method and measure.

Validity

Validity refers to the test's capacity to measure what it is intended to. For example, having a speedminton player perform a serve as many times as possible in 30 seconds is not a valid test of ability to serve in speedminton, because the rules of the game state that you can serve when you are ready.

Reliability

Reliability refers to the ability of a test to reproduce similar results when conducted in identical/similar conditions, contexts and situations. To maximise the reliability of an assessment you need to use the same or similar:

» procedures
» conditions
» equipment
» environment
» tester.

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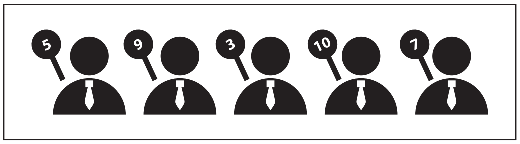
Judging of dressage (equestrian) requires quantitative scores to be assigned to qualitative assessments. The performance of the horse and rider is evaluated by at least two judges, who must sit separately.

For example, a test would not be considered reliable if you used completely different procedures, conditions, equipment and environment from one test to the next. Table 2.3 illustrates an extreme example of inconsistency in testing. However, even if we only changed one of the variables, the test would be unreliable.

TABLE 2.3 An example of inconsistent testing

Test	Procedure	Equipment	Condition/environment
Netball chest pass × 20 trials	Passing at a wall target	Senior-sized ball	Indoor
Netball chest pass × 3 trials	Passing at a moving target (another player)	Junior-sized ball	Outdoor windy day



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Establishing consistency of agreement across different observers is essential in analysing human movement.

If you were to have four different observers all rate a swimmer's performance in a 25-metre freestyle without an agreed set of criteria, assessments of the quality of the performance could vary significantly.

Inter-rater reliability

Inter-rater agreement is the degree of agreement among raters (judges). It measures **homogeneity**, or **consensus**, in the ratings given by judges, evaluators or scorers.

Assuming all observers have been trained to use a similar set of standards or judging criteria, we can compare scores across different observers. The level of consistency of scoring across different observers is called inter-rater reliability. You can achieve inter-rater reliability by getting observers to rate a particular performance (filmed), with all observers using the same performance and scoring system.

Intra-rater reliability

Intra-rater reliability refers to the consistency of ratings given by one assessor. Assuming an individual observer has been trained to use a valid set of criteria to analyse a performance, their scoring over time can be assessed for consistency by getting them to score an identical filmed performance at different times.

LABORATORY REPORT

RELIABILITY

1 Select a sport and skill to be performed and filmed.
2 Once you have selected a sport, search online for a suitable test that a coach/teacher could use to assess a specific skill.
3 Film yourself or a classmate performing the selected skill.
4 Using the scoring system/measure/test sheet, analyse the skill observed. Complete the analysis twice, with a specified amount of time between attempts (e.g. 30 minutes, a day, or a week). Do not look at your results between the two analyses.
5 Compare the scores you gave on the two separate occasions. This looks at your consistency (intra-rater reliability) of observation and evaluation. If your two scores were within 5% of each other, you would be considered highly reliable; if within 10%, reliable.
6 Now compare your scores with at least two other people who rated the same performance (use the first set of analyses completed by each observer). (This measures inter-rater reliability.) What was the level of agreement between the various observers?

Generally, the level of agreement for reliability is assessed using more sophisticated statistical analyses, which are beyond the scope of VCE Unit 3. However, it is important to understand that if either intra-rater or inter-rater reliability is poor, this means that either:

» the observers need to complete more training in the use of the observation system (e.g. looking at a performance and discussing what they are looking for while using a checklist or set of criteria), or
» the measures scoring system needs refinement, or replacement with a different test.

Error correction (intervention)

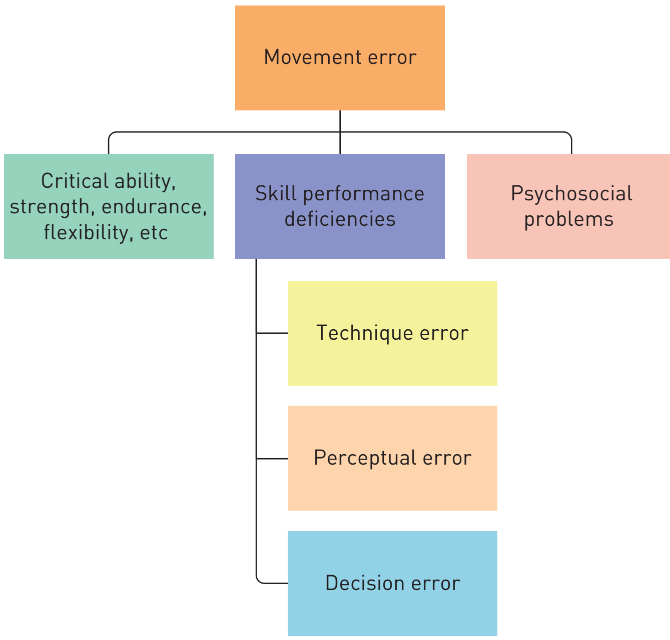
The final task of qualitative analysis is the error correction, or intervention, made by coaches or teachers based on their interpretation of the data observed.

Weaknesses are identified and strategies to address these are then developed using either direct or constraints-based coaching or instructional approaches (see pages 30–31 for further detail on constraints-based coaching). The strategies developed are based on the stage of learning the performer is in. Intervention is then undertaken via one or both of the following:

» intervention during a micro-cycle of training, via:
  - adaption of training exercises in practice
  - visual strategies (digital footage, digital clips of elite performance)
  - meetings (with individuals or the team)
  - written reports to provide feedback based on video footage

» intervention during the game by:
  - discussing at half-time
  - targeting individual players
  - providing immediate feedback
  - using gestures and other body language
  - calling time out.

There are many potential sources for movement performance error, as shown at right. In this chapter we are focusing specifically on analysing deficiencies in skill performance.



Sources of movement performance errors

Source: Knudson & Morrison, 2013

CHAPTER CHECK-UP

1 Identify six characteristics of skilled performance.
2 Outline five variables that could be observed before or during the game.
3 Describe which factors need to be kept consistent to ensure a measure is reliable when assessing movements.
4 At what stage during a micro-cycle of training could a coach intervene in order to correct errors in skill or performance?
5 Select one source of error for a sport you have played, and explain how this could affect your development of skills.

DIRECT AND CONSTRAINTS-BASED APPROACHES TO COACHING AND INSTRUCTION

In the modern world of sport there is a focus on quality practice over quantity practice, and a move away from a performance focus to a learning focus. The emphasis is on development of skills in a performance context, in which various crucial constraints of performance can be modified. This section will examine the notion of ecological dynamical systems and the organism–environment (or person–environment) relationship. This is a non-linear approach to learning.

An effective coach should integrate information from the multidisciplinary areas of sports science (biomechanics, sport nutrition, exercise physiology, skill acquisition, etc.) into their training and competition programs. A simple framework for demonstrating this integrated model of skill learning is called the 'constraints-based approach'.

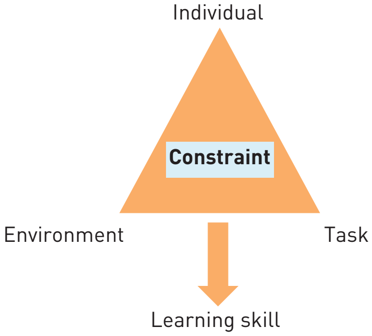
Direct coaching

Traditional direct coaching approaches are rigid, and provide feedback on every practice attempt. This limits the need for the learner to go searching for their own movement solutions.

There is a time and a place for the use of direct coaching approaches, regardless of the level at which a performer or team is working. Within the direct coaching approach, the learner/performer has limited need or opportunity to make decisions, to adapt to large variability or to think independently. Direct coaching approaches require the coach to make all the decisions relating to:

» task selection
» task sequencing
» structure of how tasks are to be performed
» timing of when tasks will be performed
» duration of time spent on practice tasks
» how tasks will be modified and progressed to make them easier or harder as required
» how technique and strategies will be refined and implemented.

Table 2.5 (page 32) summarises a comparison between traditional direct coaching approaches and more contemporary athlete/learner-centred approaches such as constraints-led coaching.



In a constraints-based model there is an interaction between the individual and the environment affecting the learner/player's perceptions and actions.

Constraints

Constraints are boundaries that shape a learner's self-organising movement patterns, cognitions and decision-making processes. Constraints influence the way performers or learners process information, make decisions and ultimately move.

Factors that influence learning and performance at any moment in time are considered 'constraints'. Although the term often suggests negative connotations, this is not always the case. Within a constraints-led approach, learners often move one step backwards for every two steps forward. The constraints-based approach to coaching employs an ecological or 'dynamical systems' approach, which takes into account the interaction between three categories of constraints: the individual, the environment and the task. The way these constraints are modified affects the execution of the goal-related task and, ultimately, the learning of the skill.

TABLE 2.4 Examples of constraints

Constraint category	Examples
Individual constraints iStock.com/yacobchuk 	» Body size (height, weight and limb lengths) » Fitness level (agility, speed, power, aerobic capacity, flexibility, etc.) » Mental skills (attentional control, concentration, confidence, arousal control) » Perceptual and decision-making skills (recognising patterns of play, anticipation based on movements or previous behaviour of opponents, known as 'reading the play') » Technical skills
Environmental constraints iStock.com/Wavebreak 	Physical environment: » locality in which player was raised (e.g. parks, backyards, empty spaces and alleyways that provide an environment for early sport opportunities) » noise level in a gymnasium or on a sports field » auditory feedback or other environment features » gravity » weather conditions (e.g. ambient temperature) » natural light » terrain » quality practice facilities (e.g. backyard structure) Social/cultural environment: » cultural norms (e.g. Australia produces great cricketers) » family support networks » peer groups (e.g. teammates) » societal expectations (e.g. Australian Rules is more popular in Victoria, whereas rugby is generally preferred in New South Wales and Queensland) » the culture of a sport club and access to high-quality coaching
Task constraints Shutterstock.com/Mindscape studio 	Factors closely related to performance: » rules of the sport » equipment available (bats, balls, wickets, racquets) » field/pitch/court dimensions » player numbers (team size) – e.g. 3 vs 3 soccer rather than 11 vs 11 » instructions about how to complete the task » relative state of the game

Constraints-based vs traditional direct coaching approaches

TABLE 2.5 Constraints-based vs direct coaching approaches

Constraints-based approaches	Direct approaches
1 No one movement solution fits all problems Learners have a number of potential solutions to solve performance problems. There is no one perfect solution to each movement challenge/problem. Each player needs to be able to solve problems in ways suited to their particular strengths and weaknesses.	Coaches instruct via demonstrations and feedback, e.g. how to hit a two-handed backhand.
2 A more natural way to learn most movement skills at a more subconscious level (implicit learning).	Players are forced to 'think' via explicit instructions.
3 Coaches can deliberately manipulate surroundings to create the conditions that foster changes in players' behaviours and self-organisation under various constraints. For example, the coach could create rule changes using small sided soccer games that allow players to shoot through goals on all four sides of the pitch/grid/playing area. Modifying the task (e.g. rules, number of defenders, goal of task, equipment) forces players to adapt/change their strategies, leading to changes in perceptual decision-making and action skills.	The task often has a fixed volume. Players have to complete a number of trials and repetitions and are directed to perform the task in a particular way.
4 Integration of sports science Other aspects of sports science are integrated at the same time as skill acquisition, e.g. strength and conditioning, mental skills or biomechanics. For example, the coach encourages players to experiment with bats of different length and weight for baseball, tennis, softball or cricket, then varies the delivery of the ball, close and away from the player's body. The conditions will force the learner to select a striking implement with a size and weight that allows them to have fast hands and to manipulate the striking instrument quickly and responsively, depending on the spin/bounce/flight of the ball.	A more traditional approach would be to have batters hitting off a tee with one size bat, or tossing the ball in a similar location/position in relation to the player. You have probably seen the old-school tennis coaches who stand with a basket full of balls, feeding them to the same spot dozens of times.
5 Create a high level of variability during practice, allowing each individual to achieve a task goal in his/her own way. Movement variability is considered intrinsic to being able to constantly adapt to changing demands. It fosters the flexibility to achieve movement goals in dynamic sport performance environments, encouraging free exploration to find novel adaptations to solve typical motor problems. Although skilled performance requires consistency, the movement pattern used to achieve the performance outcome doesn't need to be repeated in an identical manner each time. 'Variability of practice' is key, e.g. practise a jump shot in different court positions, with different levels of pressure from opponents, vary time before shot has to be made.	In contrast, movement variability has traditionally been viewed within direct approaches as negative and 'noise' to the central nervous system. Traditional direct coaching approaches encourage identical movements repeated across trials. For example, a player would complete massed practice of set shots from the free throw line, e.g. 50 shots with no defender within no set time.
6 Task constraints are the most important for a coach, parent or physical education teacher to manipulate, as there is so much potential to vary the constraints, such as the task goals, specific rules, equipment, size of playing area. The Teaching Games for Understanding (TGFU) approach to teach net or invasion games often involves teachers changing the dimensions of the courts or pitch to encourage a particular movement solution or strategy. For example, to teach students about 'hitting into space' in badminton, a teacher or coach can create a long and narrow modified court, rather than a wide and shallow court.	

PRACTICAL ACTIVITY

MODIFIED JUNIOR SPORTS

Untrained coaches of junior sport often make the mistake of getting children to play sport using adult-sized equipment, pitches, ovals or courts, or playing with adult rules or time limits.

Participate in one of the following modified junior sports:

- » Tee ball
- » Auskick
- » Netta netball
- » In 2 cricket

QUESTIONS

1 Describe how the task constraints vary from the full adult/senior version of the sport.

2 Discuss how the modifications in the task constraints would make the activity more developmentally appropriate for juniors.

3 Select two other junior sports and outline three modifications that could be made to make the sport/physical activity more suitable for children to participate in.

FYI

Often the home team's familiarity with the pitch/field/oval gives them the home game/ground advantage. For example, a baseball field that has mostly grass apart from the en-tout-cas around the bases would play very differently to an infield that is predominantly en-tout-cas. Alternatively, a grass tennis court plays very differently to a hardcourt (such as a Rebound Ace), synthetic grass or even a clay court.

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Modified sports are a more developmentally appropriate introduction to sport than the adult version.

Representative task design

A critical feature of task constraints is the performance context that learners use to coordinate their actions. Learners rely on their senses (e.g. sight, sound, touch) to process information in relation to their movements and decision making. For example, cricketers need to practise under lights in preparation for playing outdoor night games.

Affordances

Affordances are opportunities for action, in terms of the capabilities of the individual. Before a decision can be made, a player often has to determine whether or not the behaviour is possible. For example, the decision to go for a three-point shot with less than a minute of play remaining depends on how confident that particular player is with the shot. An outfielder's decision to throw directly to the catcher on a game-changing play, rather than relay the throw home via a cut off fielder, is influenced by the action capabilities of that player on the day, the wind speed, soreness, fatigue, score, ability of the relay cut off, speed of the base runner, etc.

The key aspect of affordances is that coaches (or even teachers) create learning/practice environments that allow players to process information, enabling them to make informed decisions based on an understanding of the capabilities of:

» themselves
» their teammates
» their opponents.

FYI

Generally, small-sided games are more effective than drills for learning skills.

Requirements for coaches

A constraints-based approach to coaching requires a coach to possess:

» a solid knowledge of specific sports
» experience with developing a range of games and manipulating the constraints
» an understanding of the unique individual constraints, strengths and weaknesses.

Guided discovery approaches

In this problem-based learning approach, coaches/teachers shape, guide and facilitate, rather than direct. They can use an array of questions to prompt and guide the learner to the desired outcomes. Coaches can manipulate the individual, environment and task constraints using guided discovery and self-exploration. This allows learners to take more responsibility for their own development. Learners should be encouraged to develop their ability to use **intrinsic feedback**.

TABLE 2.6 Ways a coach can manipulate or modify a range of task constraints with various sports

	Example	Result
Net sports coaches	Change court dimensions to be long and thin and add a no-go zone in the middle of the court.	This encourages players to hit long and short and vary depth of shots.
Striking and fielding coaches	Change boundary dimensions to develop technical and decision-making skills, e.g. place cones for batters to try and hit the balls through depending on where the base runners are in baseball/softball. Create small-sided games that have scoring zones and fewer fielders.	This encourages a batter, for example, to hit behind a base runner in order to move the runner over.

PRACTICAL ACTIVITY

SAMPLE CRICKET LESSON USING A CONSTRAINTS-BASED APPROACH

Individual constraints:

- Perceptual skills: inability to identify ball type from bowler's actions
- Decision-making: poor shot selection
- Actions: limited action capabilities (inability to spin the ball, limited range of sweep shots)

Task constraints:

- Size of playing area, scoring zones, ball type

Aims:

1 To improve the ability of the players to bowl spin

2 To provide opportunities to develop perceptual, decision-making and technical skills of batting against spin.

- 12–18 players
- Session length: 60 minutes
- Age: 12+
- Experience level: intermediate/advanced

Time	Task	Organisation	Questions
0–10 min	**Game 1: Spin it to win it** **Aims:** 1 To develop perceptual skills of 'picking' spin bowlers 2 To develop the skill of catching 3 To develop disguise in bowling **Rules:** 1 Standing on the edge of one side of the square, the ball must be delivered underarm to land on your opponent's side of the court 2 Your opponent must catch the ball before it bounces twice or you score a point 3 Alternate 'serves' 4 Play a five-point game (win 5–0, 4–1, 3–2) **Extensions:** 1 Catch with one hand 2 Increase length of pitch (you can now stand where you want but you have to let the ball bounce)	2 x 2 m square with a line across halfway (one ball and four cones)	How can you make it more difficult for your opponent? How can you work out what spin is on the ball? Where is the best place to stand in the 'long court' game?
10–25 min	**Game 2: Pick it!** **Aims:** 1 To develop disguise and variety in spin bowlers 2 To develop catching (wicket keeper) 3 To develop the ability to pick spinners **Rules:** 1 Bowl the ball to your opponent 2 Your opponent must 'move' in the direction of the spin before the ball lands 3 A correct call gets one point 4 A successful two-handed catch after the ball has passed the stumps gets one point 5 First to score 20 points **Extensions/changes:** 1 Bowl underarm 2 Change the type of ball	Two sets of stumps (one ball)	How can you disguise the deliveries? How can you make it more difficult to catch the ball? How can you identify which type of spin is on the ball? What is the most effective way to catch the ball?

>

30–60 mins	**Game 3: Sweeps** **Aims:** 1 To develop the skills of sweeping 2 To develop decision making when playing spin 3 To develop decision-making skills when setting fields for spin bowling 4 To practise fielding when the ball is spinning **Rules:** 1 Each batter will face six balls 2 The bowler will be from the batting team (underarm) 3 Score 1 every time you hit the ball through a zone 4 Fielders can choose which zone(s) to defend 5 Caught out loses six runs **Extensions/changes:** 1 Bowl overarm 2 Change the scoring system	2 vs 2 One set of stumps and a cone. Four hitting zones for lap slog, sweep, paddle, reverse sweep (one ball, two bats, eight cones)	**Fielding side:** Where should you try to defend? Where should you leave gaps to encourage risk? **Batting side:** What are the safe options? What are the risky options?

Source: Renshaw et al., 2010

QUESTIONS

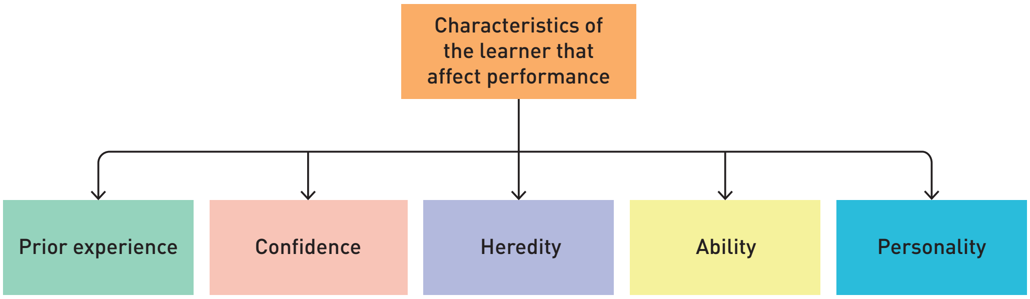
1. Identify two individual constraints outlined in this activity.
2. Outline two examples of task constraints in this activity.
3. Describe how you could manipulate the batting activity, using a modification to the environment, so that a player could practise hitting on a slow pitch.

Summary of constraints-based approaches to coaching and instruction

There is no such thing as a 'one size fits all' approach for developing skills, and it is important that coaches avoid trying to force all players/athletes to use a single technique or perfect movement template. Coaches need to allow athletes to solve problems in the way that best suits their own individual constraints. As long as the athlete's technique is biomechanically sound, and won't cause injury, they should be encouraged to solve problems using techniques of their choosing.

SOCIOCULTURAL INFLUENCES ON SKILL DEVELOPMENT AND CHARACTERISTICS OF THE STAGES OF LEARNING

Sociocultural influences are customs, lifestyles and values that characterise a society or group. These factors are the key force within cultures and societies that affect our thoughts, feelings and behaviours. An understanding of sociocultural factors (see the flow chart on the next page) is crucial in developing instructional teaching and coaching strategies. Sociocultural factors influence skill development at all stages of learning, however the same factor can influence a learner in the cognitive stage very differently to someone in the autonomous stage.



A range of the cultural and social factors that may influence skill development are listed below.

Cultural factors

- Education
- Politics
- Religion
- Social organisations
- Technology
- Values
- Attitudes
- Race
- Climate
- Housing
- Child-rearing practices
- Geographic location

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Social factors

- Family structure
- Role and status in society
- Time
- Available resources
- Access to equipment
- Access to coaches
- Discrimination
- Personality
- Self-belief (e.g. perceived competence)
- Self-motivation
- Active role models
- Parental encouragement

Perceived competence is based on self-evaluation of one's effectiveness or capability in a specific context. Consistency of perceived competence of motor skills is associated with actual skill competence, and often with participation in physical activity.

There are dozens of sociocultural factors that have the potential to influence skill development. In this chapter, we will focus only on a few examples and look at how these factors can influence skill development at the different stages of learning.

QUICKVID

Go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 37 are video interviews with Professor Damian Farrow, and Dr Michael Spittle, each discussing aspects of Improving performance skills.

Video

iStock.com/microgen

Alamy Stock Photo/PCN Photography

Skill improvement at the three stages of learning

Chapter 1 outlined the characteristics of learners in each stage of learning, based on the Fitts and Posner model. To improve skills, learners need different things within different stages of learning.

Learners in the **cognitive stage** need the following:

» no more than two simple instructions at a time to focus on
» plenty of demonstrations (live and digital) to give the learner a mental picture of the task
» complex skills to be broken down into smaller parts
» a focus on simple fundamental movement skills
» strategies to keep motivation high
» positive and constructive feedback.

Learners in the **associative stage** need the following:

» regular feedback to refine skills and reduce chance of poor habits developing
» opportunities to practice with increased variability.

For example, in tennis the person may be able to hit the ball over the net, but not always with the desired accuracy or speed.

Learners in the **autonomous stage** need the following:

» practice using game-like situations to focus on tactics, shot selection
» psychological skills training (see chapter 16) to help the player cope under pressure
» practice opportunities with a high level of variability
» practice which challenges the athlete to use higher-order thinking via a range of problem-based learning scenarios.

For example, tennis practice could focus on a return passing shot against a left-hander using a kick serve.

REAL WORLD APPLICATION

Relationship between psychosocial factors and perceived competence in swimming

Western Australian researcher Cecily Strange examined the relationship between psychosocial factors (socioeconomic status, geographic location and perceived competence in swimming, perceived athletic competence, and general self-worth) and swimming competency and attendance at a swimming program among Year 7 students ($n = 540$).

Her findings indicated that:

- The lower socioeconomic status (SES) groups had a significantly lower swimming stage and lower perceived self-worth than the higher SES group.
- Students from the lower socioeconomic inland area had the lowest mean swimming stage as well as lower perceived social support for sport and swimming than either of the other two groups (compared to coastal areas) in the study.
- The two lower socioeconomic groups also attended less swimming instruction and placed less emphasis on the importance of learning to swim well than the higher socioeconomic group.
- Despite these findings, the lower socioeconomic groups did not view themselves as any less able in terms of athletic and swimming competence.

Source: Strange, 2008

Questions

1 Explain why you think being from a low SES group is a barrier to accessing swimming programs.
2 Discuss why you think children living in coastal areas had a higher swimming level on average than young people living further inland.
3 Why did the researcher examine perceived competence?
4 Why is this important to skill development?

TABLE 2.7 Sociocultural factors that influence skill development at different stages of learning

Sociocultural factor	Cognitive stage	Associative stage	Autonomous stage
Time	Some parents make the time to play with their child or to take them to a coaching session to learn new skills within modified sports and other physical activities such as swimming, cycling, dancing, gymnastics, athletics.	Most learners spend a long time in this stage. Hundreds of hours of practice are generally required to move to the autonomous stage.	Time management is a crucial component of competing at the highest level. Many athletes have to balance a full- or part-time job with training and competition. Perfecting and fine-tuning skills at the highest level takes thousands of hours.
Role models	Developing a mental image of the skill being learnt is critical, so demonstrations from a parent, teacher or coach are very important.	Refining skills via demonstrations from a coach or teacher is still very important.	At this level viewing of opponents to develop game plans becomes more important than having a role model.
Family structure	Having siblings or parents to play with, model and learn from is a powerful influence on skill development.	Having access to other family members to practise with or to provide support such as transport increases the likelihood of skill development.	By this stage family structure would not play much of a role unless the athlete is at an elite level and is unable to transport themselves to practice and competition.
Child-rearing practices	Some parents place a large emphasis on learning movement skills and spend large amounts of time teaching their children skills or enrolling them in early childhood physical activity/movement programs, modified sports, and primary schools with PE specialists.	Generally not as important to this stage of learning	Not relevant to this stage. However, unless the child-rearing practices were supportive of skill development it is unlikely a person would reach this stage pre-adulthood.
Politics	Politicians make decisions that influence the infrastructure of programs, facilities and other opportunities that facilitate movement skill development. Development of supportive policies such as having a mandate for PE in schools has the potential to influence skill development.	Accessible government-funded/supported resources, facilities and programs allow people to access environments such as sporting clubs.	Often, being able to refine their skills to an international standard requires athletes to have access to world-class facilities, training and sporting institutes, supported by quality coaching programs, scholarships, highest standards of equipment and competitions.
Geographic location	This influences people's access to various physical activities and the variety of options they can try. For example, people living in coastal areas are more likely to develop aquatic skills, whereas people living in alpine regions are more likely to develop skills associated with alpine sports.	Some regional areas produce a higher proportion of elite sporting people per capita in particular sports because they place a large emphasis on particular physical activities.	At the highest level, geographic location is important in terms of climatic conditions and being able to access competitions of a high enough standard. For example, some athletes have to move to a new geographic location to be able to access facilities, climate, coaches and appropriate competition.

CHAPTER SUMMARY

- Young people with good motor skills may find it easier to be active and engage in more physical activity (PA) than those with less developed motor skills.
- Qualitative movement can be analysed for many purposes, including: diagnosis of strengths and weaknesses of players or teams; to obtain a rank in competition; for talent identification or team selection; or to predict future performance results.
- Coaches need to develop an observation strategy based on a solid knowledge of the game and the characteristics of skilled performance relating to the relevant skills of the sport. Coaches need to determine the specific purpose of the analysis and which player/s will be observed, and determine how progress will be monitored.
- Observations can be influenced by: accumulation of experience, knowledge of the games and skills required, academic training and technical training.
- 'Evaluation' (and diagnosis) generally refers to a judgement of quality. When evaluating human performance, the analyst should become a human movement detective or physician, and decide what the problem is, what is causing it, and how it can be addressed.
- Qualitative movement analysis can be made more objective using checklists, rating scales or criteria.
- Validity refers to the test's capacity to measure what it is intended to. Reliability refers to the ability of a test to reproduce similar results when conducted in identical/similar conditions, contexts and situations.
- Error correction can be either an organisational training process or a set of processes the coach can use to communicate information to the players.
- An effective coach should integrate information from the multidisciplinary areas of sports science (biomechanics, sport nutrition, exercise physiology, skill acquisition, etc.) into their training and competition programs. A simple framework for demonstrating this integrated model of skill learning is called the 'constraints-based approach'.
- Constraints are boundaries that shape a learner's movement patterns, cognitions and decision-making processes.
- The constraints-based approach takes into account the interaction between three categories of constraints: the individual, the environment and the task. How these constraints are modified affects the execution of the goal-related task and skill learning.
- Creating a high level of variability during practice to allow each individual the opportunity to achieve a task goal in his/her own way is a key element of constraints-based approaches. Movement variability is important for being able to constantly adapt to changing demands.
- Affordances are opportunities for action in terms of the specific action capabilities of an individual.
- Sociocultural factors influence skill development at all stages of learning, but each factor can influence a learner in the cognitive stage very differently to someone in the autonomous stage.

CHAPTER REVIEW

Multiple-choice questions

1 In the ________________ stage of learning only two simple instructions should be provided to the learner at a time.
   A rudimental
   B cognitive
   C associative
   D autonomous

2 _____________________ are opportunities for action and are defined in terms of the action capabilities of the individual.
   A Constraints
   B Skills
   C Affordances
   D Motivators

Short-answer questions

3 a Describe the link between the development of movement skills and participation in physical activity and sport.
   b Discuss how the development of movement skills affects performance.
   c How can a lack of skill development impact on students' experiences with physical education programs?

4 a Outline four reasons qualitative movement analysis is conducted.
   b Select a sport of your choice and outline two variables/components of movement used in that sport that could be assessed qualitatively.

5 Explain why, in order to use qualitative movement analysis, you need strong interdisciplinary knowledge. Give an example.

6 a Outline the four principles of qualitative movement analysis.
   b Summarise three key features of the preparation stage of movement analysis.
   c Compare and contrast subjective vs objective assessment of movement.

7 a Describe three ways qualitative measurement can be made more objective.
   b Select one of these ways and provide an example.
   c Describe the key difference between the terms 'reliability' and 'validity'.

8 a Describe what is meant by the concept of 'error correction'.
   b Outline four potential sources for movement error.
   c Provide an example of a decision error in performance.

9 a Explain the main components of the constraints-based approach to coaching and instruction.
   b Discuss how this approach varies from more traditional direct approaches.
   c Outline two examples of affordances within a particular context and scenario.

10 Select two cultural and two social factors that influence performers within each stage of learning.

CHAPTER 3

KINETIC CONCEPTS OF HUMAN MOVEMENT

Key knowledge

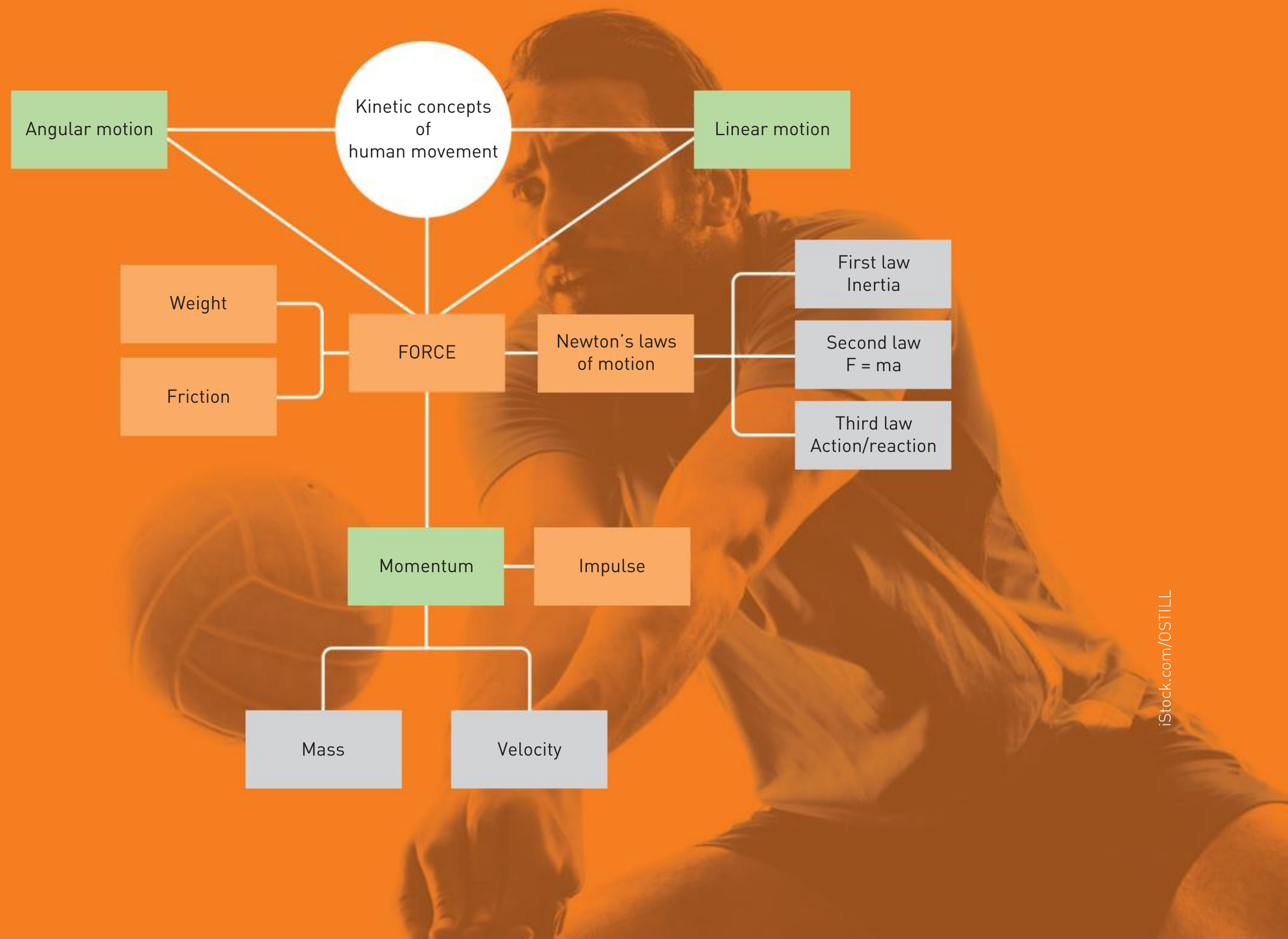
» biomechanical principles for analysis of human movement including: angular and linear kinetic concepts of human movement; Newton's three laws of motion; inertia, mass, force, momentum and impulse

Key skills

» perform a qualitative analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

» analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills in a coaching context

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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WHAT IS BIOMECHANICS?

Biomechanics is the science that studies living things from a mechanical perspective. Using the principles of physics associated with motion and forces, biomechanics can help develop and refine human movement. Biomechanics helps us understand why golfers use a longer club to drive the ball and a shorter one to chip it, how an Olympic sprinter can run so fast, and how a baseball pitcher can make the ball curve. It also enables us to refine movement in order to improve performance. Biomechanics looks at the structure and design of equipment used in sport, movement techniques, the causes of overuse injuries, impaired mobility in the elderly, maintaining bone density in space, and improving movement in people with disabilities such as cerebral palsy and lower-limb amputations. The field of biomechanics is broad, but this chapter will focus specifically on the use of biomechanical principles in a coaching context to improve movement skills in sport and physical activity.

It is important for all physical education teachers, personal trainers and coaches to have an understanding of basic biomechanical principles. Elite athletes use biomechanical analysis to improve their performance, equipment and technique, but the correct application of biomechanical principles can lead to improved performance, greater efficiency and accuracy at all levels of sport and physical activity.

BIOMECHANICAL MOVEMENT ANALYSIS

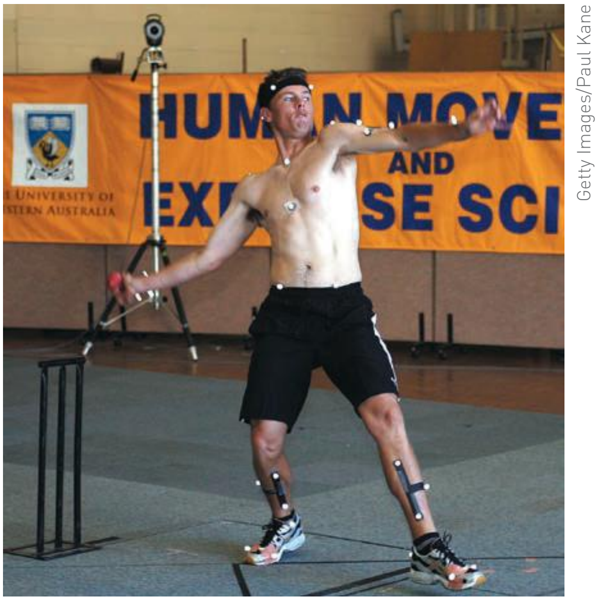
A biomechanical movement analysis can be quantitative or qualitative. As covered in chapter 2, **quantitative analysis** looks at numerical data, whereas **qualitative analysis** is a description of the quality of the performance.

In biomechanics, quantitative analysis is based on measurement of kinetic (force) and kinematic (distance, speed, acceleration) variables. For example, quantitative analysis of a 200-metre race could involve the coach recording the time taken to complete the race, 20-metre split times, the reaction time out of the blocks, stride rate and stride length. They would then use this information to evaluate the runner's technique.

A biomechanical qualitative analysis would involve a description such as 'You were a bit slow out of the blocks because your weight wasn't far enough towards the front of your stance. However, your acceleration over the first 40 metres was great, and you held your speed until the end'. Another qualitative analysis of the same race may be 'That was a very good race'. Qualitative analysis can be general or highly detailed.

In biomechanics, both types of analysis are equally important. In a biomechanical laboratory, quantitative data is used to answer specific questions. However, coaches, teachers and trainers rely heavily on qualitative observations to provide feedback to students and athletes.

Chapter 2 explained how to perform a qualitative analysis.



Getty Images/Paul Kane

Biomechanical analysis at the Australian Institute of Sport in Canberra

Planning a biomechanical analysis

1 Identify the question of interest.
   » Why is the volleyball player having difficulty serving the ball over the net?
2 Determine the best perspective from which to observe the movement.
   » Front-on or side-on?
   » Close/medium/distant view?
   » Single player or whole court?
3 Decide on the number of times the movement skill is to be executed – repeated observation can help determine whether the error is consistent or random.
   » Perform five, 10 or 15 serves?
   » Observe during a competitive game or at training?
4 Consider other factors:
   » subject's clothing (loose clothing can obscure some movements)
   » setting (team practice, during class, at competition events)
   » visibility, lighting, background, etc.
5 Visual and/or digital recorded observation?
   » Recorded data can be replayed, shown to the athlete, slowed down, and freeze frames taken, meaning specific skills and players can be isolated.
6 Consider the characteristics of the performer:
   » age
   » gender
   » **anthropometry**
   » developmental and skill level.

LABORATORY

PLANNING A BIOMECHANICAL ANALYSIS

Observe and analyse one student performing two slightly different versions of a particular movement. Complete the template below to plan how you will collect the data and what biomechanical concepts you will look for. Examples have been provided in italics. There is an online template available via http://www.nelsonnet.com.au. You will need your login code.

Scaffold

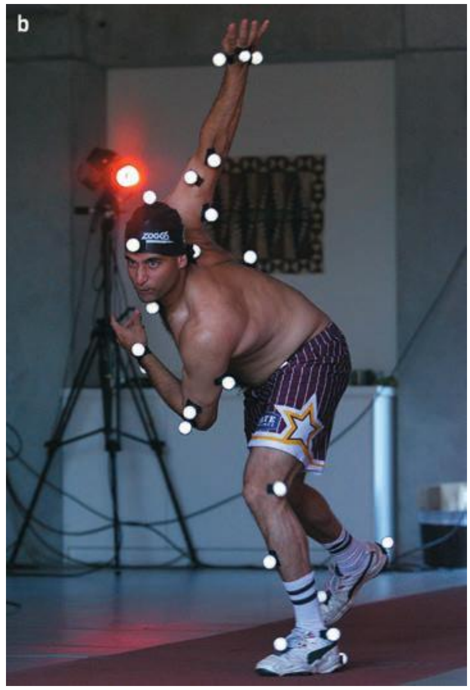
Movement selected	*Cricket: spin bowling and fast bowling*
Viewing perspectives	*Side-on and front-on*
Reasons for selection of viewing perspectives	*Both views will be required as hand position will be difficult to observe from side-on and foot plant will be difficult to see from a front-on position.*
Viewing distances	*Mid-wicket and behind the wicket keeper*
Reasons for selection of viewing distances	*Mid-wicket to be in line with the bowler as they plant their foot and deliver the ball. Behind the wicketkeeper for safety and a front-on view.*
Biomechanical concepts	*Distance of run-up, speed of run-up, angular motion of the bowling arm, etc.*

Measurement tools in biomechanics

Technology can be used in biomechanics to measure aspects such as joint angles, velocity and force. This technology has developed rapidly over the years. For example, video recordings have long been used as a tool to analyse human movement. However, the introduction of digital imaging has made this easier, as well as improving the quality of the data. The availability and portability of computers and their software means that athletes can be filmed in competition rather than in a laboratory simulation.

Video analysis can be a qualitative or quantitative process. In its simplest format, video footage can be viewed repeatedly, in slow motion, paused and saved for comparison at a later date. A more complex use would be digitising the footage (converting body landmarks to computer coordinates) so a quantitative analysis can be conducted to calculate distances, speeds, forces and momentum.

Centre for Orthopaedic Biomechanics, University of Bath



Getty Images/Phil Walter

Optoelectronic motion analysis (a) placing the reflective spheres on the body and (b) capturing the 'image' under infrared light

Optoelectronic motion analysis (see above) uses cameras that project infrared light onto reflective spheres, called targets, placed on the body. For a whole-body analysis, 16 targets are placed on the joints. The targets reflect an 'image' that can be captured by the camera, transmitted to a computer as digital information, and analysed.

Goniometry is the measurement of joint angles. Manual goniometers measure the angle of a joint in a static position. Electro-goniometers are devices that span a joint to be measured. Attachments are fixed to the upper and lower limb segments so the actual angular change at the joint can be measured.

There are a number of devices that can be used in the analysis of movement. Accelerometers measure the acceleration of the body. Light gates, combined with timers, measure speed and velocity. Force platforms, which are often embedded in running tracks, laboratory floors and diving platforms, measure ground reaction forces. **Electromyography** records the electrical activity within a muscle just prior to contraction. The data that is recorded is displayed on an EMG (electromyogram). Many apps, such as Dartfish Express, Coach's Eye and Ubersense, allow the use of smart phones and tablets to capture video footage and perform a movement analysis.

Image courtesy of Dartfish: www.dartfish.com. Used with permission

Smart phone and tablet apps have made movement analysis highly accessible to coaches, teachers and athletes.

CHAPTER CHECK-UP

1 Define the role of a biomechanist.
2 Compare and contrast qualitative and quantitative analysis of movement. Construct a table and list the key aspects of each approach.
3 Discuss how a Little Athletics coach would benefit from knowledge of biomechanics.
4 Research a piece of equipment used by biomechanists at the Australian Institute of Sport (AIS). Determine the type of analysis recorded by the equipment, the type of data obtained and how the information can be applied to improve performance.

Weblink

Link direct to the AIS via: http://vcepe34.nelsonnet.com.au.

Getty Images/JACQUES DEMARTHON

Forces can cause objects to change shape. The force on the ball as it contacts the racquet strings causes it to temporarily change shape.

FORCE

A **force** is defined as a push or pull. In sporting situations it is very easy to see when a force is acting. The force of gravity will pull a ball back to the ground after it has been thrown, hit or kicked. The force generated by a muscle when it contracts pulls on the bone to produce movement.

Forces can affect objects in two ways:

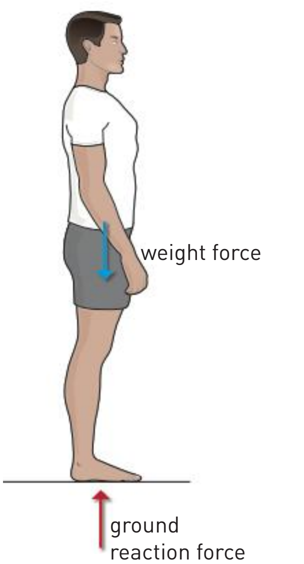
1 Change the shape of the object (stretching, squashing or twisting)
2 Move the object (starts moving from rest, speeds up or slows down, changes direction)

Forces can produce movement or change the motion of an object. The force that a cyclist applies to the pedals of their bike changes the motion of the bike from stationary to moving. When a baseball is caught correctly, the forces absorbed by a baseball glove prevent the player getting hurt by the impact of the ball. The force changes the motion of the ball by stopping its flight. All forces produce or alter movement, but this effect is not always obvious. When you jump, the effect of the reaction force between your feet and the ground cannot be seen because the object to which the force is being applied, in this case the Earth, is so massive the movement cannot be seen.

Force causes objects to accelerate. Force can be calculated by multiplying the mass of the object by the acceleration:

$$\text{force} = \text{mass} \times \text{acceleration}$$

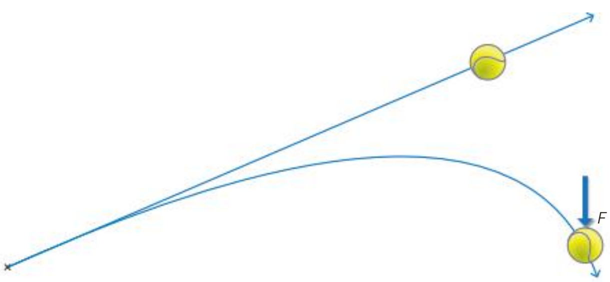
The unit of force is the newton (N), which is the amount of force required to accelerate 1 kg of mass at 1 m/s^2. The unit of force is named after Sir Isaac Newton, an English physicist who formulated the laws of motion.



Forces acting on the human body when standing. The weight force and ground reaction forces are equal in size but opposite in direction. No movement occurs because the resultant force acting on the body is zero.

Types of force

A number of different external forces act on the body, such as gravitational forces (weight) and frictional forces including drag forces in air and water. In a sporting situation, these forces can speed up, slow down or change the direction of a ball, bat or body. For example, without gravity, a ball thrown into the air would just keep going. It is the force of gravity that brings the ball back down and creates the parabolic path (see page 47).



The effect of gravity on the flight path of a ball

Gravity is a constant force that acts through the centre of mass of an object towards the Earth. Weight force is the product of mass and gravity (see page 49).

Friction

Friction occurs when two surfaces come in contact with each other. Friction opposes the motion of an object. In everyday living, adequate friction is needed in order to walk (friction between feet and floor), ride a bike (friction between wheels and path), and to pick things up (friction between hand and object). In sporting situations, there are times when it is beneficial to decrease the friction between two surfaces, such as in downhill skiing. In other examples, it may be important to increase the friction between the surfaces.

Manipulating the amount of friction between surfaces is common in physical activity, sport and exercise. A gymnast or weightlifter will use magnesium chalk to increase the friction between their hands and the bar. Sports shoes are designed to utilise friction. For example, shoes worn in volleyball, squash and badminton have rubber soles, while sports played on grass pitches often have studs. If the friction between the surface and the shoe is too great, however, and the shoe or boot doesn't turn, this can greatly increase the risk of injury.

FYI

In the freely movable joints of the body, synovial fluid acts as a lubricant to reduce the friction between the articulating surfaces. Joint injury, disease, overuse (where the rate of wear is faster than the rate of repair) and ageing can reduce the lubrication in the joint, leading to excessive wear and painful joints.

a

Getty Images/Bob Thomas

b

Shutterstock.com/John Wollwerth

c

Shutterstock.com/Pressmaster

(a) Weightlifters use chalk to increase the friction between the bar and their hands; (b) Ballroom dancers wear shoes with highly polished soles and dance on a polished floor in order to reduce the friction between the two surfaces; (c) Studs in football boots increase the friction between the grass and the boot.

To start an object moving across a surface, you must first overcome friction by applying an increasingly greater force. As the applied force increases, so does the friction, to a certain point. The maximum amount of friction that can be generated between two non-moving surfaces is called maximum static friction. If the applied force increases beyond the maximum static friction value, then the object will begin to move.

FYI

Fluid such as oil or water dramatically reduces friction between two surfaces. Bowling lanes are oiled to reduce the friction between the ball and the lane.

PRACTICAL ACTIVITY
INVESTIGATING FRICTION

AIM

To investigate the effects of friction on a hockey puck (in indoor hockey) and a ball (in field hockey)

METHOD

Participate in a game of indoor hockey (using a puck) and a game of field hockey (using a ball).

QUESTIONS

1 Compare and contrast the role of friction in each of the two games. How does this affect the equipment, footwear and rules of each game?
2 What difference would it make if you played field hockey on artificial turf instead of grass?
3 What other variables would affect the amount of friction between the ball and the field? Are these likely to increase or decrease the friction force?
4 How could the friction between the puck and the floor be reduced in indoor hockey?
5 The ball in field hockey is affected by rolling friction. Do you think rolling friction is greater or less than sliding friction? Suggest two other examples of rolling friction.
6 Ice hockey is played on an almost frictionless surface. What impact does this have on the skills, techniques and tactics used by the players?

Air and water resistance – drag force

When an object or body moves through air or water (or any other gas or fluid) it will experience a drag force. Drag forces oppose the direction of motion of the object, slowing it down. Drag is affected by a number of factors including air density, cross-sectional area of the body and the speed the object is travelling. Any increase in speed results in an increase in drag.

To maximise speed, athletes try to reduce the impact of the other factors. In sports that require high speed, drag is often minimised through technique (body position) and clothing (fabric and design). The same is true for activities where the body (swimming) or an object (e.g. a boat) is moving through water as quickly as possible.

Getty Images/Francis Bompard/Agence Zoom

Downhill skiers try to minimise drag by reducing the cross-sectional area of their body while going as fast as they can. Can you think of any other examples where drag force might affect performance?

Gravitational force

A gravitational force is the force of attraction between two bodies or objects. On Earth the gravitational force is the force (gravity) that causes objects to fall downwards – towards the centre of Earth. The acceleration due to gravity is equal to 9.8 m/s^2. All objects hurled, thrown or projected into the air are affected by the force of gravity (see chapter 4 for more detail).

Weight

Mass and **weight** are often used interchangeably, although they are two different quantities. Mass is a measure of the amount of matter an object is made up of. The units of mass are kilograms. Because body 'weight' is often given in kilograms, the two terms are often used to mean the same thing. However, weight refers to the force that is exerted on the body by gravity. Weight is directly proportional to the mass of an object. It can be calculated by multiplying mass by the acceleration due to gravity. Because weight is a force, the units used are newtons.

$$\text{weight} = \text{mass} \times \text{gravity}$$

INERTIA

An object will remain at rest or in constant motion unless acted upon by an external force. **Inertia** is the tendency for a body to resist a change in its state of motion, whether that state is at rest or moving with a constant velocity (see chapter 4 for more on velocity). In the human body, muscles provide the force to start or stop motion, accelerate or decelerate, or change direction.

It is much harder to move or change the state of motion of an object that has greater inertia. The amount of inertia an object has is directly related to its mass. The greater the mass of an object, the greater its inertia, and the greater the force needed to change its state of motion. For example, it takes much more force to move a 100 kg barbell than a 5 kg barbell. The heavier (more massive) barbell has much greater inertia than the lighter one. A wet football requires a greater force to move it than a dry football, because as the ball becomes waterlogged the mass increases.

If the force applied to an object is not greater than the inertia of the object, there will be no change in the object's motion. The strength of a muscle is related to the force it can produce. For example, to lift a kettlebell: the force exerted must be greater than the weight of the kettlebell or it will not move. Similarly, a gymnast performing a handstand applies a force on the floor but the floor does not move because the force being applied by the gymnast is not greater than the inertia of the Earth.

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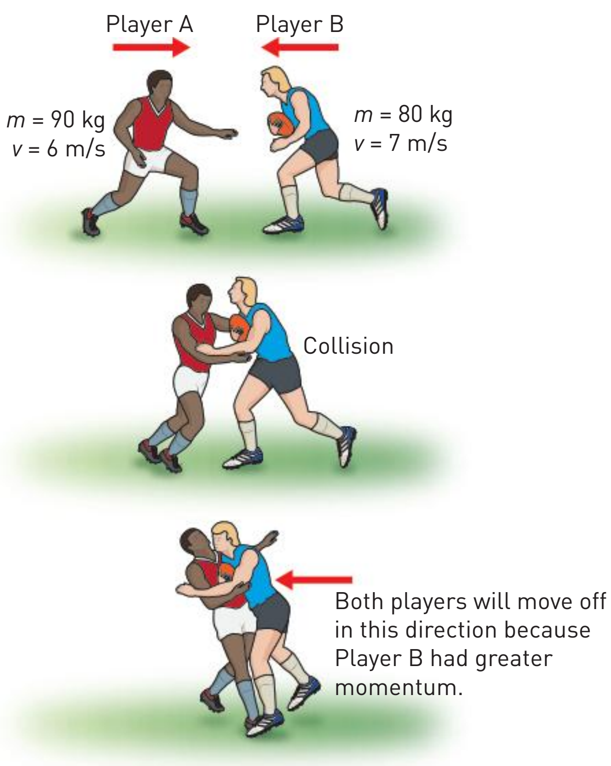
Which kettlebell has the greatest inertia? Which requires the greatest force to lift?

MOMENTUM

Momentum is a measure of the amount of motion an object has and its resistance to changing that motion. Momentum is equal to the mass of the object multiplied by its velocity. The units of momentum are therefore kg m/s:

$$\text{momentum} = \text{mass} \times \text{velocity}$$

An object that is not moving would have zero momentum because it has no velocity. However, if two objects have the same mass but different velocities, the object with the



The player with the greatest momentum will be least affected by the collision.

greater velocity will have the greater momentum. Similarly, if two objects have the same velocity but different masses, the object with the greater mass will have the greater momentum. Objects with greater momentum are harder to stop. Consider a cricket ball that has been struck forcefully by the batsman. Even though the ball does not have a very high mass, its velocity is very high, which means it has a large amount of momentum. A cricket ball travelling at high speed resists changes to its speed or direction and is harder to stop than a cricket ball that has just been padded away by the batsman.

Momentum plays a key role when objects collide, making it very important in sport. Every time two objects collide, there is a change in the momentum of each object. The mass of the object remains the same, so the change in momentum is a result of a change in the object's velocity. When two objects collide, both will usually continue moving in the direction of the object with the greatest momentum. For example, if two ice hockey players moving with similar velocities collide, both players will continue moving in the direction of the player with the greater mass.

When a collision occurs, the player or object with the greater momentum will dominate the collision (as shown in the illustration at left). This may be a smaller, lighter player moving with greater velocity, or a larger, heavier player moving with the same velocity as their opponent.

LABORATORY

MOMENTUM OF THE HUMAN BODY

AIM

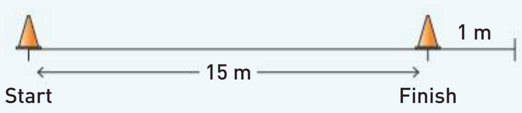
To investigate the amount of momentum the human body possesses

EQUIPMENT

Two witch's hats, line-marking equipment

METHOD

1 Set up the witch's hats 15 metres apart, on a flat surface suitable for sprinting.
2 Mark a distance 1 metre beyond the end of the 15 metres, as shown below.



3 Perform the following activities. At the end of each trial, try to stop within the 1-metre end zone.
- Jog 15 metres at about 50 per cent of maximum pace.
- Run 15 metres at 75 per cent of maximum pace.
- Sprint 15 metres at maximum pace.

DISCUSSION

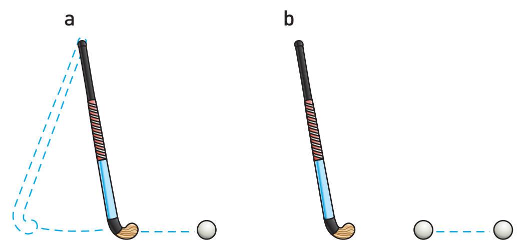
1 In which of the sprints, if any, were you able to stop within the end zone?
2 Explain why it is more difficult to stop when sprinting than when jogging or running.
3 100-metre sprinters often continue running through after the conclusion of the race, whereas marathon runners generally come to a stop as they cross the finish line. Explain, in terms of momentum, why athletes in these two events finish their races so differently.

Conservation of momentum

Momentum is conserved in an isolated system where there are no external forces acting. The principle of conservation of momentum states that the total momentum of the system before the collision is equal to the total momentum after the collision. In sporting collisions, for example, the effects of external forces such as air resistance and friction would be present, but they can be ignored in order to qualitatively determine changes in momentum.

In conservation of momentum, we need to look at the objects involved in the collision before and after impact. Consider a hockey ball placed on the ground, ready to be hit. The momentum of the ball is zero, because it is not moving. The momentum of the hockey stick will be the product of its mass and velocity. The total momentum of the two objects before the collision can be found by adding the two individual momentums together. Therefore, the total momentum before the collision is equal only to the momentum of the stick.

After the collision, the ball moves off very quickly, with a high velocity (V), and the stick slows to zero velocity at the end point of the follow-through. The total momentum after the collision is equal to the momentum of the ball. The principle of conservation of momentum states that the momentum before the collision will equal the momentum after the collision. Because the stick has a greater mass than the ball, the velocity of the stick must have been less than the velocity of the ball after the collision. The diagram below demonstrates this.



Momentum of stick + momentum of ball = momentum of stick + momentum of ball

$M \times v + m \times 0$ **(ball not moving) =** $M \times 0$ **(stick not moving) +** $m \times V$

Total momentum before collision = total momentum after collision

$\therefore Mv = mV$

where M = mass of stick
m = mass of ball
V = velocity of ball
v = velocity of stick

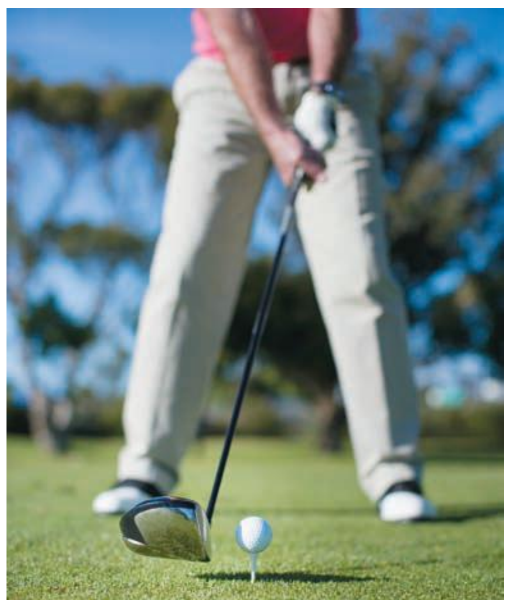
Conservation of momentum

Summation of momentum

When the main objective of a sport is to hit, kick or throw an object or ball as far as possible, it is important that the object is released or struck with maximum velocity. Any movement skill that involves multiple joints requires **summation of momentum** from the beginning of the movement to the end. In golf, for example, to hit the ball as far as possible when driving off the tee, the club head speed must be at its maximum at the point where it connects with the ball. This is a result of the summation of momentum of the lower body, trunk, shoulders, arms and wrists.

By coordinating all of the body segments that are involved in the movement, athletes are able to generate maximum velocity.

Summation of momentum is also known as summation of forces or summation of speed, or the kinetic link principle. Maximum velocity results from momentum being generated in a sequential manner, from the body parts closest to the centre of gravity to those further away. In throwing, for example, the momentum generated in the lower body is transferred to the hips and trunk, then to the shoulders and elbow, and



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For maximum velocity, club head speed must be at its greatest at the point of impact with the ball.

finally to the wrist. This momentum is conserved, so the larger body parts move more slowly (large mass, smaller velocity) and the lighter body parts more quickly (small mass, larger velocity). Highly skilled performance is characterised by well-timed, coordinated movements that result in optimal velocity of the object at impact or release.

CHAPTER CHECK-UP

1 What two factors determine an object's momentum?
2 Which object would be harder to stop: a volleyball that has been set up ready to be spiked, or a baseball that has been struck into the outfield? Justify your answer.
3 Using the information from the diagram on page 50, calculate the momentum of both players before the collision. Which player has the greater momentum? How could the player with less mass increase their momentum?
4 In your own words, explain the principle of conservation of momentum.
5 Use a sporting example to demonstrate your understanding of this principle.
6 Explain how the correct summation of momentum can maximise the release velocity of a ball in an overarm throw.

LABORATORY

SUMMATION OF MOMENTUM

AIM

To investigate how summation of momentum affects the distance a ball can be thrown

EQUIPMENT

Tennis ball, tape measure

METHOD

With a partner, complete the following.

- Sit with your back against a wall, arm by your side, and throw the tennis ball using only your wrist.
- Sit with your back against the wall, and throw the ball using your wrist and elbow.
- Kneel, then use your wrist, elbow and shoulder to throw the ball.
- Stand up, keeping your feet together, and use your trunk, shoulder, elbow and wrist to throw the ball.
- Stand, step forward and throw the ball using your trunk, shoulder, elbow and wrist.

RESULTS

Record the distance of each throw.

DISCUSSION

1 In which trial did the ball cover the greatest distance?
2 Explain your results in relation to summation of momentum.
3 How is momentum conserved when each body segment has a different mass and moves with a different velocity?
4 Young children often throw using only their arm. Outline three teaching points you could use when teaching them to throw correctly.

CONCLUSION

What conclusion can be made about summation of momentum and the increased release velocity of a ball in an overarm throw?

IMPULSE

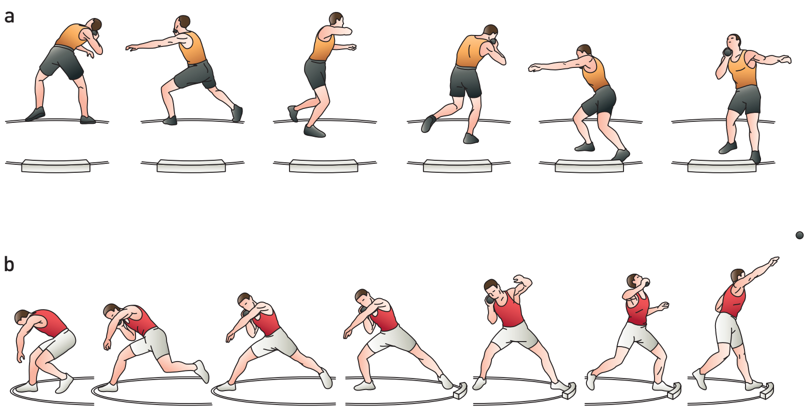
Impulse is equal to the change in momentum of an object. To change the momentum of an object, a force must be applied over a period of time. Impulse is equal to the force applied multiplied by the length of time the force was applied:

$$\text{impulse} = \text{force} \times \text{time}$$

Impulse is an important quantity in sporting situations. Any change in momentum will be the result of a change in velocity, because the mass of the object will remain the same. A change in an object's momentum can result from a large force being applied over a very short period of time or a small force being applied over a longer period of time.

Consider a softball struck with a large force. The ball is in contact with the bat for a fraction of a second. Compare this to a golf ball rolling over the putting green until it comes to an eventual stop. This is a small force applied over a greater period of time. Both experience a change in momentum. In sporting situations, the impulse applied to an object can be manipulated to either increase or decrease the velocity of an object.

Shot-putters and discus throwers, for example, increase the time over which the force is applied to the shot and discus. Compared to a standing technique, the rotational or glide technique used in shot-put increases the time over which the force is applied, which results in a greater impulse being applied and a greater release velocity of the shot.



The (a) rotational and (b) glide techniques used in shot-put allow greater impulse to be applied to the shot.

QUICKVID

Watch videos on rotational technique and glide technique via http://vcepe34.nelsonnet.com.au.

Weblink

PRACTICAL ACTIVITY

DON'T BREAK THE EGG!

AIM

To model the impulse principle through the challenge of catching raw eggs

EQUIPMENT

Uncooked eggs, outside testing area with 5 and 10 metre lengths marked, other equipment as required

METHOD

1 In groups of four or five, devise a strategy for catching uncooked eggs without breaking them when they are thrown underarm from 5 metres and overarm from 10 metres.
2 Prior to carrying out the testing, justify why your method will work.
3 Perform one trial and then make any necessary adjustments to your design. Complete a second trial.

DISCUSSION

1 Which two variables were manipulated in devising your strategy?
2 If the egg did not break, how was this achieved?
3 If the egg did break, what adjustments would need to be made to increase the chance of success?
4 How can your results be applied to injury prevention in sport?

Getty Images/Jonathan Daniel

Soccer players move in the direction of the ball to increase the time over which the force of the ball is applied.

Manipulating impulse can reduce the risk of injury, particularly when catching a fast-moving ball. Increasing the time over which the force is applied decreases the impact force and reduces the likelihood of injury. Athletes achieve this by 'giving' with the ball. That is, once the ball makes contact with the hands or the glove, the hands continue moving in the direction the ball was travelling.

There are many sporting examples of reducing impact forces by increasing the time over which the force is acting. This can be done through the use of equipment, such as wearing gloves in cricket and baseball, or through the use of technique, such as using particular landing techniques. Bending the hips, knees and ankles on landing in volleyball, basketball or netball reduces the impact and the risk of injury. Soccer players move with the direction of the ball when receiving a pass on the chest. This increases the time over which the force is applied, which in turn reduces the force. As a result, the ball will drop to the player's feet rather than bouncing away.

CHAPTER CHECK-UP

1 Baseball and softball fielders wear gloves to protect their hands. Explain how a glove can reduce the impact force on the hand when catching the ball.
2 Young gymnasts are taught to 'ride your motorbike' on landing. Explain how this assists in teaching them the correct position for a safe landing.
3 Outline three teaching points that show the correct application of biomechanical principles that you could use when teaching a young cricketer how to catch.

PRACTICAL ACTIVITY

QUALITATIVE ANALYSIS OF A TEAM SPORT

1 Select a team sport for the whole class to participate in, then select three movement skills from the game to focus your analysis on.
2 Determine the best method for recording the game: a fixed or roving camera, multiple cameras, wide shots, bird's-eye view, etc.
3 As a class, participate in the game and record at least 10 minutes of play for analysis.
4 For each of the three movement skills selected, identify the key biomechanical concepts related to efficient and refined execution of the skill.
5 Analyse the movement skills from the video to identify and diagnose errors in technique or performance outcomes.
6 Using your knowledge of biomechanical principles, suggest ways to improve the movement skills observed.

NEWTON'S LAWS OF MOTION

Newton's three laws of motion have many applications to human movement in physical activity, sport and exercise, and can be used to understand and analyse movement skills and techniques.

Newton's first law

Newton's first law of motion is the law of inertia. The law states:

'A body will remain at rest or in uniform motion in a straight line unless acted upon by an external force.'

A ball projected into the air would continue travelling in a straight line without gravity. Gravity is the external force that acts to bring the ball back to Earth, creating the parabolic path shown on page 47.

Newton's first law of motion can be seen in many sporting situations. A soccer ball won't move from the position it has been placed in until a player applies a force by kicking it. A tennis ball will continue travelling in the direction of the serve until the player at the other end applies a force and hits it back.

Shutterstock.com/bikeriderlondon

The skier will continue through the air until the force of gravity brings them back down to Earth!

Newton's second law

Newton's second law is the law of acceleration. This law allows us to calculate force and acceleration. The law states:

'A force applied to an object will produce a change in motion (acceleration) in the direction of the applied force that is directly proportional to the size of the force.'

The acceleration that occurs is proportional to the force and inversely proportional to the mass of the object. More simply, increased force means increased acceleration, and increased mass means decreased acceleration. Newton's second law allows for quantitative analysis of human movement. If the mass of an object is known and the applied force is known, then the resulting acceleration can be calculated. Alternatively, if the mass is known and the acceleration is known, then the force can be calculated. We use the formula:

$$F = ma$$

where F is force (Newtons), m is mass (kg) and a is acceleration (m/s^2).

For example, the average force exerted on a golf ball during a drive can be calculated if the mass of the ball and change in velocity (acceleration) of the ball are known:

$$F = 0.046 \times 140\,000$$
$$F = 6440 \text{ N}$$

Successful performance in sport isn't always determined by applying maximal force. Skilled performance is often about controlling the amount of force applied. For example, hitting a tennis ball as hard as possible won't necessarily win the point. Skilled athletes judge the force required for accuracy and efficiency in their movements.

Shutterstock.com/Dragon Images

The acceleration of the ball depends on the force applied.

FYI

Research has found that the average force acting on a player's head when heading a ball in soccer can be 900 N! That would be the equivalent of dropping a 90-kg weight on your foot! Yet concussion is rarely caused by intentional heading because the impact is only about 13 N per second and concussion is likely to occur when the impact is 22 N per second.

Source: Kirkendall et al., 2001

Newton's third law

Newton's third law is the law of action–reaction. When two objects come into contact with one another, they exert forces that are equal in size but opposite in direction on each other. The law states:

'For every action there is an equal and opposite reaction.'

FYI

Divers, gymnasts, and long jumpers all utilise Newton's third law. Once in the air, movement of one body part produces a reaction in another part, allowing them to twist and turn!

Getty Images/Masashi Hara

The **action** of the upper body preparing to hit the ball causes a **reaction** of the lower body.

In sporting situations, it is sometimes difficult to see the reaction force. When a tennis ball is hit, it is easy to see the force the racquet applies to the ball because the ball changes direction and accelerates. The reaction force of the ball on the racquet is harder to see. This is because the racquet has a greater mass than the ball, and the change in its acceleration is very small.

It is important to remember that even though the two forces are equal in size and opposite in direction, they don't cancel each other out. The forces are acting on different objects, so the effect of each force will be different.

When running, we push down and back with our feet and the surface pushes up and forward (ground reaction force). Running on a track is easier than running on sand, because the sand dissipates the force applied by the foot, reducing the reaction force.

It is easier to observe Newton's third law when the surface is almost frictionless. For example, if you stand on a skateboard on a smooth surface and throw a medicine ball to a person who is standing on the floor, the action of throwing the ball in one direction will produce a reaction, causing your body to move in the opposite direction.

LABORATORY

LAWS OF MOTION

Complete the following pairs of tasks with a partner. After completing each task, circle the task that was easier to perform, then, based on Newton's laws of motion, explain why this was the case. Find an online table at http://www.nelsonnet.com.au, using your login.

Scaffold

	Paired tasks	Explanation
a	Throw a baseball OR throw a shot put	
b	Kick a soccer ball OR kick a nerf/gator skin ball	
c	Run 20 m on the oval OR run 20 m in the gym	
d	Catch a volleyball that was thrown from 10 m away OR catch a cricket ball that was thrown from 10 m away	
e	Using a softball bat, hit a tennis ball across the oval OR using a softball bat, hit a nerf/gator skin ball across the oval	

Note: try to throw or kick each object with an equal amount of force.

CHAPTER CHECK-UP

1 Describe two ways that a force can affect an object or body.
2 State each of Newton's three laws and give a sporting example to demonstrate your understanding of each law.
3 Using Newton's second law of motion, explain why a medicine ball will not move as quickly as a basketball when they are both thrown with the same force.
4 Identify two sports in which athletes intentionally manipulate the amount of friction between two surfaces. Outline the method used to increase or decrease the friction, and the biomechanical benefit of the change.
5 Provide three examples of action and reaction forces in sport.
6 Investigate the difference between sliding friction and rolling friction. With the information that you find, explain why it is more difficult to ride a bike with flat tyres.

Weblink

Newton's laws of angular motion

How do divers, gymnasts, skaters and trampolinists control the speed of their rotations in the air? Why is it easier to complete a double somersault in the tuck position than in the full layout position? Angular motion obeys the same principles as linear motion; however, they have a slightly different spin!

Newton's laws of motion have a corresponding angular version (see Table 3.1).

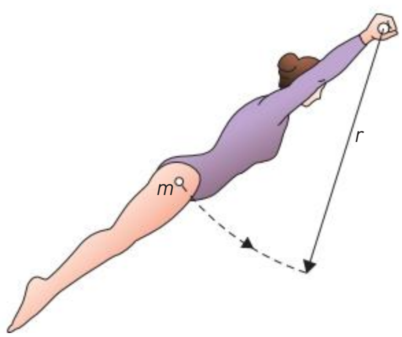
TABLE 3.1 Newton's laws of angular motion

First law of angular motion	The angular momentum of a body remains constant unless acted upon by an external **torque**.
Second law of angular motion	A torque applied to an object will produce a change in angular motion in the direction of the applied torque that is directly proportional to the size of the torque and inversely proportional to the moment of inertia of the object.
Third law of angular motion	For every torque there is an equal and opposite torque.

The amount of angular motion possessed by a body is known as its **angular momentum**. It is the product of the **moment of inertia** and the angular velocity of an object rotating around an axis. The moment of inertia of a body is its tendency to resist changes in its rotary motion. For example, young children will often swing a racquet or bat and continue turning in a full circle. Even elite athletes over-rotate, particularly when rotating through the air or when landing after completing a rotation. This is because a rotating body will continue rotating unless acted upon by an external torque (Newton's first law of angular motion).

How difficult it is to change angular motion depends on the moment of inertia of the body or object. The moment of inertia of a body is the product of the distribution of the mass (m) of the object and the axis about which it rotates:

$$\text{moment of inertia} = \text{mass} \times \text{radius}^2$$



Moment of inertia = mass × radius^2

PRACTICAL ACTIVITY

ANGULAR MOTION IN TOTEM TENNIS

AIM

To investigate angular motion in a game of totem tennis

METHOD

Participate in a game of totem tennis.

QUESTIONS

1 What effect would shortening the length of the rope have on the angular velocity of the ball, the radius of rotation of the ball and the angular momentum of the ball?

2 Explain why the ball is more difficult to hit when it gets wrapped around the pole.

3 a Predict what would happen if the rope was lengthened.

b Would it make the game easier or harder to play? Explain.

Getty Images/ David Freund

Junior sports equipment is modified to make it easier for young players to use.

FYI

Increasing the mass of a tennis racquet does not necessarily lead to an increase in ball velocity. Studies have shown that a 33% increase in mass of the racquet produced only a 5% increase in ball speed, whereas a 33% increase in racquet speed produced a 31% increase in ball speed. Players who are able to rotate a lighter racquet more quickly will increase the ball speed far more than a player with a heavier racquet who swings more slowly.

The location of the mass is important in reducing or increasing an object's moment of inertia. An object whose mass is located closer to the axis of rotation is much easier to rotate than one whose mass is distributed further away. This explains why juniors will hold a racquet further up the handle, effectively reducing the moment of inertia and making it easier to swing. It also explains why it is easier to complete somersaults in the tuck position.

Sporting equipment modified for juniors is usually lighter and shorter, effectively reducing both the mass and radius of rotation and the overall moment of inertia. This makes the club or bat much easier to swing and control. A young child swinging a bat that is too big for them is unlikely to connect with the ball and will often keep rotating after the follow-through in the direction of the swing, because the momentum of the bat is so great.

Many athletes control the distribution of mass of the human body in order to increase or decrease their rate of rotation. For example, springboard divers bring their arms in towards their body when performing a twist. This decreases the moment of inertia, as the mass is now concentrated closer to the radius of rotation. This results in an increase in the rate of rotation. Similarly, by pulling their bodies into a tight tuck position, they reduce their moment of inertia, meaning the rotation will be much faster than in a pike position.

PRACTICAL ACTIVITY

ROTATION OF A BODY

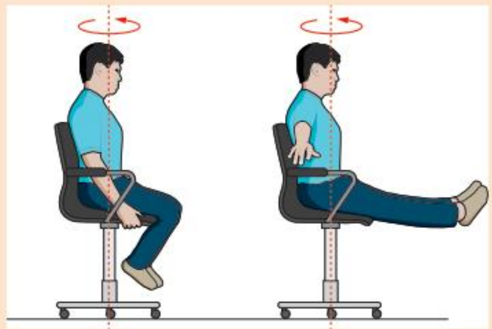
ROTATION OF A BODY

AIM

To investigate the effect of changing the distribution of mass on the rotation of a body

EQUIPMENT

A swivel chair or stool, or a smooth surface such as a table top or wooden floor



METHOD

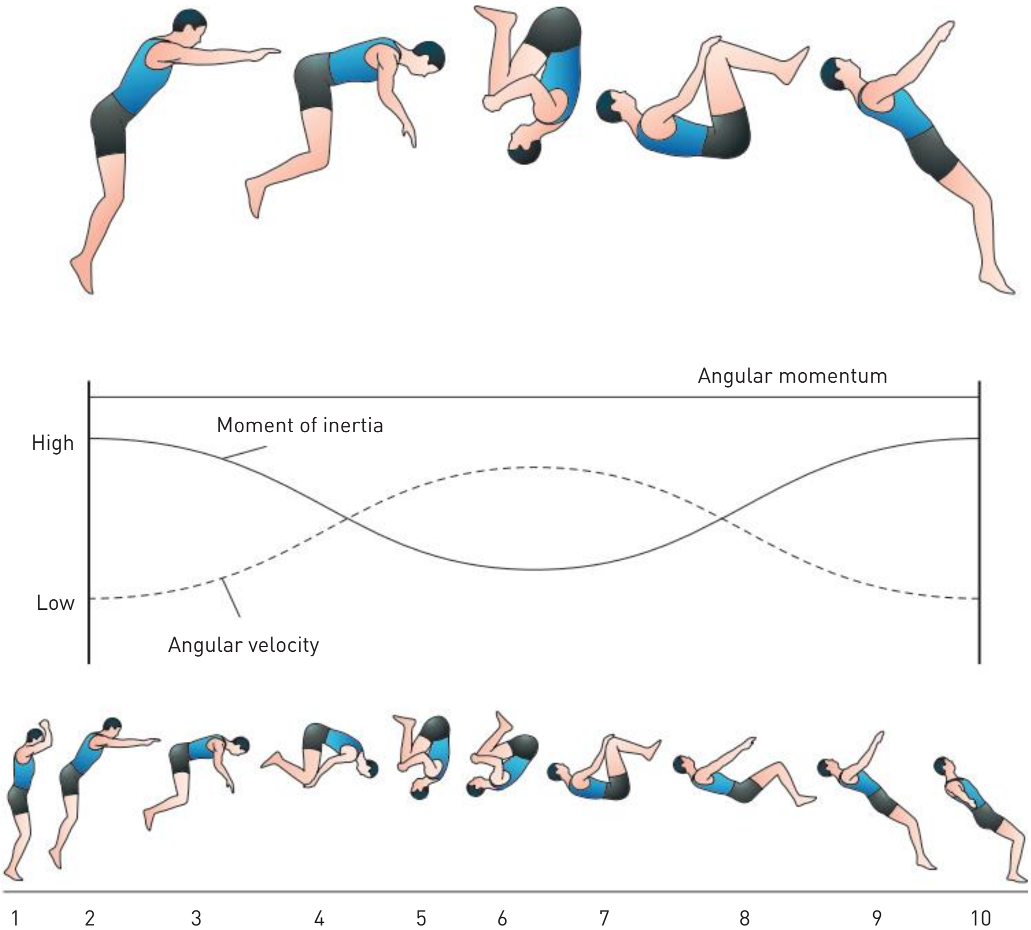
1 Work in pairs. Sit on a swivel chair or stool with your arms and legs tucked in close to your body, then have your partner spin you around.
2 Extend your arms and legs and have your partner spin you around again.

DISCUSSION

1 In which position did you spin faster?
2 How is the distribution of mass related to spinning speed?
3 When was the moment of inertia greatest? When was it lowest? How did you control the moment of inertia? Which variable did you change?
4 How do divers and gymnasts use this technique to control their movements?
5 A characteristic of elite sprinters is flexion of the knee joint in the swing phase of each stride. Explain how this would increase a sprinter's performance.

Conservation of angular momentum

Angular momentum is conserved when the body is in flight. This is a useful principle when analysing human movement in activities such as diving, trampolining and gymnastics. If the total angular momentum of a body is conserved, and the mass of the body cannot be changed, then there must be a trade-off between angular velocity and moment of inertia, in particular the radius of rotation. The diagram on page 60 illustrates this relationship. As the gymnast moves into the tuck position, the moment of inertia decreases and the angular velocity increases, but the total angular momentum remains constant throughout the whole movement.



The relationship between moment of inertia and angular velocity. The angular momentum is conserved, so remains constant throughout the movement.

REAL WORLD APPLICATION

Long jump

To maximise performance in long jump, athletes need to maximise both flight time (vertical velocity) and distance (horizontal velocity). However, it is not possible to maximise both, so athletes compromise. Horizontal velocity is generated through the run up, but vertical velocity is generated at take-off, when the athlete pushes down on the board. The resulting ground reaction force is slightly eccentric, causing some forward angular momentum. If the athlete does not control this momentum, they will continue to rotate forward and land face down in the sand! Athletes rotate their arms and legs in a technique known as the 'hitch-kick'. This keeps the trunk upright during flight, and forward in preparation for landing (so they don't fall backwards when they land). This technique utilises a number of biomechanical principles to improve and refine the athlete's performance.

The hitch-kick allows athletes to use the angular momentum generated at take-off.

QUICKVID

Watch a video of a long jumper in action via http://vcepe34.nelsonnet.com.au

Weblink

CHAPTER CHECK-UP

1 A gymnast performs three different somersault dismounts off a beam. In which of the following positions will the moment of inertia be the greatest? In which position will rotation be fastest?
   A Pike
   B Tuck
   C Layout
2 Provide a sporting example that demonstrates the correct application of each of Newton's three laws of angular motion.
3 How can the moment of inertia of a golf club be increased or decreased? Outline the advantages and disadvantages of selecting a longer club.
4 Describe the changes in angular momentum, angular velocity and moment of inertia as the gymnast moves through each of the positions listed in question 1.

QUICKVID

Go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 61 is a video interview wiith Dr Elaine Tor, a biomechanist from the Victorian Institute of Sport, discussing the role of biomechanics in sport.

Video

QUICKVID

Watch a clear explanation and summary of momentum by one of the authors. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for chapter 3, page 61 and choose the 'interactive'.

Video

CHAPTER SUMMARY

- Biomechanics is the study of living things from a mechanical perspective. It is the physics of human movement.
- Biomechanics helps us to analyse and understand human movement to improve performance in physical activity, sport and exercise.
- Biomechanists use many different tools to record and measure data in laboratories and in the field.
- A force is a push or pull that produces motion or changes the motion of an object.
- Forces in the body are generated by muscles. External forces that affect motion of the body are gravity, air and water resistance, friction and reaction forces. Objects and opponents also apply forces to the body.
- Friction is a force that occurs between two surfaces in contact with each other. Friction always opposes the motion of an object and can be increased or decreased depending on the desired outcome.
- Mass is the amount of matter an object is made up of.
- Weight is a force exerted on the body by gravity. Weight equals mass × acceleration due to gravity.
- Inertia is the tendency of a body to resist change in its state of motion. An object requires a force to start it moving and another force to stop it once it is moving. Inertia is related to mass. The greater the mass, the greater the inertia of the object.
- Momentum is equal to mass × velocity. The greater the mass or velocity, the more momentum a body has and the harder it is to stop.
- Momentum is conserved when objects collide.
- Summation of momentum is the transfer of momentum from the larger, slower-moving body parts to the smaller, faster-moving body parts to maximise the release velocity of the object.
- Impulse is equal to a change in the momentum of an object. Impulse equals the force applied × the time over which it is applied.
- A force absorbed over a larger period of time reduces the risk of injury to an athlete.
- Newton's first law of motion states that a body will remain at rest or continue in a state of constant motion unless acted upon by an external force.
- Newton's second law of motion states that a force applied to an object will produce a change in motion (acceleration) in the direction of the applied force that is directly proportional to the size of the force.
- Newton's third law of motion states that for every action there is an equal and opposite reaction.
- A body rotating will have angular momentum and obey Newton's laws of angular motion. Angular momentum is the moment of inertia × the angular velocity of a body.
- Moment of inertia is the tendency of an object to resist change in its rotary motion and is determined by the length of the radius and the mass of the object.

CHAPTER REVIEW

Multiple-choice questions

1 Of the following measurement tools, which would be useful in performing a qualitative analysis of motion?
  - A force platform and computer interface
  - B digitised video footage
  - C manual and/or electrogoniometers
  - D observation and video footage

2 Which one or more of the following would decrease the friction between two contact surfaces?
  - A the use of magnesium chalk in gymnastics
  - B screw-in stops in football boots
  - C synovial fluid in a joint
  - D waxing a surfboard

3 Which of the following is an example of Newton's first law of motion in sport?
  - A the observation that a football kicked with greater force will travel faster
  - B forward rotation of the lower body when performing a spike in volleyball
  - C a golf ball sitting on a tee
  - D the friction between the ground and a runner's shoe

4 The angular momentum of a gymnast performing a double somersault dismount will be
  - A highest during the tuck phase.
  - B highest during the layout phase.
  - C lowest during the layout phase.
  - D constant throughout the movement.

Short-answer questions

5 Estimate the momentum possessed by each of the following objects and rank them from the most momentum to the least.
  - a tennis ball served by an elite player
  - a football handballed to another player
  - a horse and jockey racing down the straight
  - a netball centre walking back to position

6 a In baseball, what is the advantage of being able to run through first base?
  b What is the biomechanical principle demonstrated in this example?

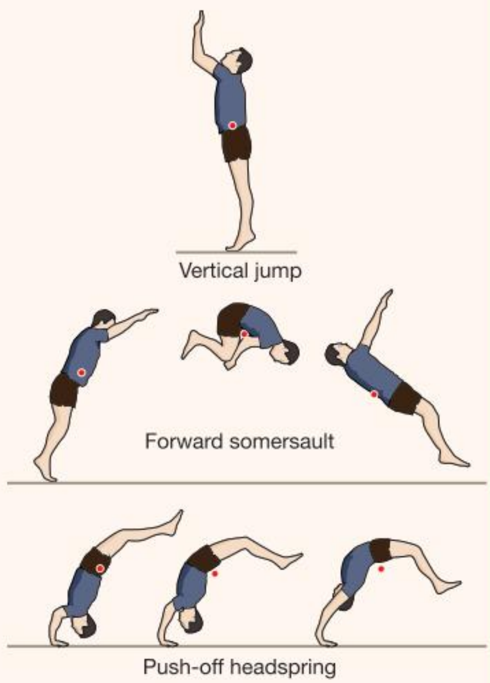
7 Explain why a junior golfer would not use a full-length club.

8 Compare and contrast the techniques used by an elite and a novice shot-putter. Outline the biomechanical principles that would typically be applied by the elite athlete but not by the novice.

9 Using a sporting example, explain the principle of conservation of momentum.

10 How could the coach of a junior gymnastics club use their knowledge of biomechanics to improve the technique of the gymnasts in the following activities?
  - a tumbling
  - b landing

11 On the diagrams below, show the direction of the ground reaction forces in a:
  - a vertical jump
  - b forward somersault
  - c push-off headspring.



12 In sports such as pole vault, high jump and long jump, the landing surface is different from the surface the athlete takes off from. Explain why mats and sand are used as landing surfaces in these sports.

CHAPTER 4

KINEMATIC CONCEPTS OF HUMAN MOVEMENT

Key knowledge

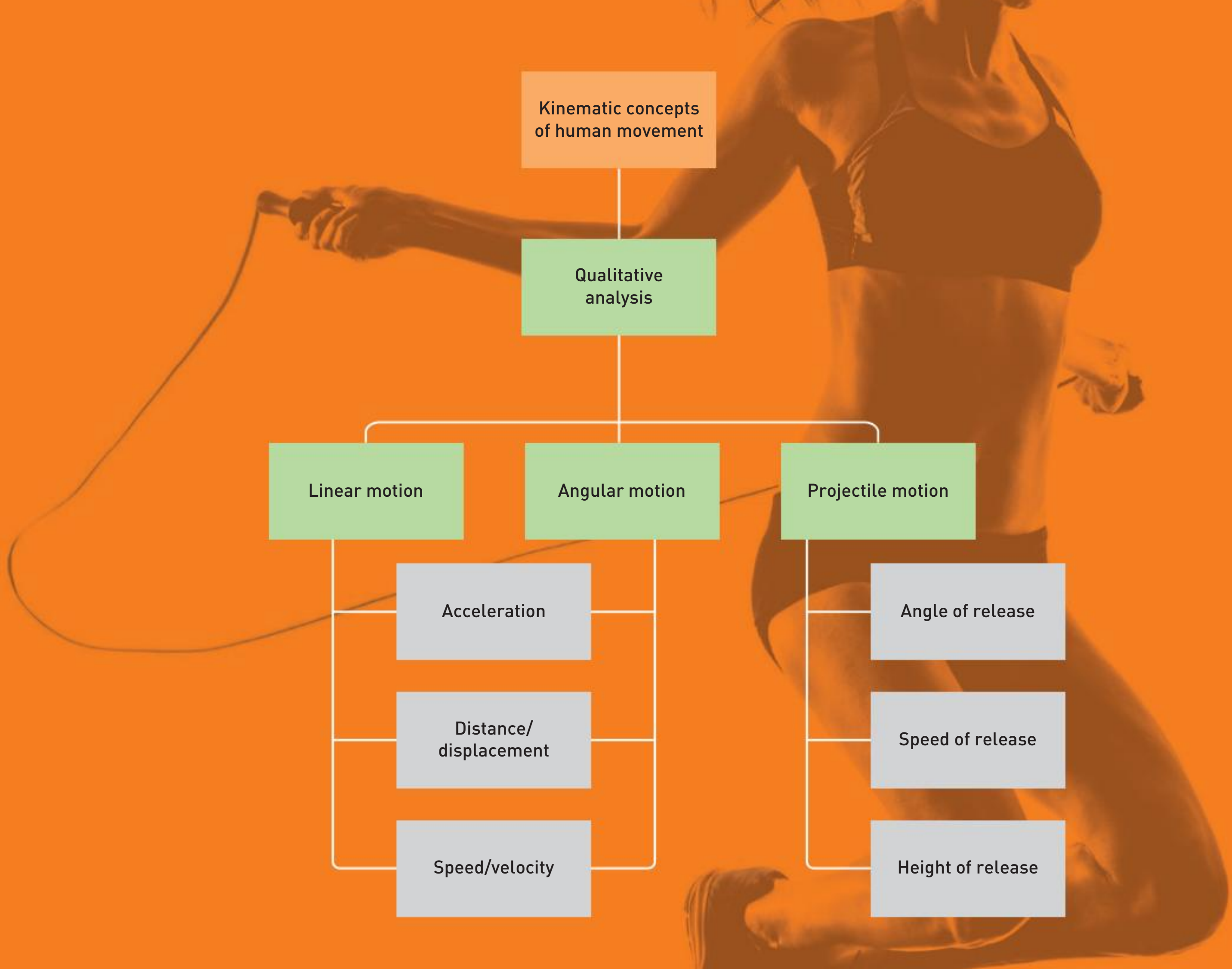
» biomechanical principles for analysis of human movement including:
- angular and linear kinematic concepts of human movement: distance, displacement, speed, velocity, acceleration and projectile motion (height, angle and speed of release)

Key skills

» perform a qualitative analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

» analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills in a coaching context

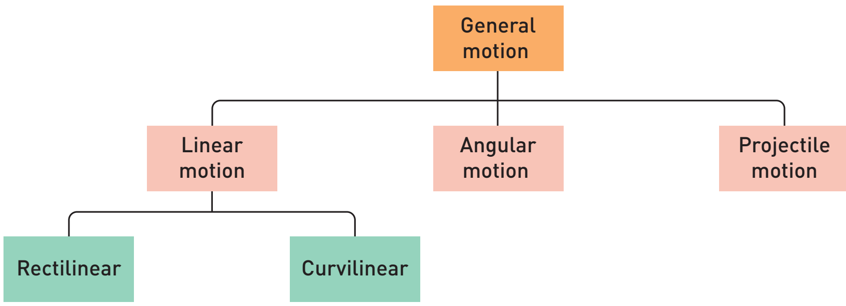
Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



iStock.com/OSTILL

MOTION

Human movement involves many different types of motion. For example, a cricketer bowling the ball must first run in a straight line, using a combination of hip, knee and ankle movement. To bowl the ball, rotation of the shoulder, elbow and wrist joints is required. This complex combination of movements is called **general motion**. Nearly all human movement is considered general motion, which is a combination of both **linear** and **angular motion**. If the body or an object such as the ball leaves the ground, it will then experience **projectile motion**.



Types of motion in human movement

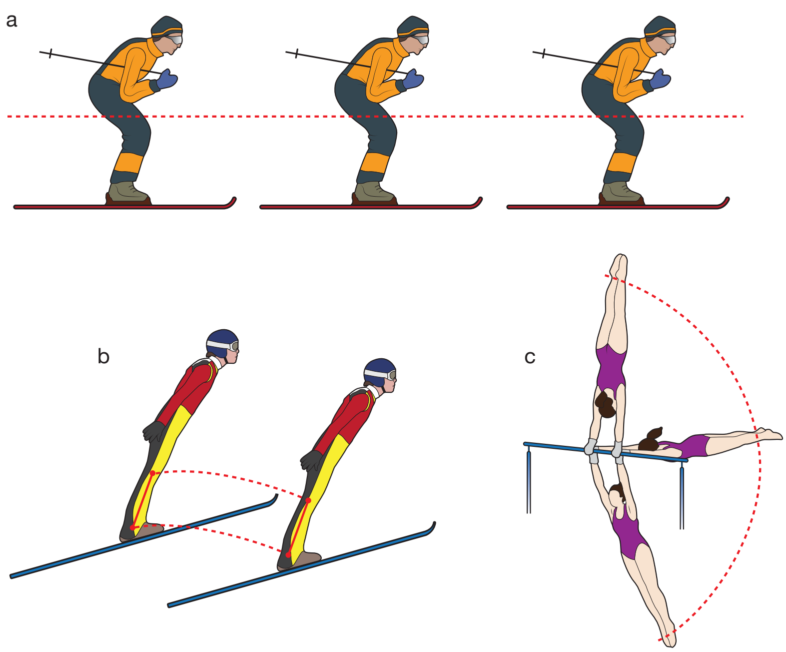
When looking at a skill or movement pattern from a biomechanical perspective, it is often easiest to break the skill down into its linear and angular components and analyse them individually. Linear motion occurs when all the body parts are moving at the same speed in the same direction along a curved or straight line. If the line is straight, the motion is called rectilinear. If the line is curved, the motion is called curvilinear. Angular motion involves movement around a central axis. The diagram above shows some examples of the different types of motion. Projectile motion will be looked at later in the chapter (see page 76).

LINEAR MOTION

As stated above, linear motion is the movement of a body along a straight or curved path where all body parts move in the same direction at the same speed. Describing this motion can be done by looking at the distance, displacement, speed, velocity and acceleration of the body. These characteristics are quantitative, which means they can be measured and/or calculated.

Linear distance and displacement

Distance and **displacement** both measure how far a body has travelled. However, they are quite different. Distance measures the path travelled from start to finish, regardless of direction. A netballer who weaves, dodges,



Types of motion: (a) rectilinear, (b) curvilinear, (c) angular

REAL WORLD APPLICATION

Wheelchair racing

Alamy Stock Photo/Calamy stock images

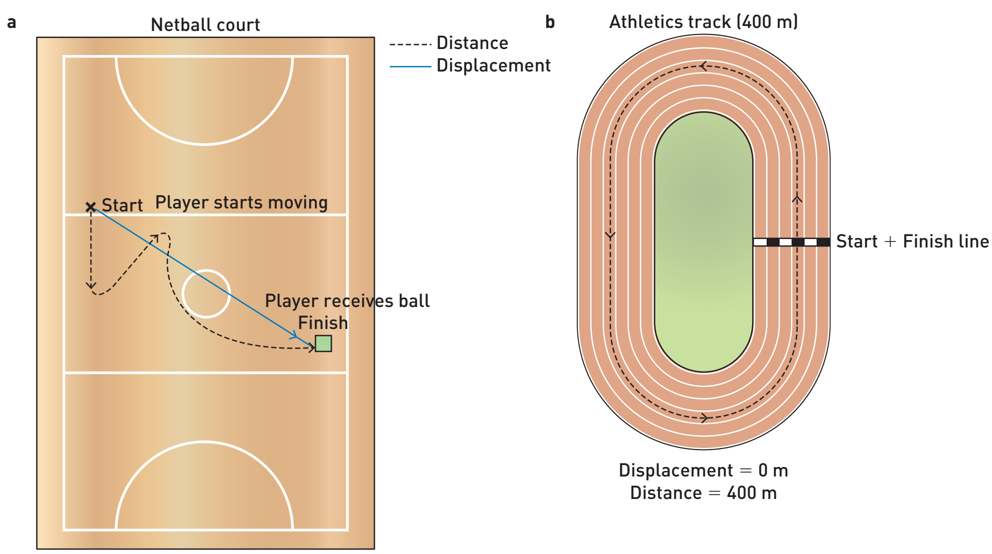
The angular motion of the arms and wheels creates linear motion of both the athlete and the wheelchair.

Wheelchair racing is an excellent example of the combination of linear and angular motion. We see angular motion in the repetitive rotating action of the athlete's arms as they push the wheel rim, and in the resulting rotation of the wheels. The rotation of the wheels carries the athlete and the wheelchair in a straight line. This is an example of linear motion.

The combination of angular and linear motion is general motion.

baulks and then sprints forward to receive the ball may cover 15 metres in total, so the distance travelled is 15 metres.

Displacement is defined as change of position – how far it is from the initial position to the final position. When measuring displacement, the direction of motion is important. The displacement of the netballer in the previous example would be measured in a straight line from where they started to where they finished. Consider a running race on an athletics track. The distance covered by the runners is 400 metres but the displacement is 0 metres, because the start and finish points of the race are in the same place.



Distance and displacement both measure how far an athlete has travelled, either in total or from their starting point.

Either distance or displacement can be used to describe motion, depending on which will provide the most useful information. In many sporting situations, distance is a more important variable than displacement. A marathon runner will be less interested in their displacement than the distance they cover, because many marathons start and finish at a similar point. An Australian Rules footballer would be more interested in the total distance covered in the game.

Linear speed and velocity

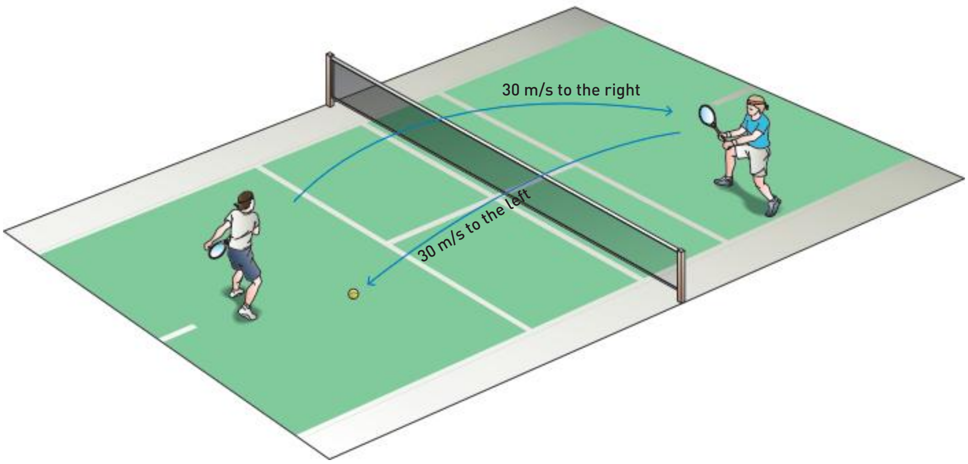
The terms 'speed' and 'velocity' are often used interchangeably, but they mean very different things. **Speed** is defined as the ratio of the distance covered to the time taken (distance divided by time).

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Velocity is the ratio of displacement, or change in position, to the time taken (displacement divided by time). Velocity has both a size and a direction.

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

The units for speed and velocity are metres per second or m/s. A change in velocity could be a change in speed, a change in direction, or both. A tennis ball hit at 30 m/s over the net and then returned at 30 m/s over the net has the same speed but has changed velocity because it has changed direction.



A tennis ball hit in one direction over the net and then returned in the opposite direction has changed velocity, even though it has not changed speed.

Analysis of the speed of human movement is important in sports such as swimming and athletics, where time is the determinant of a successful performance.

DATA ANALYSIS

TABLE 4.1 5-kilometre split times and average speeds for each split for a female marathon runner

Distance (km)	Time (min:sec)	5 km split time (min:sec)	Average speed in each 5 km split (m/s)
5	15:47	15:47	5.28
10	32:17	16:30	5.05
15	48:34	16:17	5.12
20	65:55	16:21	5.10
25	81:03	16:08	5.17
30	97:27	16:24	5.08
35	114:07	16:40	5.00
40	130:26	16:19	5.11
42.195*	137:42*	7:16*	5.03*

*The time for the final 2.195 km of the race was used to calculate the average speed of 5.03 m/s.

1. Using the information in the table above, calculate the average speed for the whole race.
2. What can be said about the running speed of the athlete throughout the race? Use data to support your answer.
3. What was the average speed of the race in km/h?
4. Predict what a distance–time graph and a speed–time graph would look like for this event.
5. Marathons often have pace runners (the runners wearing 'Pace' on their bibs in the photo below) that help runners maintain an even pace for the duration of the race and finish by a target time. If the pace runners shown below aim to finish the marathon (42.195 km) in a time of 3 hours, 45 minutes, what pace will they need to set to achieve this target time?

Alamy Stock Photo/Simon Balson

Linear acceleration

Sport commentators often refer to an athlete's **acceleration**: 'He has accelerated out of the blocks'; 'She accelerated past her opposition to receive the ball'. Acceleration refers to a change in velocity in a given period of time (change in velocity divided by change in time). It can be a positive or negative figure – speeding up or slowing down. Acceleration is measured in units of m/s^2.

The ability to accelerate or decelerate is important in sport: A 10 000-metre runner who can accelerate in the last 1000 metres to catch and pass the lead runner has a distinct advantage. Decelerating into turns while mountain biking allows riders to maintain balance. Being able to accelerate in the first part of a sprint means the athlete can reach their top speed quickly, and then maintain it until the end of the race.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

It is important to remember that when acceleration equals zero, this does not mean that the athlete, the ball or the racquet, for example, has stopped moving. It just means that it is no longer speeding up or slowing down. An athlete or an object moving with zero acceleration will have a constant velocity. For example, a sprinter will accelerate out of the blocks, then try to maintain their maximum speed before decelerating or slowing down, because of fatigue, towards the finish line.

DATA ANALYSIS

THE 100-METRE SPRINT

Analysis of speed variation during short sprints such as the 100- and 200-metre sprints can provide coaches with useful performance information.

Key performance indicators for sprints are:

- time taken to achieve maximum speed
- maximum speed
- length of time that maximum speed is maintained
- difference between maximum speed and speed at the finish.

Usain Bolt ran the 100-metre sprint in a world-record time of 9.58 seconds at the IAAF World Championships in 2009. Table 4.2 shows the times for each 10-metre split. From this data, his average speeds (in km/h) were calculated and are graphed on the following page.

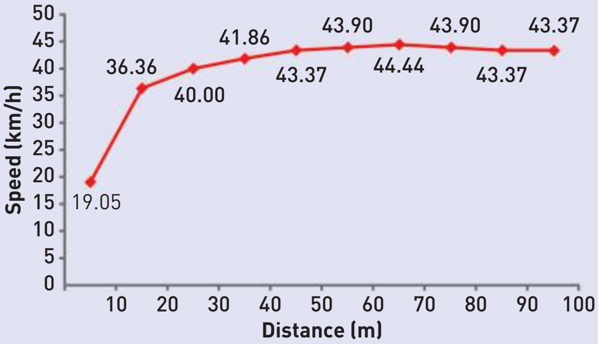
TABLE 4.2 Usain Bolt's times in the 100-metre sprint in 2009

Distance (m)	Time (s)	Split times
10	1.89	1.89
20	2.88	0.99
30	3.78	0.90
40	4.64	0.86
50	5.47	0.83
60	6.29	0.82
70	7.10	0.81
80	7.92	0.82
90	8.75	0.83
100	9.58	0.83

QUICKVID

You can watch Bolt's record-breaking run via http://vcepe34.nelsonnet.com.au

Weblink



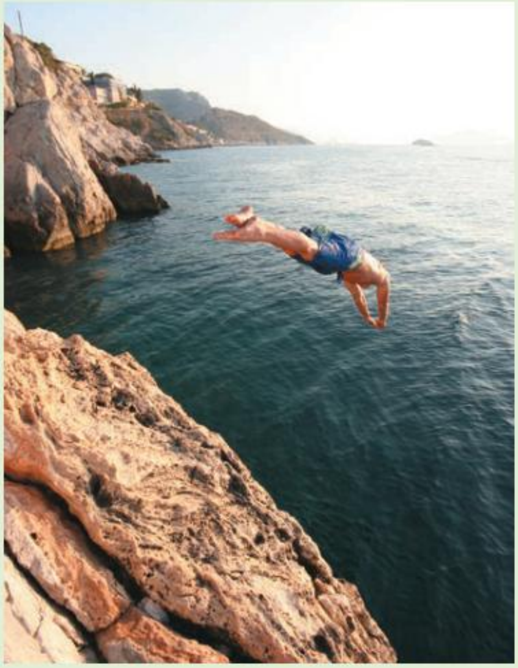
Graph of Usain Bolt's average speeds in the 100-metre sprint

QUESTIONS

Use the data in the table (on previous page) and the graph at left to answer the following questions.

1 What distance did the race cover? Is this different from the displacement? Explain.
2 What was Bolt's maximum speed? How long did it take him to achieve this speed?
3 Calculate the speed in m/s of each 10-metre split. (Remember: speed = distance/time.) You could use an Excel spreadsheet or similar to calculate the speeds.
4 Calculate the average speed for the race. Why is the average speed different from the individual split speeds?
5 Define the term 'constant velocity'. Support your answer with data from the table or the graph. Which predictor of performance does this data provide information on?
6 In which 10-metre split was the runner's acceleration the greatest?
7 What is the difference between Bolt's maximum speed and his final speed? Why is this a significant predictor of race performance?
8 From the graph, identify in which periods Bolt's acceleration was positive, zero and negative.
9 With your knowledge of acceleration and speed, suggest a suitable race strategy for a 100-metre runner.

CHAPTER CHECK-UP



iStock.com/Thomas TrAtscher

Cliff divers dive from great heights, hitting the water at high velocities.

Scaffold

1 Using a triathlon event as an example, define the terms 'distance' and 'displacement'.
2 In sprinting, runners can run into a headwind or with a tailwind. Explain why the term 'velocity' would be used rather than 'speed' when commenting on the effect of wind on an athlete's performance.
3 A runner completes the first lap of an 800-metre race (run on a 400-metre track) in 54 seconds, and the second lap in 52 seconds. Calculate the average speed for each lap, and for the whole race. Record your calculations in a table.

Lap	Time (s)	Distance (m)	Average speed (m/s)
1			
2			
Total time			

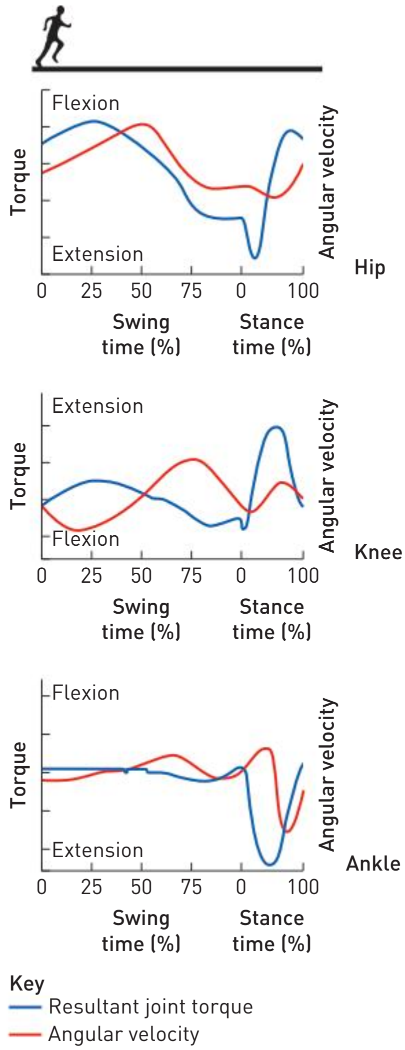
4 A diver leaving the 10-metre platform will enter the water at approximately 14 m/s (52 km/h). Discuss the relationship between distance, change in velocity and acceleration in platform diving.
5 Cliff divers can dive from as high as 45 metres above the ocean. Calculate the velocity at which they will strike the water if the time taken to hit the water is 3 seconds. Include correct units in your answer.

ANGULAR MOTION

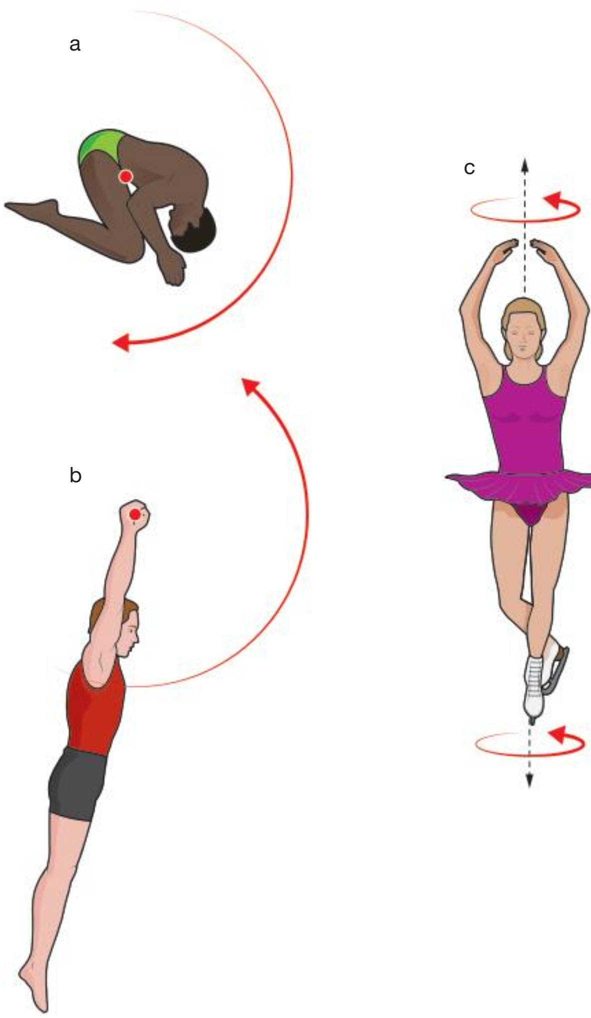
Angular motion is a component of general motion and involves rotation around a central axis or a fixed point. Many linear body movements such as walking, running, cycling and rowing result from the angular motion of the body parts. Angular motion of the limbs results in linear motion of the whole body. For example, when we run, the thigh rotates around the hip axis, the lower leg rotates around the knee axis and the foot rotates around the ankle axis; these in turn cause linear motion of the body. That is, the body moves forward in a straight line. The graphs at right demonstrate the relationship between the joint **torques** of the hip, knee and ankle and the angular velocity during running.

The axis of rotation can be real or imaginary, internal or external. Examples of internal axes are the joints of the body. An external axis could be the centre of gravity. This is also an example of an imaginary axis (diagram a). The body rotates around the imaginary point. The axis of rotation is external when performing a rotation on a high bar, where the axis is the bar itself – in other words, it is a real axis (diagram b).

Angular motion can be described using the same measurements as for linear motion, except we now refer to angular distance and displacement, angular speed and velocity and angular acceleration.



The relationship between the joint torques and angular velocity in running

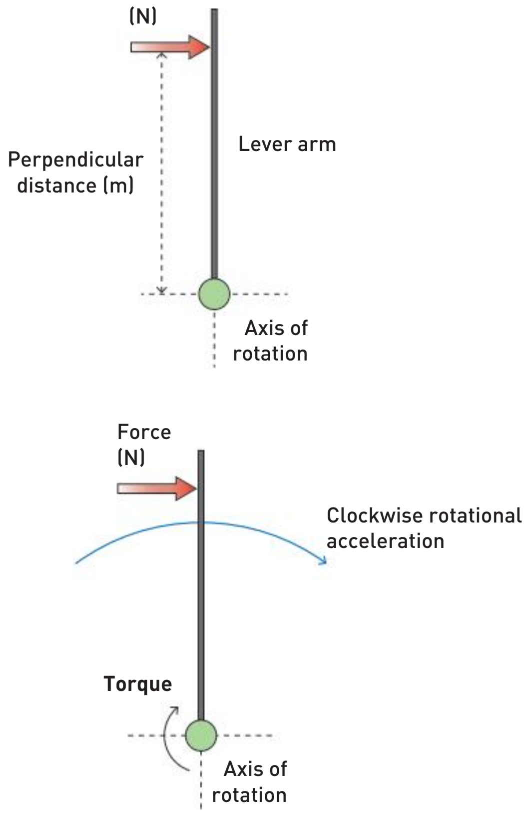


Angular motion: (a) rotation around an imaginary external axis, (b) rotation around a real external axis, (c) rotation around an imaginary internal vertical axis

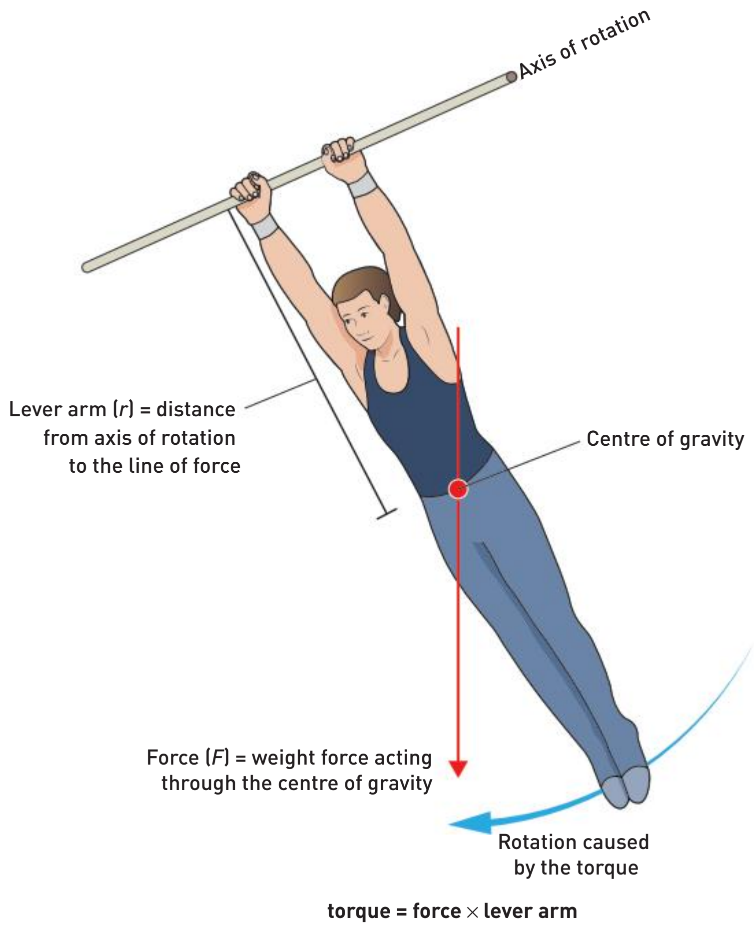
Torque

Angular motion is caused by an **eccentric force**, which is a force that does not act through an object's centre of gravity. Eccentric forces cause objects to rotate and move forwards. This effect is known as torque, which refers to the tendency of an object to rotate. Torque, sometimes called moment of force, can be calculated by multiplying the force by the lever arm of the force. The lever arm is the perpendicular distance from the axis of rotation to the line of action of the force. Torques cause rotation about an axis and cause angular acceleration; the greater the torque, the greater the angular acceleration.

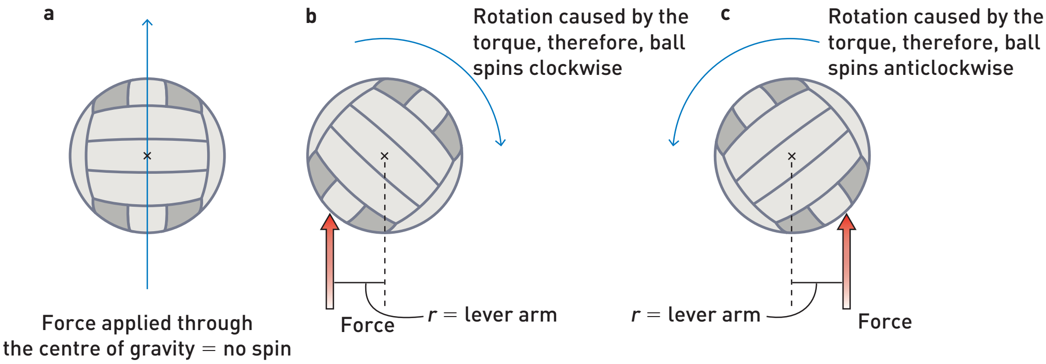
The size of the torque is determined by two factors: the length of the lever arm and the size of the applied force. Increasing the rotation of an object can be beneficial in sport. Spin is created by the athlete applying an eccentric force. If the force applied to a ball is not directly through its centre of gravity, then it will rotate or spin, as shown in the diagram at the top of page 73.



Torque: the force applied at a distance from the axis causes a turning effect.



Torque will cause the gymnast to rotate around the bar.



Eccentric forces cause objects to spin.

Eccentric forces also cause objects to deviate from their original path. Bouncing straight up and down on a trampoline is achieved by applying the force through the centre of gravity. However, if an eccentric force is applied, the resulting motion will be angular, a torque will be created and the trampolinist will rotate. Elite trampolinists will control and use this rotation to initiate different movements, such as somersaults. However, young children on a trampoline often fly off in different directions because they have not landed on the mat with their weight over their feet.

Shutterstock.com/Libor Fousek

Enclosed trampolines are safer for children

PRACTICAL ACTIVITY

GENERATING SPIN IN BALL SPORTS

Participate in a game of volleyball. Experiment with different types of overhead serves by striking the ball at different angles.

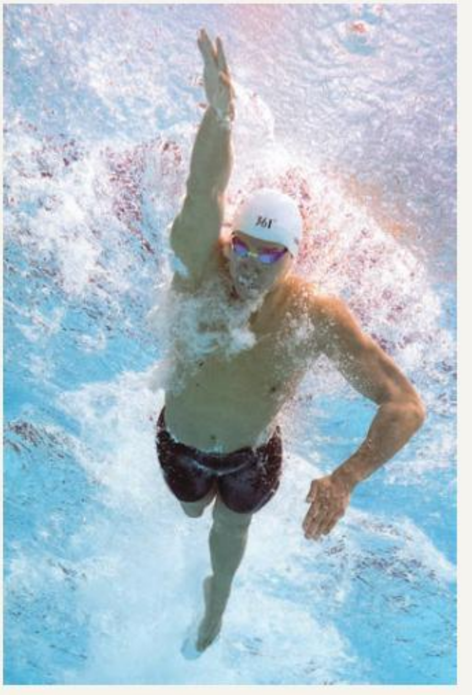
From your observations in the game, answer the following questions.

1 Explain, in terms of application of force, how you could cause the ball to rotate in different directions and generate side spin, top spin and back spin.
2 Think about how spin is generated in other sports. When is spin beneficial in sport?
3 Mis-hits and poorly cued kicks are often a result of an eccentric force. Using a specific sporting example, explain what happens when a force is not applied through an object's centre of gravity.

REAL WORLD APPLICATION

Bent elbows in swimming

Olympic freestyle swimmers have used biomechanical analysis to view and modify their technique. Increased understanding of biomechanical principles such as torque has led to improved performance. Elite level swimmers now use a very pronounced bent elbow action in the pull phase of freestyle. Previously, they used an extended straight arm to pull through the water, thinking that the greater lever length would generate more force and propulsion. However, this placed excessive torque and loads on the shoulder joint, making it susceptible to injury. The bent elbow action allows swimmers to pull through the water with maximum propulsion while protecting the shoulder joint. The swimmer shown at right demonstrates this technique.

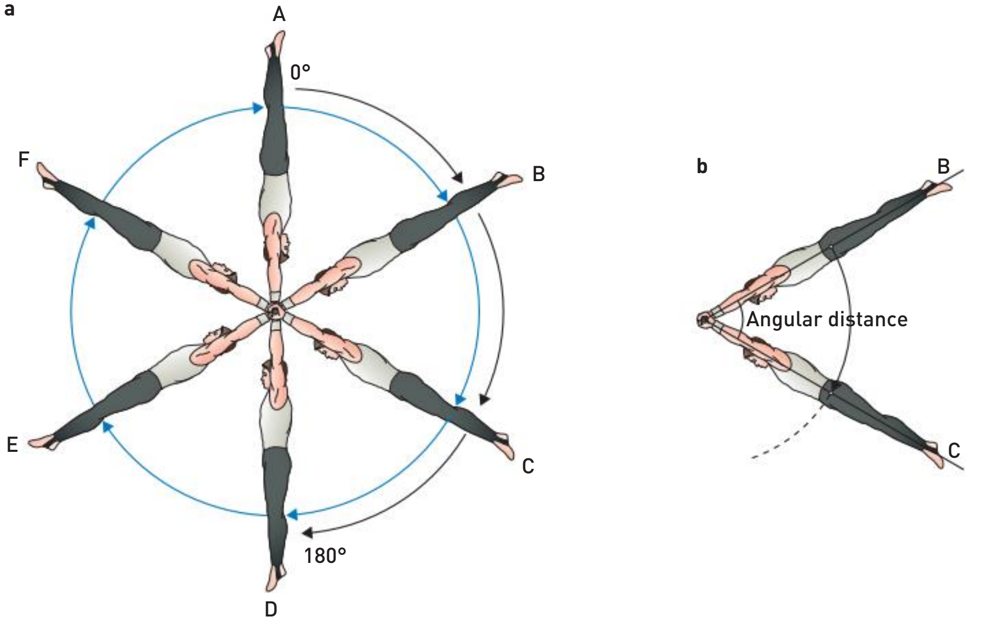


Getty Images/FRANCOIS XAVIER MARIT

Increased elbow flexion increases propulsion in freestyle swimming. Notice the bent elbow position at the beginning of the pull phase of the stroke.

Angular distance and displacement

The **angular distance** covered by a rotating body is the sum of all of the angular changes the body undergoes. For a gymnast performing 1½ giant circles on the high bar, as shown in (a) below, the angular distance covered is the sum of the angular distance of one full rotation (360°) plus half a rotation (180°). The total angular distance is 540°.



(a) Angular displacement and (b) angular distance

The **angular displacement** is the difference between the initial and the final angular position of an object; the direction of the angular motion needs to be considered.

For the example of the gymnast performing 1½ giant circles, the initial position is taken as 0°, which is point A in the first diagram on previous page. The final position is point D, so the angular displacement is 180°.

Angular speed and velocity

Angular speed is defined as the angular distance covered divided by the time taken to complete the motion. **Angular velocity** is the rate of change of the angular displacement of a body over time. Angular speed and velocity are measured in degrees per second. If the gymnast in the previous example took 3 seconds to complete the 1½ giant circles, the angular speed would be 180° per second, but the angular velocity would be 60° per second, in a clockwise direction.

Speed of rotation is important in sports such as diving, gymnastics and dancing, where athletes need to complete rotations during limited flight time. Studies have shown that an ice skater performing a triple axel (3½ rotations, see right), will increase their angular velocity to more than 1800° per second. Angular velocities increase with the difficulty of the skill being performed. The angular velocity required to complete a single rotation is not as great as the angular velocity required to complete a triple rotation. (The methods that athletes use to increase their speed of rotation were discussed in chapter 3.) Notice that the figure skater shown at right has decreased her moment of inertia by crossing her legs and bringing her arms in close to her body so that she can spin faster and complete the rotation before landing.

In order to increase a ball's linear velocity when it is thrown, it is important to increase the angular velocity of each body segment used in the throwing motion, as this will increase the final velocity at the point of release. The relationship between linear and angular velocity is given by:

linear velocity = radius of rotation × angular velocity.

Alamy Stock Photo/ITAR-TASS Photo Agency

What is the relationship between increasing the number of rotations performed and the speed of the rotations?

The summation of speed principle suggests that movement is initiated from the larger, slower-moving body parts to the smaller, faster-moving body parts (see chapter 3). As each part of the body approaches extension, which is the point at which both linear and angular velocities are maximal, the next body part begins its movement. Highly skilled athletes have precise coordination, which leads to exceptional timing of the movement of each body segment.

When hitting a ball, increasing the radius of rotation results in an increase in the linear velocity imparted to the ball. The most practical way to do this is to increase the length of the implement being used. Linear velocity is equal to the radius of rotation multiplied by the angular velocity. All other aspects being equal, the greater the radius of rotation, the further the ball being struck will travel. This explains why drivers in golf are longer than 9 irons, why elite players prefer longer baseball bats and why a tennis racquet can hit a ball further than a bat used to play bat tennis. However, if the longer bat or racquet is too heavy to be swung as quickly as a shorter bat or racquet, the angular velocity will be compromised by the increase in radius of rotation. (Lever length will be discussed in more detail in chapter 5.)

FYI

The angular velocity of the elbow joint in Major League baseball pitchers has been measured at 2320° per second.

Angular acceleration

Angular acceleration is the rate of change of angular velocity, or how quickly a body changes its angular position. Angular acceleration can be positive, negative or zero. Changes in angular acceleration can be made by changing the size or direction of the acceleration. Zero acceleration means that the angular velocity of the body is constant – it is not speeding up or slowing down. The units of angular acceleration are degrees per second squared ($°/s^2$).

LABORATORY

BIOMECHANICS OF A VERTICAL JUMP AND STANDING BROAD JUMP

Work in small groups. Two students from each group will perform a vertical jump (one at a time). Other members of the group should observe the two students from a side-on position. Video their performance (to replay), or have each subject repeat their jump a number of times. Measure the height jumped by each performer. The second pair of students perform a standing broad jump. Again, record the jump if possible, or have the subject repeat the jump a number of times. Measure the distances jumped by each performer.

	Student 1	Student 2
Vertical jump (cm)		
Standing broad jump (cm)		

OBSERVATIONS AND DISCUSSIONS

1 Carry out a qualitative analysis of the vertical jump and the standing broad jump by comparing the outcome of each jump for each student.
2 Which subject jumped higher or further?
3 Is the force applied in a vertical jump eccentric? Is the force applied in a standing broad jump eccentric? Explain why the answer to one of these questions is yes, and how this impacts on the direction of the jump.
4 Write a description of the jumps, commenting on the angle of the ankle, knee and hip joints. Identify the biomechanical principles being applied in the movement.
5 How does the angular motion of each body segment translate into linear (rectilinear or curvilinear?) motion of the body during the jump?
6 From your description, suggest a reason why one jump was higher/further than the other.

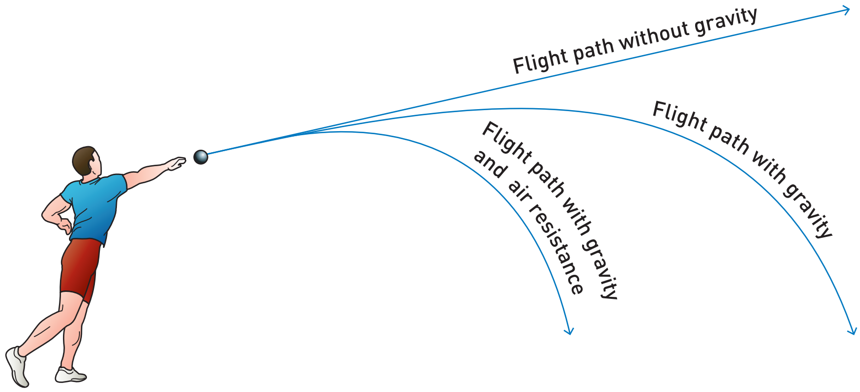
CHAPTER CHECK-UP

1 Select three sports. Identify and classify the motion performed in each sport as linear, angular or general.
2 Using a sporting application, draw a diagram to explain torque. Identify the axis of rotation, the lever arm, the force and the direction of the rotation caused by the torque.
3 Explain biomechanically why a gymnast may over-rotate a landing from a vault.
4 A gymnast using the uneven bars rotates once in a full layout position and then dismounts, performing a 1½ somersault prior to landing. Identify the axis of rotation and angular distance covered in each movement.
5 Explain why a junior baseball player should not use a full-size bat.

PROJECTILE MOTION

An object or body that is launched into the air and affected only by the forces of gravity and air resistance can be considered a **projectile**. Projectile motion looks at the factors that influence the flight path of the projectile. In sport and physical activity, the human body is often a projectile – there are many examples where the aim of the activity is to move through the air. In athletics, diving and gymnastics, athletes must often project themselves into the air and then complete a movement or sequence of movements. Divers use the spring from the diving board, and gymnasts the beat board or mini-tramp, to gain extra height.

There are numerous examples of projectiles in sport and physical activity. Balls, shuttlecocks, arrows, javelins and discuses all act as projectiles when they are thrown, kicked, shot or hit. The goal is often to throw, kick or hit as far or as accurately as possible, to hit a target or pass the ball to another player.



Projectile paths with and without gravity and air resistance

Divers become projectiles when they are in the air. The only forces acting on them are gravity and air resistance.

Vertical and horizontal components

Anything that can be considered a projectile will have horizontal and vertical components. The outcome of a long jump depends on maximising the horizontal displacement of the body, whereas the high jump requires the vertical component to be as great as possible. Events that are judged on accuracy need to manipulate both components in order to ensure the projectile hits the target. For example, a footballer would need to consider the distance to the goals as well as the height required to clear the player on the mark. Netballers often use a lob pass, maximising the vertical component of a pass to get the ball over the head of a defender. To analyse motion biomechanically, it is easiest to break it down into its horizontal and vertical components.

FYI

If you drop one ball and throw another ball from the same height at the same time, they will both hit the ground at the same time because they have the same vertical component of motion.

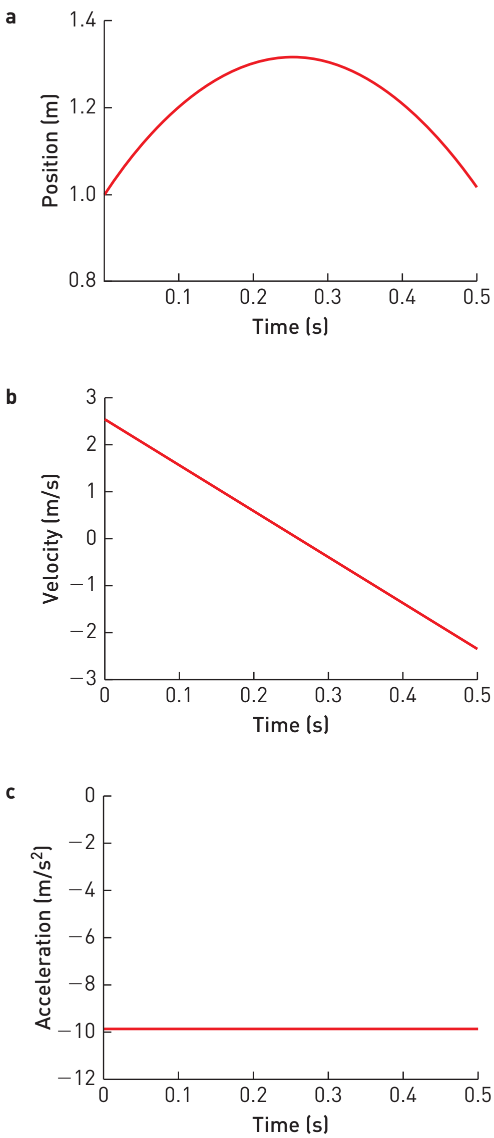
Vertical component

The vertical component of projectile motion is influenced by gravity and the vertical component of the initial projection velocity. Gravity is a force that acts on all bodies

Getty Images/Andy Lyons

Fairfax Syndication/Pat Scala

Maximising the vertical component of the body's motion aids in completing a successful jump in high jump (a), but for long jump (b) the horizontal component needs to be maximised!



(a) Vertical position, (b) velocity and (c) acceleration of the centre of gravity of an athlete during the flight phase of a standing vertical jump

close to the Earth's surface, causing objects to accelerate towards the Earth at a rate of 9.81 m/s^2. Gravity gives projectiles their parabolic flight path. Acceleration due to gravity is constant for any object, regardless of size, shape or weight. This means that a medicine ball and a tennis ball dropped from the same height will reach the ground at the same time (ignoring the effects of air resistance).

The vertical component of motion relates specifically to the height reached by the projectile. If there were no gravity, a projectile would just keep going, following the same path it was projected with. The vertical speed of an object decreases as it goes up and then increases as it comes back down. If the object is thrown and caught at the same height, the final speed will be the same as the initial speed.

Horizontal component

The horizontal component of projectile motion is affected by air resistance and relates to the horizontal distance covered by the projectile. Without air resistance, the horizontal velocity of a projectile would remain the same. When analysing sports and activities quantitatively, often air resistance is not taken into account, or is considered negligible. However, in a number of sports air resistance is very important, as it affects the horizontal component of the projectile's velocity. The time of a sprinter who runs with a tailwind may not be recognised because it was 'wind affected'. The same can be said for throws and jumps, as the air resistance becomes an external force that has assisted the athlete to gain extra horizontal distance or velocity.

DATA ANALYSIS

GRAPHICAL ANALYSIS OF A THROW

A cricket ball is thrown upward with a release velocity of 10 m/s from a height of 2 metres. The flight time, velocity and displacement are provided in the table at right.

Getty Images/Darrian Traynor

Using a spreadsheet program such as Excel, plot each of the following graphs:

- displacement–time
- velocity–time.

Scaffold

The data from the table is available online in an Excel spreadsheet, to make plotting your graphs easier. Go to http://www.nelsonnet.com.au and use your login code.

Time into flight (s)	Velocity (m/s)	Displacement (m)
0	10.0	2.0
0.2	8.04	3.80
0.4	6.08	5.22
0.6	4.11	6.23
0.8	2.15	6.86
1.0	0.19	7.10
1.2	–1.77	6.94
1.4	–3.73	6.39
1.6	–5.70	5.44
1.8	–7.66	4.12
2.0	–9.62	2.38
2.2	–11.58	0.26
2.222	–11.80	0.00

Note: The negative sign shows that the ball is travelling downward

QUESTIONS

1 According to your first graph, what was the greatest vertical height reached by the ball?

2 What was the velocity of the ball at the highest point? Explain why this is not shown in the table.

3 State the two forces acting on the ball while it is in flight.

4 What acceleration will the ball experience? What force is causing the ball to accelerate?

5 Provide an example of a sport where the projectile (e.g. the ball) needs to travel vertically to allow for a successful performance.

LABORATORY

INVESTIGATING AIR RESISTANCE AND GRAVITY

Experiment with a number of different pieces of sporting equipment (for example, different sized balls, frisbees, rubber chickens, beanbags, poly dots, shuttlecocks) to investigate the effects of air resistance and gravity. Drop each object from the same height and time how long it takes for it to reach the ground. (Safety: ensure that there is no one below when dropping the equipment!)

1 Construct a table that identifies the size, shape and weight of each object and the time taken to reach the ground.

2 What conclusions can you make about the effects of air resistance on different objects and their acceleration due to gravity?

Factors affecting the path of a projectile

The path of a projectile depends on three factors:

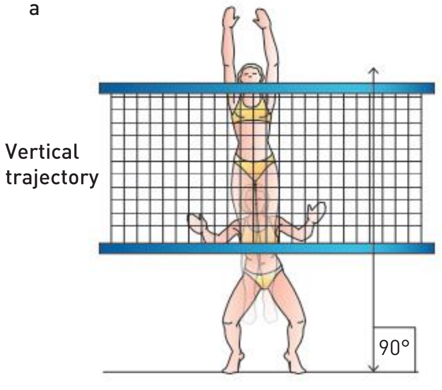
» angle of release
» speed of release
» height of release.

Coaches and athletes can manipulate these variables to find the best combination for optimum performance. That might be to gain the greatest horizontal distance in long jump, the most accurate goal shooting in basketball or the best position for catching a pitch in baseball.

TABLE 4.3 Factors influencing projectile motion

Variable	Factors of influence
Flight time	Initial vertical velocity Height of release
Distance (horizontal)	Horizontal velocity Height of release
Distance (vertical)	Initial vertical velocity Height of release
Flight path	Initial speed Angle of release Height of release

a



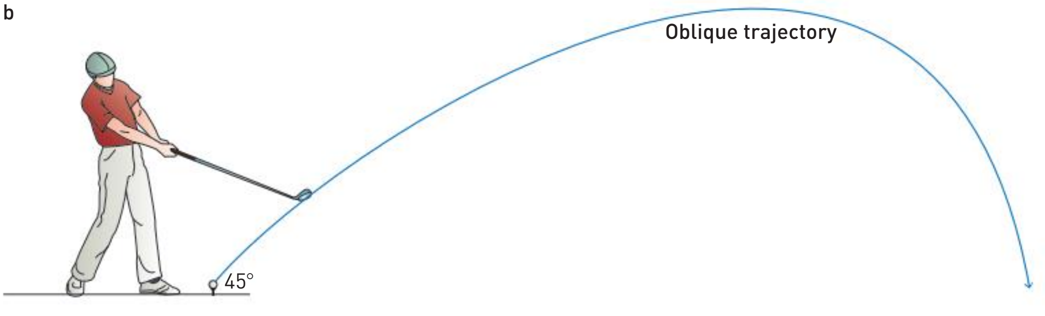
Angle of release

The **angle of release** is the angle (with respect to the horizontal) at which an object is projected into the air. This angle will determine the flight path of the projectile. There are three shapes that a flight path can form, depending on the angle of release.

The first is a purely vertical shape where the body or object goes straight up and comes straight back down again. An example would be performing a vertical jump, where the performer jumps straight up and returns to the ground in the same path.

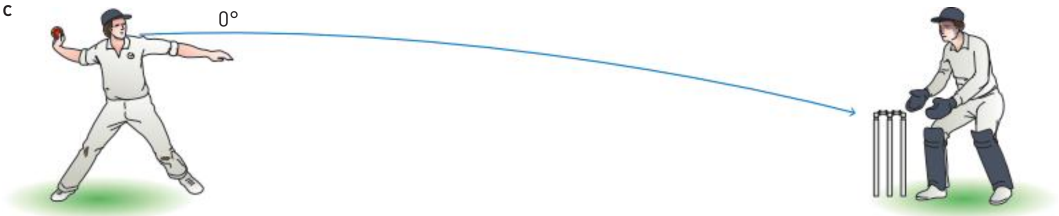
The second flight path is parabolic. This occurs when the angle of projection is between 0 and 90 degrees.

b



The final shape determined by the angle of release is half a parabola. An object projected at 0 degrees, or perfectly horizontal, will follow this path.

c



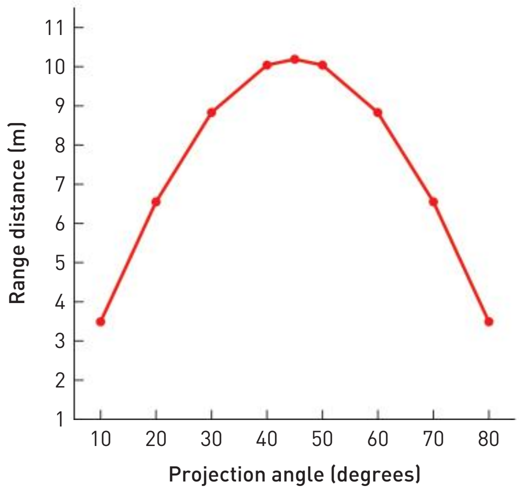
Horizontal trajectory

The effect of angle of release on the flight path of a projectile

The angle of release of a projectile affects the horizontal distance covered. For any given release velocity, where the projectile lands at the same height from which it was released, the best angle of release, to result in the greatest horizontal distance, is 45 degrees. Table 4.4 shows how varying the angle and speed of release changes the distance the projectile will travel.

TABLE 4.4 Effect of projection angle and speed of release on the distance a projectile will travel

	Distance travelled (m) at different projection speeds		
Projection angle (degrees)	**10 m/s**	**20 m/s**	**30 m/s**
10	3.49 m	13.94 m	31.38 m
20	6.55 m	26.21 m	58.97 m
30	8.83 m	35.31 m	79.45 m
40	10.04 m	40.15 m	90.35 m
45	10.19 m	40.77 m	91.74 m
50	10.14 m	40.15 m	90.35 m
60	8.83 m	35.31 m	79.45 m
70	6.55 m	26.21 m	58.97 m
80	3.49 m	13.94 m	31.38 m

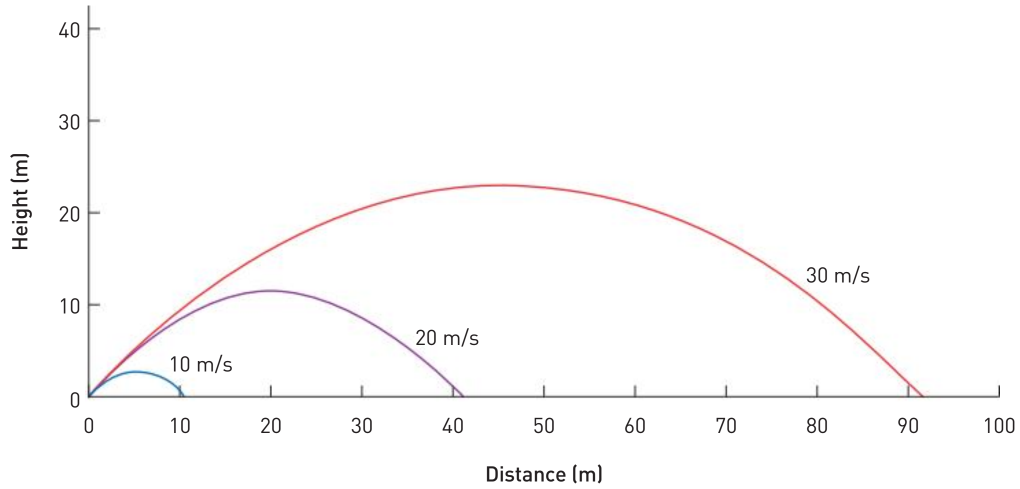


The effect of angle of projection on the distance covered by a projectile released at 10 m/s from a constant height

Source: Hall, 2007

Speed of release

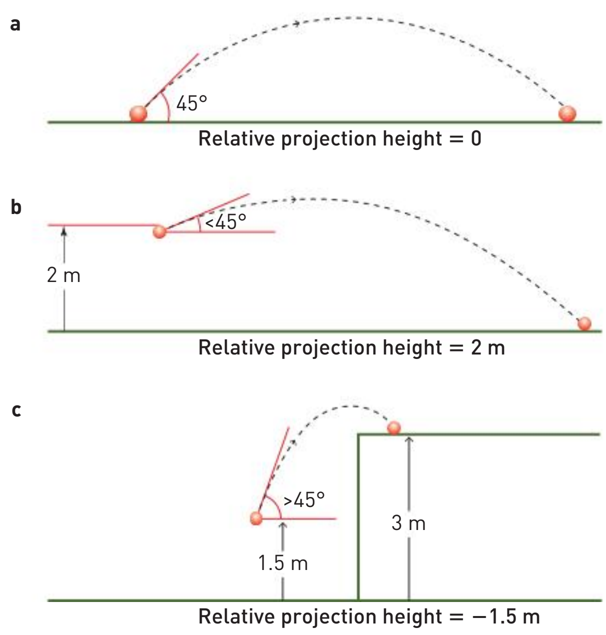
The speed at which an object is thrown, kicked or propelled into the air is referred to as the speed of release. Projectiles have both a vertical and horizontal component of release speed. The vertical component determines the height reached and the flight time of the projectile, and the horizontal component determines the horizontal distance covered by the projectile. The greater the speed of release, the greater the horizontal range of the projectile.



The effect of speed on the distance covered by a projectile released at 10, 20 and 30 m/s from a constant angle (45 degrees)

Height of release

The height of release is the difference between the height that a projectile is released from and the height at which it lands or stops. When the height of release is zero (a, left), the projection height equals landing height, and the optimal angle of release is 45 degrees. When the height of release is greater than zero (b), the projection height is greater than the landing height, and the optimal angle of release is less than 45 degrees. When the height of release is less than the landing height, the optimal angle of release is greater than 45 degrees (c).



The optimal angle of release depends on the relative height of release. Relative projection height is: (a) 0 m, (b) 2 m, (c) –1.5 m.

Table 4.5 shows the different release angles for different sporting events. The goal of high jump is to gain as much vertical height as possible and therefore a higher projection angle is required. In shot-put, where the height of release is greater than the landing height, the angle of projection decreases to about 36 degrees.

TABLE 4.5 Optimal angle of release for different sporting events

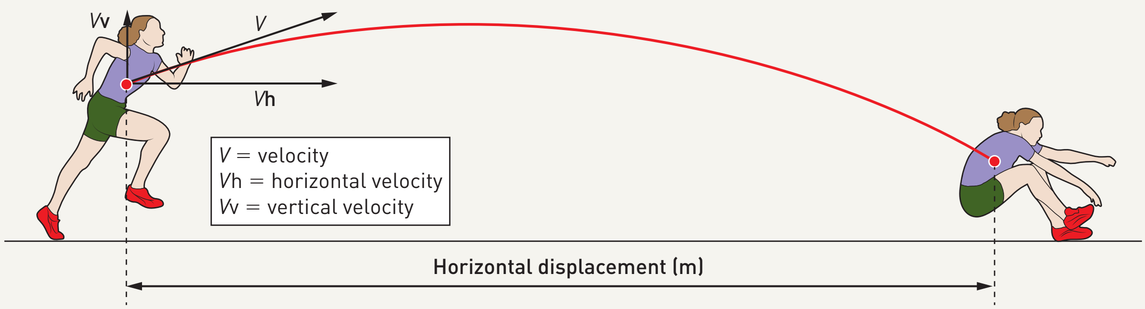
Sport	Optimal angle of release
Long jump	15–27°
High jump	40–48°
Shot-put	36–37°

REAL WORLD APPLICATION

Flight path of a long jump

An analysis of men's long jump has shown that the theoretical optimal release angle (45 degrees) for maximal horizontal displacement (longest jump) is different to the actual release angle (15–27 degrees). Part of the reason for this is the height of the centre of gravity. The height of the centre of gravity at take-off is greater than on landing.

Additionally, to achieve the predicted optimal angle of 45 degrees, the athlete would need to decrease their take-off velocity by half, which would then decrease the overall horizontal distance achieved in the jump. Through training, athletes optimise their height, leg length, strength and power to achieve the optimal combination of take-off velocity and take-off height. This has resulted in a take-off angle of between 15 and 27 degrees.



CHAPTER CHECK-UP

1 List and explain the three factors that influence the flight path of a projectile.
2 Identify sporting situations where different angles of release achieve the desired outcomes.
3 When is 45 degrees the optimal angle of projection? Using specific sporting examples, explain why 45 degrees is not always the optimal angle of projection.
4 In basketball, players often have to shoot from various distances from the basket, and with defenders in close proximity. Explain how changing the angle of release can assist the player in making a successful shot.
5 In both springboard and platform diving the height of release is greater than the landing height. Compare and contrast the way both forms of diving use the factors associated with projectile motion to maximise performance.
6 Using the data in Table 4.4, explain the relationship between angle of release, speed of release and distance travelled.

LABORATORY

INVESTIGATING PROJECTILE MOTION

AIM

To investigate the variables that affect projectile motion

EQUIPMENT

Garden hose with nozzle close to grassed area, tap (preferably connected to a tank), large protractor, measuring tape

METHOD

1. Connect the hose to the tap and turn it on so that the spray lands on the grass.
2. With constant water pressure and the hose nozzle at ground level, measure the horizontal distance the water covers when the angle of the nozzle is at 15°, 25°, 45°, 65° and 75° with the ground.
3. With constant water pressure, and keeping the angle of release the same, raise the hose nozzle 1 metre off the ground. Measure the horizontal distance covered by the water. Change the height of the hose nozzle to 50 cm and 2 metres off the ground.
4. Keeping the hose nozzle on the ground at a constant angle of 45°, turn the tap on to vary the water pressure. Measure the horizontal distance covered by the water each time.

RESULTS

1. Record the measurements.
2. Graph your results as:
   - distance vs angle of release
   - distance vs height of release
   - distance vs projection velocity.

DISCUSSION

1. Draw the flight path of the water in each of steps 2–4.
2. What is the relationship demonstrated between each of the variables and the horizontal distance covered?
3. How could you increase the vertical component of the projectile's motion? What would be the benefit of increasing the flight time (the vertical component) in activities such as diving, dancing or gymnastics?
4. As the coach of a junior baseball team, how could you apply the principles of projectile motion to instruct your batters to hit a line drive?
5. Select a sport or activity and identify when optimal performance would require a change in either angle of projection, height of release and/or projection velocity.
6. How could you modify this activity to investigate the effect of each of the variables on the vertical displacement of a projectile?

PRACTICAL ACTIVITY

OBSERVATION OF HIGHLY SKILLED, MODERATELY SKILLED AND UNSKILLED PERFORMERS

Scaffold

1. Select a sports skill where ability level differs within your class. It might be kicking a drop punt, shooting for goal in netball, a push pass in hockey or a pass in volleyball.
2. Observe three individuals performing the skill: a highly skilled, a moderately skilled and an unskilled individual.
3. Qualitatively describe the differences observed (use correct terminology in your description).
4. Provide relevant feedback/cues to each performer to improve or refine their performance.

Sport skill selected: ____________________

	Highly skilled performer	Moderately skilled performer	Unskilled performer
Observations			
Cues provided			

QUICKVID

If you did not watch this video in chapter 3, go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 85 is a video interview with Dr Elaine Tor, a biomechanist from the Victorian Institute of Sport, discussing the role of biomechanics in sport.

Video

QUICKVID

Watch a clear explanation and summary of angular motion by one of the authors. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for chapter 4, page 85 and choose the 'interactive'.

Video

CHAPTER SUMMARY

- There are two main forms of motion – linear and angular motion. Most movements of the human body are a combination of linear and angular motion, called general motion.
- Rectilinear motion is where all the body parts move in the same direction at the same time in a straight line.
- Curvilinear motion is where all the body parts move in the same direction at the same time in a curved path.
- Distance and displacement are measures of how far an object or a body has travelled. Both measurements are recorded in metres.
- Speed and velocity measure how fast an object is travelling. Velocity identifies the speed as well as the direction.
- Acceleration is a measure of how quickly an object or body changes its velocity. Acceleration can be positive, negative or zero (this occurs when velocity is increasing, decreasing or constant, respectively). Athletes manipulate their acceleration to optimise the outcome of their performance.
- Angular motion is the rotation of an object or body around a central axis. The axis of rotation can be internal or external, real or imaginary.
- Rotation and angular motion are caused by the application of an eccentric force. Eccentric forces are those that are applied at a distance from the centre of gravity of an object.
- Torque is the turning effect of the force that has been applied. It is the product of force and the lever arm.
- Angular motion can be measured and analysed by the same variables as linear motion but from an angular perspective: angular distance and displacement, angular speed and velocity and angular acceleration.
- Increasing angular velocity and/or the radius of rotation leads to an increase in linear velocity of the object being hit, struck or kicked.
- Angular velocity is increased through the coordinated summation of velocity of each individual body segment or through an increase in the length of the radius of rotation.
- Any object or body that is propelled into the air can be considered a projectile.
- Projectiles have both a vertical and a horizontal component to their motion.
- Air resistance and gravity are the only forces affecting projectiles and often the effect of air resistance is negligible.
- The flight path of a projectile depends on the velocity and height of release and the angle of projection.
- The optimal angle of projection for the greatest horizontal distance a projectile can travel is 45°, when the height of release is zero.
- When the height of release is greater than zero (above the landing height) the optimal angle of projection is less than 45°.
- When the height of release is less than zero (below the landing height), the optimal angle of projection is more than 45°.

CHAPTER REVIEW

Multiple-choice questions

1 When batting, a baseball player could increase the linear velocity of the baseball by:
  - A decreasing the radius of rotation by sliding their hands down the handle of the bat, 'choking' it.
  - B swinging the bat faster by increasing the angular velocities of the individual body segments.
  - C increasing the length of the bat.
  - D both B and C

2 A golf club is 0.90 metres long and the angular velocity of the club head at impact is 55°/s. Which is the linear velocity imparted to the ball?
  - A 49.5 m/s
  - B 495 m/s
  - C 61 m/s
  - D 610 m/s

3 Which of the following statements about the vertical component of projectile motion is correct?
  - A The vertical component of projectile motion is affected by gravity and air resistance only.
  - B Vertical velocity is zero at the highest point of the projectile's motion.
  - C The force of gravity determines the vertical component of a projectile.
  - D All of the above.

Short-answer questions

4 List three different sports in which the linear motion of the body is a result of angular motion. Outline the rotational movement of the body segment/s and any equipment that contributes to the linear motion of the body.

5 A student completes 5½ laps of a 400-metre running track in a 12-minute run test. Calculate the following:
  - a the distance the runner covered
  - b the displacement of the runner after 12 minutes
  - c the runner's average speed for the 12 minutes (Hint: Don't forget to show the time in seconds.)
  - d the runner's average velocity.

6 In terms of the race distance, the swimmers' velocity and acceleration, contrast a sprint event in swimming such as the 100-metre freestyle with an endurance event such as the 1500-metre freestyle.

7 In Australian Rules football a ball kicked using a drop punt will spin end over end, and a torpedo punt will spin in a spiral motion. Use these two different skills to explain how eccentric forces cause rotation.

8 Refer back to the diagram on page 74 to answer the following questions.
  - a Redraw the diagram and label each position with the correct angular distance: 0°, 60°, 120°, 180°, 240° and 300°.
  - b Determine the angular displacement of the gymnast in position C compared to position A.
  - c Determine the angular displacement of the gymnast after completing 1½ rotations.
  - d If the time taken to rotate from position B to F is 0.6 seconds, calculate the angular velocity of the gymnast.

9 Taking into account the height of release and the landing heights, predict the optimal angle of release for the flowing athletic events and justify your decision:
  - triple jump
  - discus
  - javelin

10 Draw a diagram of an athlete putting a shot into flight. Include the flight path, angle of projection, direction of the force of gravity and air resistance and the vertical and horizontal components of the motion.

CHAPTER 5

BIOMECHANICAL PRINCIPLES OF EQUILIBRIUM

Key knowledge

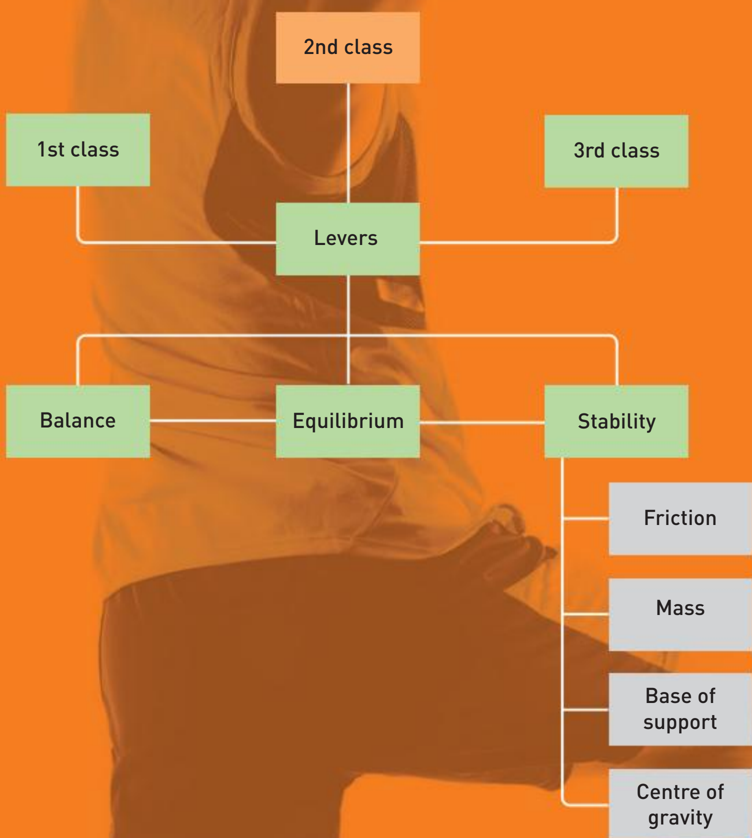
» biomechanical principles for analysis of human movement including:
  - equilibrium and human movement: levers (force, axis, resistance and the mechanical advantage of anatomical levers), stability and balance (centre of gravity, base of support and line of gravity)

Key skills

» perform a qualitative analysis of a movement skill using video and systematic observation to analyse and improve a variety of movement skills

» analyse, interpret and apply graphical, visual and physical representations of biomechanical principles to improve movement skills in a coaching context

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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EQUILIBRIUM

The terms **equilibrium**, balance and stability are often used interchangeably, but in a biomechanical context, the three terms each have different meanings. There are many activities where maintaining balance is important, such as performing a handstand on the beam in gymnastics, or holding an arabesque in a floor routine, but many sports also require athletes to maintain their equilibrium while moving. Why is it easier to remain upright on a bike that is moving compared to when it is stationary? How do footballers remain upright while dodging and weaving around opponents? Why do swimmers and sprinters crouch low in preparation for the starter's gun?


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Why do swimmers place one foot in front of the other and bend at the knees and hips on the blocks at the start of a race?

Biomechanically, the definitions of equilibrium, balance and stability are very specific. This chapter will look at how an understanding of the factors that affect equilibrium, stability and balance can be used to improve and refine performance in physical activity, sport and exercise.

An object is said to be in equilibrium when there are no unbalanced forces or torques acting on it (see chapter 3, page 57). An object in equilibrium is either motionless or moving with a constant velocity; that is, it is not accelerating (see chapter 4, pages 68–69). There are two types of equilibrium:

» static equilibrium
» dynamic equilibrium.

Static equilibrium

For the body or an object to be in static equilibrium it must not be moving or rotating. All the forces and torques acting on the body or object must add up to zero.

For an object or body to be in a state of static equilibrium, where it is completely motionless, it must meet three conditions:

1 The sum of all the vertical forces acting on the body must be zero.
2 The sum of the horizontal forces acting on the body must be zero.
3 The sum of all torques must be zero.

Dynamic equilibrium

When the body or an object is moving with a constant velocity – that is, with no change in speed or direction – it is said to be in dynamic equilibrium.

CHAPTER CHECK-UP

1 Define static equilibrium. Give two examples of an athlete in a state of static equilibrium in different sporting situations.
2 Define dynamic equilibrium. Provide two sporting examples where dynamic equilibrium can be observed.
3 A junior shot-putter holding the shot at their neck is in equilibrium just prior to beginning their action to release. Describe how the conditions of equilibrium can be changed to release the shot.

FYI

Maintaining stability of the body is largely an unconscious process. The body's balance systems automatically redistribute body weight to maintain stability.

STABILITY AND BALANCE

Equilibrium, **stability** and **balance** are closely related. Stability is the resistance to the disruption of equilibrium, and balance is the ability to control equilibrium.

When stability is increased, it is more difficult to unbalance an object; when stability is decreased, it is easier to unbalance the object or body. In some sports, the aim is to increase stability; in others it is beneficial to decrease stability. For example, swimmers use a stance on the blocks that minimises their stability, so that only a small movement is required to initiate the dive into the pool (see photo page 89). Wrestlers, on the other hand, use positions that increase their stability, making it more difficult for their opponents to disrupt their equilibrium.

Weblink

QUICKVID

Link via http://vcepe34.nelsonnet.com.au to a video clip showing the correct procedure for the Turkish get-up.

PRACTICAL ACTIVITY

BALANCE

Complete the following activities:

- Move from a sitting to standing position (e.g. get up out of your chair).
- Move from a standing to sitting position.
- Move from a lying to standing position.

Were you able to maintain your balance while completing each task?

Which was the most difficult to complete? Why?

Did you use your hands to increase your balance in any of the tasks?

Now try a Turkish get-up, after viewing the Quickvid above. You can do this with or without holding a weight, but you must have your hand above your head.

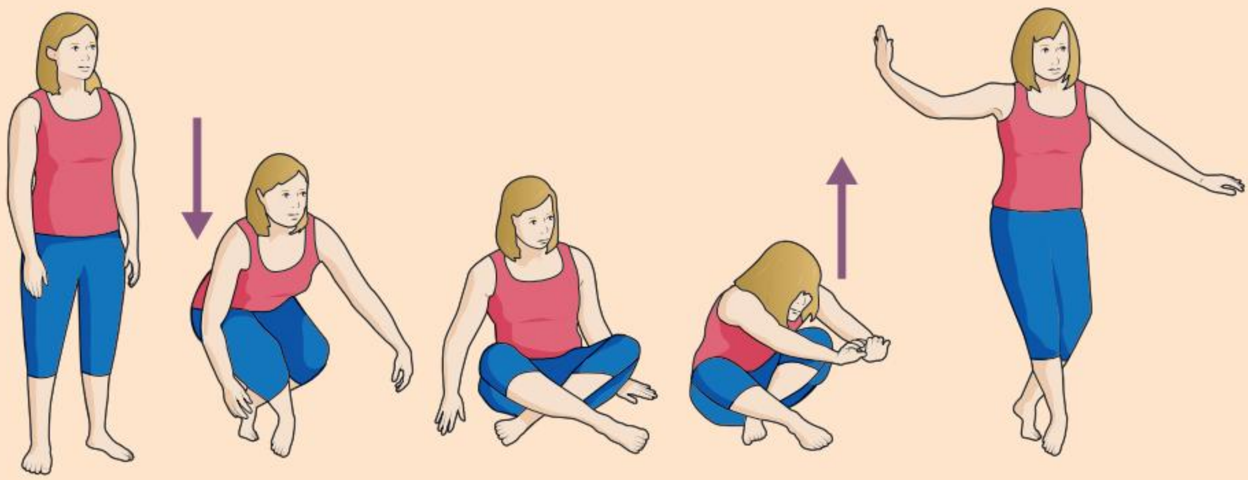
Was it difficult to maintain your balance during the exercise?

How did you adjust your body position to maintain your balance?

PRACTICAL ACTIVITY
UP AND MOVING

Try this simple sitting test for yourself:

1 Stand in comfortable clothes in your bare feet, with clear space around you.
2 Without using any type of support, lower yourself to a sitting position on the floor. This should be a controlled movement; you should not be concerned about the speed of the movement.
3 Now stand back up, without using your hands, knees, forearms or the sides of your legs for support, and without loss of balance.



SCORING

The two basic movements in the sitting-rising test – lowering to the floor and standing back up – are each scored on a scale of 1 to 5, with one point subtracted each time a hand or knee is used for support and 0.5 points subtracted for loss of balance. The maximum score achievable is 10.

Controlling the equilibrium of the body is important in lots of sporting activities. Gymnasts need good balance in order to complete routines on the floor and on the balance beam. There are times when a gymnast must hold a very stable position, such as when landing, and other times when it is advantageous to decrease their stability so they can launch into a series of movements. Controlling equilibrium while stationary or moving requires a high degree of balance, and to achieve balance we need to maximise stability.

Adequate stability is important for good performance in all sports, and balance is generally required. A platform diver must maintain their balance by holding a stationary position on the board, and a hockey player needs to maintain balance while dodging and weaving through other players on the field. A number of factors can be applied to enhance equilibrium, maximise the body's stability and therefore achieve balance.

FYI

Loss of musculoskeletal strength and flexibility have been associated with loss of balance and falls in older adults. Using a simple sitting-rising test (SRT), researchers found that the ability to sit and rise from the floor was a predictor for mortality (death) in 51–80-year-old subjects. People who scored fewer than 8 points were more likely to die in the next 6 years compared to those who scored higher in the test.

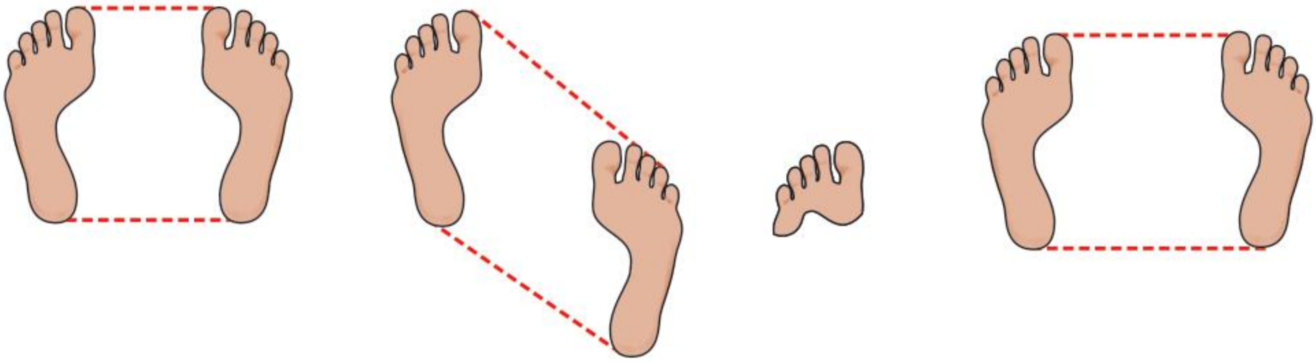
Factors affecting stability

A body's ability to maintain equilibrium is affected by:

» base of support
» centre of gravity
» body mass
» friction between the body and the surface or surfaces contacted.

Base of support

Generally, the larger the base of support, the greater the stability of an object. The base of support is the area bound by the outside edges of the body parts in contact with the supporting surface. The diagram below shows how different feet positions can produce different areas for the base of support.



Base of support (area inside the lines, including the feet)

Increasing the base of support can be as simple as moving your feet further apart. Moving one foot in front of the other increases your stability forwards and backwards. To increase side to side stability, move one foot further away from the midline of the body. As the area of the base of support increases, the degree of muscular effort required to maintain stability tends to decrease. Standing on one foot requires much more muscular effort to maintain balance than standing on two feet.

This principle can be applied to enhance sporting performance. Baseball and softball players will stand with one foot well in front of the other when hitting so that they can hit the ball hard without losing their balance.

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Baseball players use a wide stance to maximise stability while hitting.

Shutterstock.com/Daxiao Productions

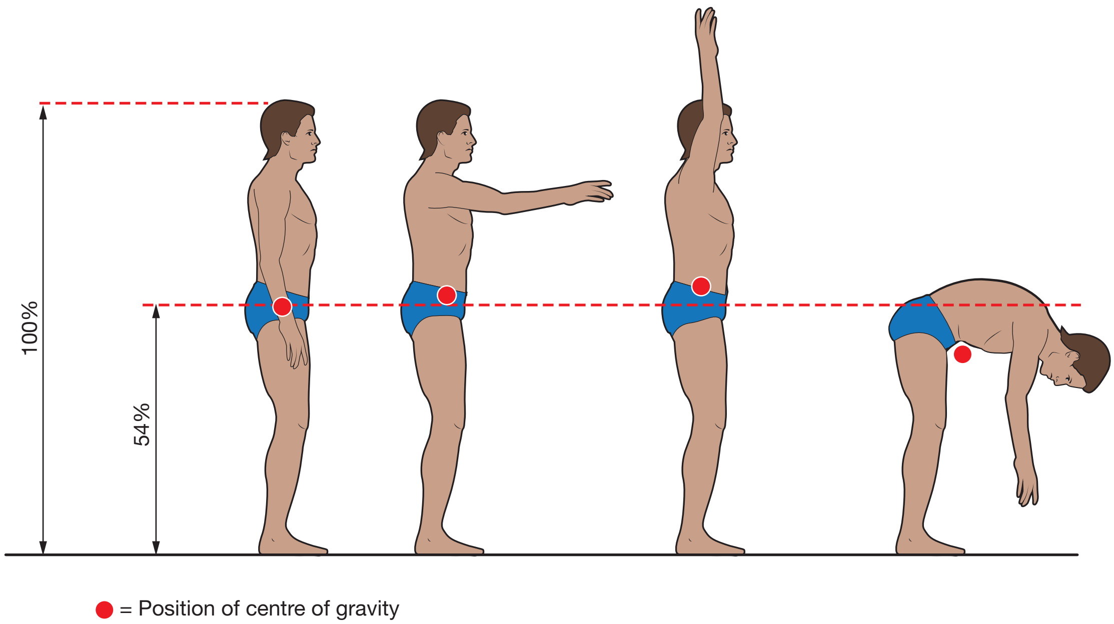
The dancer will make continual minor adjustments to ensure her line of gravity remains inside the base of support to maintain balance while performing an arabesque.

In some physical activity, the base of support for movement is very small. This means that the area that the line of gravity has to intersect is also very small. Any movement of the line of gravity in any direction except along the line of support will result in a loss of balance. Examples include movements along a balance beam in gymnastics, walking on a tightrope or performing an arabesque.

Centre of gravity

The body's **centre of gravity** is the point around which its weight is balanced, regardless of the position of the body. Generally, the centre of gravity in people is found close to the navel (belly button). Working out where our centre of gravity is and then changing it can increase stability. We can move our centre of gravity simply by moving our body parts.

The illustration below shows how the centre of gravity can shift depending on the position of the body. Stepping forward and extending both arms out in front, such as when performing a chest pass, moves the centre of gravity to just outside the body; putting your arms above your head raises it. Pregnant women often find that their balance is affected because, as their body grows to accommodate the baby, their centre of gravity moves outwards to the outer edge of the base of support.



The centre of gravity can also be raised or lowered depending on the position of the body. Try standing on your toes and compare your stability to when you crouch down low. The higher the centre of gravity, the less stable a body will be, and the lower the centre of gravity, the more balanced and stable it will be. Flexing the hips, bending the knees and flexing the ankles are ways to lower the centre of gravity. These techniques are often used in sporting situations where the athlete requires greater stability.

FYI

In some sports, such as pole vaulting and high jump, the most efficient position of the centre of gravity is actually outside of the body – often below the height of the bar!

Shutterstock.com/Aspen Photo

The maximum height of the centre of gravity during pole vaulting can actually be lower than the height of the bar!

Locating the centre of gravity in a) a baseball bat; b) a baseball; c) a golf club. The centre of gravity is located towards the end with the greater distribution of mass.

Locating the centre of gravity

Biomechanists are interested in finding a body's centre of gravity because the human body behaves as though all of its mass is concentrated at that point. The path of the centre of gravity can be used to analyse performance in many events. The specific movement of the centre of gravity in elite high-jump, long-jump, pole-vault and sprint athletes has been identified as significant for improved performance.

The centre of gravity of a perfectly symmetrical object (a solid rubber ball) that has constant density and mass and uniform weight distribution will be in the exact centre. However, very few objects are like this. When the mass distribution in the object is not constant, the centre of gravity will shift in the direction of greater mass. For example, a baseball bat has greater distribution of mass towards the end away from the handle, so the centre of gravity is closer to this end. The centre of gravity of a golf club is close to the club head and slightly outside the shaft because of the weight distribution in the head of the club. You can locate the centre of gravity of a golf club or baseball bat by balancing the club or bat on your finger and finding the point where it will balance.

Finding the centre of gravity of the human body is much more difficult because of the moving parts and the different densities of the muscle, bone, fat and other body tissues, which are not equally distributed throughout the body. Many methods can be used to determine a person's centre of gravity, some of which require complicated mathematical formulas. For example, a reaction board can be used and the sum of the torques acting on the body can be calculated to find the centre of gravity. The segmental method involves looking at each segment of the body through film images, determining the centre of gravity of each segment using *x* and *y* coordinates, and then adding all the centres of gravity and dividing the result by the total body mass to find the coordinates of the total body's centre of gravity. This calculation is done using a digitised image and a computer program.

Line of gravity

Gravity acts on a body through the centre of gravity. The direction in which the gravity acts is called the **line of gravity**. When the line of gravity acts through the centre of the base of support, stability is increased. When it moves to the outside edge of the base of support or outside of the base of support, stability is disrupted. Athletes can use this to their advantage. Swimmers position themselves on the starting blocks so that their centre of gravity is close to the front of the base of support (see photo page 94). This means the swimmer is unstable and can easily accelerate forward into the dive when the starting gun sounds. Sprinters use this same principle to increase their acceleration out of the blocks (see below).

Moving the line of gravity to the edge of the base of support can actually aid in maintaining equilibrium. Rugby players will lean forward as they move towards an opposition. This moves the line of gravity closer to the oncoming force, meaning it has further to be moved before it moves outside the base of support and stability is disrupted.

Determining the centre of gravity by segmentation

Alamy Stock Photo/Aflo Co., Ltd.

Can you estimate where the sprinter's centre of gravity is located?

Alamy Stock Photo/Jeff Morgan 01

Rugby players will crouch forward as they move towards oncoming players, lowering their centre of gravity and moving the line of gravity closer to the front of the base of support.

Body mass

The greater the mass of an object or body, the greater the force required to move it, and therefore to disrupt its equilibrium (see chapter 3 for more about Newton's second law, $F = ma$). If all other factors are equal, the body with the greatest mass will be most stable. In some sports, such as wrestling, a greater mass and the increased stability that comes with it can be an advantage, but in sports where changes in stability are required to execute the skill, such as gymnastics, lower body mass is more beneficial.

LABORATORY
INVESTIGATING STABILITY

1 List 10 positions that have different areas for their base of support and different horizontal and vertical positions of the centre of gravity and line of gravity. These could include standing on two feet or one foot, balancing on one hand and one foot, and crawling on hands and knees.
2 With a partner, get into each position. Once in the position, have your partner gently push you. Were you able to maintain your equilibrium? Record your observations for each of the 10 positions.
3 Draw a diagram to represent the base of support of each position and comment on the stability of the position.
4 From your observations, what factors would affect the stability of the human body?
5 Provide some practical examples of sports in which athletes change the area of their base of support or the position of the centre of gravity to improve their performance.

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Waxing their board gives a surfer increased stability.

Friction

Increasing the friction between the body and the surface it is in contact with increases the person's stability. For example, a surfer waxes their board to increase the friction between their feet and the board, which in turn increases their stability. A golf glove increases the friction between a golfer's hand and the club, reducing the likelihood of the club slipping in their hand. See chapter 3, page 47 for more about friction.

Enhancing equilibrium, maximising stability and achieving balance

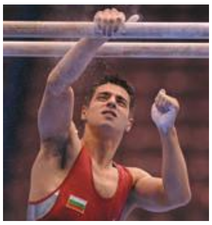
In summary, athletes can maximise stability by:

» increasing the size of their base of support
» ensuring the line of gravity falls within the base of support
» lowering their centre of gravity
» increasing their mass
» increasing the friction between their body and the surface or surfaces contacted
» extending their base of support in the direction of the oncoming force
» shifting the line of gravity towards the oncoming force.

CHAPTER CHECK-UP

1 Use the images provided and your knowledge of factors affecting stability to complete the table below. You can fill it in online by going to http://www.nelsonnet.com.au and using your login code.

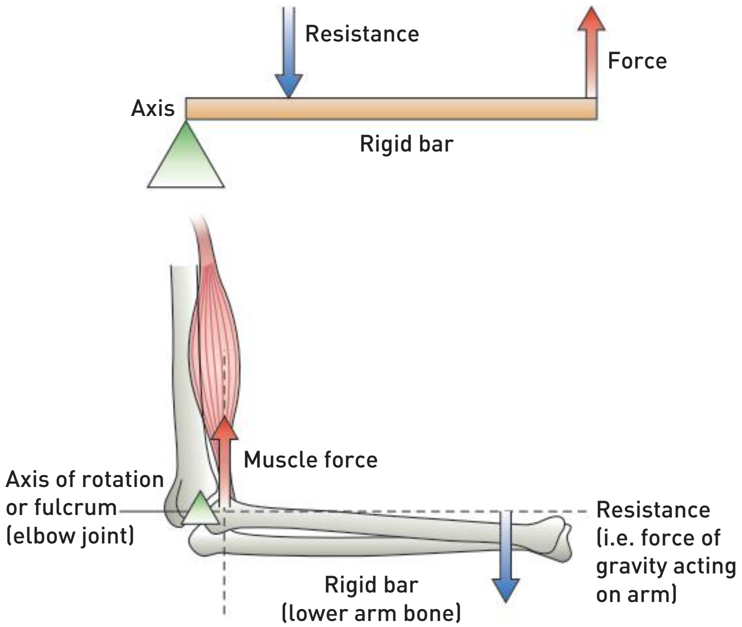
Scaffold

Sport/activity	Equipment	Effect on stability	Effect on performance
Golf – shoes			
Bobsleigh skeleton – sled			
Gymnastics – mag chalk			
Mountain bike riding – tyres			

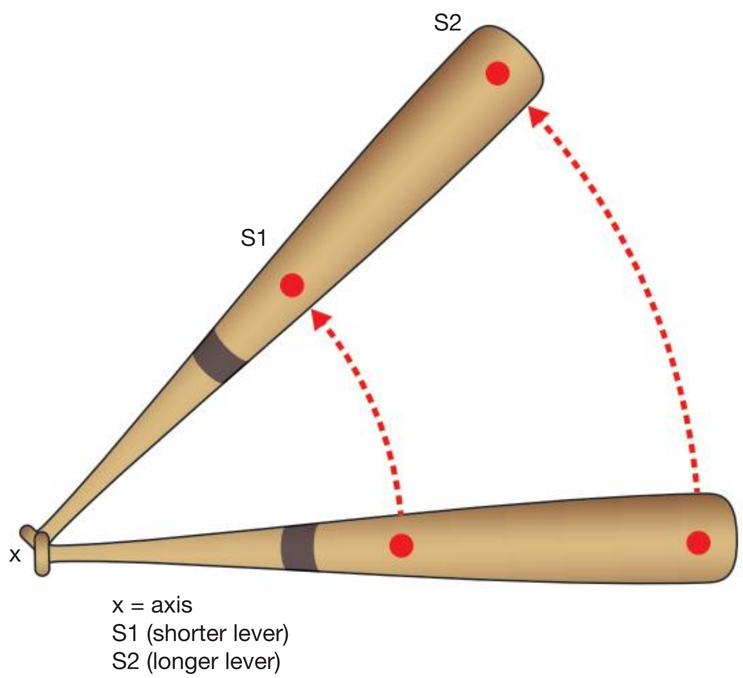
Photos, top to bottom: Shutterstock.com/urbanbuzz; Alamy Stock Photo/imageBROKER; Shutterstock.com/Paolo Bono; Shutterstock.com/homydesign

CHAPTER CHECK-UP

1 Define equilibrium, balance and stability.
2 List four sporting examples where contact surfaces are manipulated to either increase or decrease an athlete's stability.
3 List the four factors that can affect stability. Explain the effect each has on the stability of an object.
4 Coaches often instruct junior athletes to 'Bend your knees'. How would this instruction benefit a young athlete?
5 Explain how a gymnast can be balanced but also have low stability.



Components of a lever: (a) mechanical example, (b) human body example



The end of the longer lever (S2) travels a greater distance in the same time, so it moves at a greater velocity. This principle applies to sports where it is possible to increase the lever length with a racquet or bat.

LEVERS

The human body is a system of levers that allow movement to occur. A **lever** is a simple machine consisting of a rigid bar that can be made to rotate around an axis in order to exert a force on another object. In the human body, the bones represent the rigid bars, the joints are the axes and the muscles contract to apply the force (see illustration below). For a lever to move a resistance – which can be the bones themselves, the weight of the body segment or an additional load, such as a bat or racquet – a force must be applied. The mechanical advantage provided by levers allows us to apply a small force (or effort) to move a much greater resistance, or to move one point of an object a small distance, causing another point of the same object to move a relatively large distance (see diagram, left).

There are many other examples of levers in everyday life. Levers are designed to make jobs easier: a bottle opener makes it easier to open a bottle; a wheelbarrow makes it easier to shift a heavy load.

All levers have three parts:

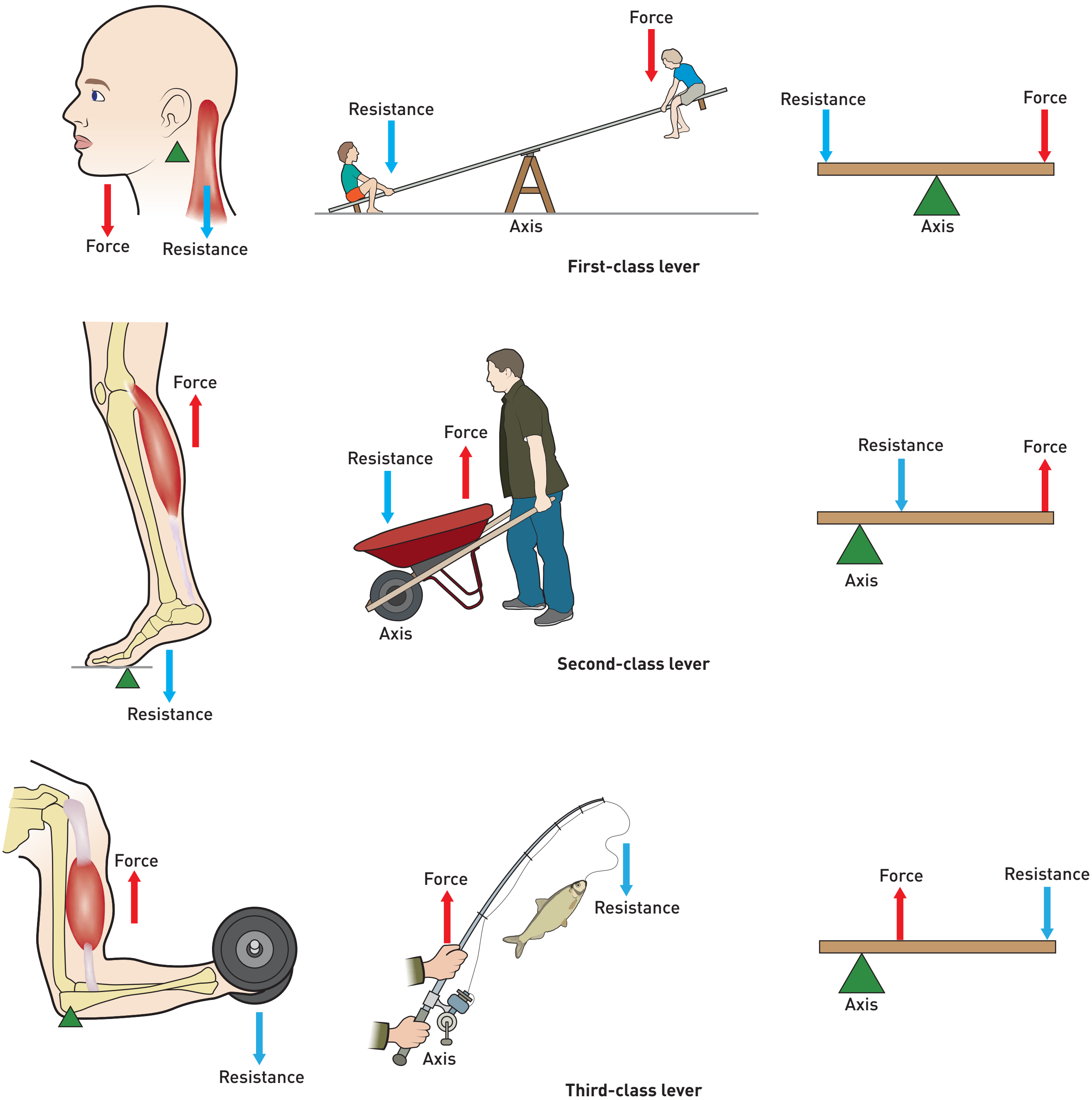
» an axis (or fulcrum or pivot point)
» a resistance (or weight or load to be moved)
» a force (or effort).

Lever classification

The position of the three components determines the class of lever: first, second or third. The illustrations on the facing page show the position of the axis, resistance and force in each class of lever.

» First-class lever – the resistance and the force are on either side of the axis.
» Second-class lever – the resistance is between the force and the axis.
» Third-class lever – the force is between the resistance and the axis.

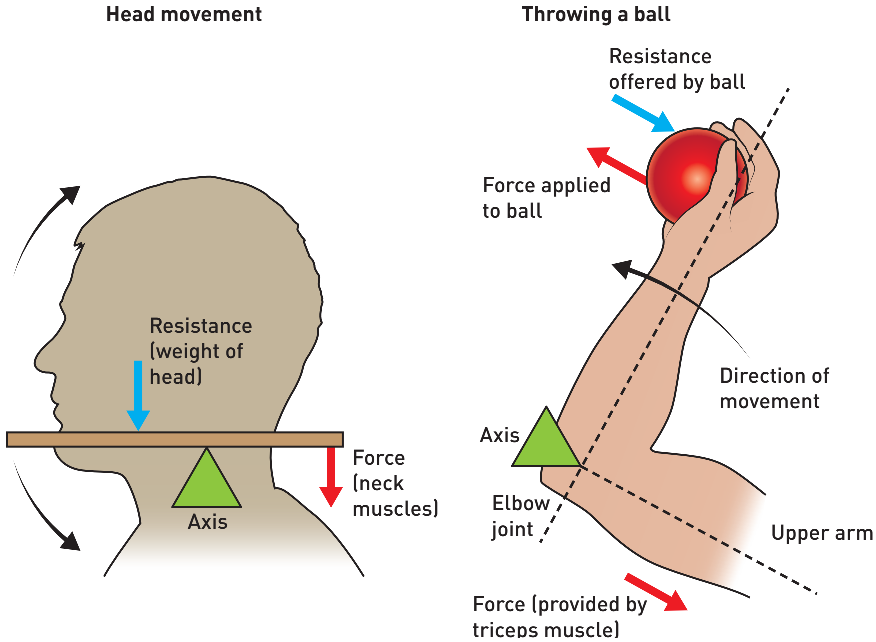
The lever system in the human body is designed for speed and range of motion, not force production. Most of the muscles and bones in the body operate as first-class or third-class levers, with a mechanical advantage of less than 1.



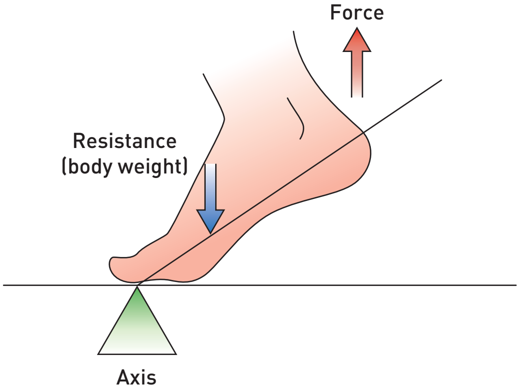
Classification of levers

First-class levers

In the human body, muscles work in pairs, on opposites sides of a joint axis. This is an example of a first-class lever. The agonist muscle provides the applied force and the antagonist muscle provides the resistance. First-class levers can be manipulated to increase either the force output by increasing the distance from the axis to the force (force arm), or the speed and range of motion of the lever. By increasing the distance from the axis to the resistance (resistance arm), an increase in the range of motion of the lever is achieved, as well as an increase in how quickly the resistance is moved.



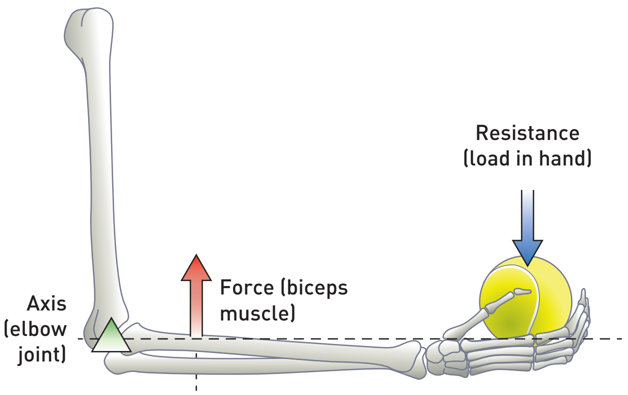
First-class levers in the human body



A second-class lever in the body is used when standing on tiptoes.

Second-class levers

There are very few examples of second-class levers in the human body because the body is not designed to apply great force through its system of levers. The resistance in a second-class lever is closer to the axis than the force, so the force arm is longer than the resistance arm. An example of a lever in which the resistance is positioned closer to the axis in the human body is a person standing on tiptoes. The resistance to be moved is the weight of the body, the axis is the toes and the force is the tension generated in the calf muscles as they contract, as shown at left. Second-class levers are beneficial in increasing the force output. They are useful when a heavier load needs to be moved.



Third-class lever in the human body

Third-class levers

Third-class levers are the most common type of lever both in the human body and in sporting applications of human movement. In human movement, the resistance is generally at the end of the lever. For example, the weight to be moved is often a bat, club or ball held in the hand. The axis of rotation is the joint and the force is applied by the contracting muscle. In third-class levers, the resistance is further from the axis than the force being applied. Third-class levers require greater force to move a given resistance, but greater range of motion and speed are gained. A simple example is to look at flexion of the elbow. When the elbow is flexed, the axis is the elbow joint, the force is the attachment of the biceps muscle close to the joint and the resistance is something being held in the hand, such as a dumbbell or a ball.

LABORATORY

USING LEVERS IN THE HUMAN BODY

Perform a sit-up under the following conditions:

- Legs bent, arms by your sides
- Legs bent, arms extended above your head
- Legs bent, arms behind your head
- Legs bent, holding a 2.5-kg weight above your head

QUESTIONS

1 From which position was it easiest to perform the sit-up? Which was most difficult? Rank the four positions from easiest to hardest.

2 Draw a diagram and label the axis of rotation, resistance and force. (Hint: The force will be the muscles responsible for the movement, the resistance will be the weight that has to be moved and the axis is where the rotation occurs). Draw in the resistance and force arms.

3 Explain your findings in terms of your understanding of levers.

The mechanical advantage of anatomical levers

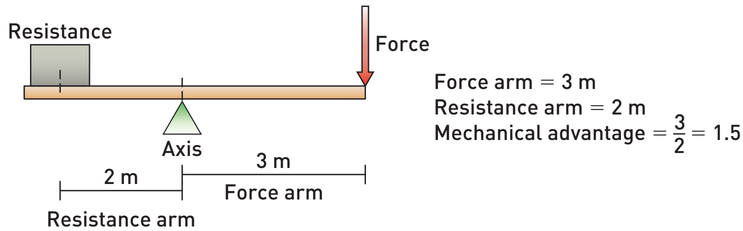
Understanding the role of levers in sport and human movement requires an understanding of the **mechanical advantage** a lever system can have. The mechanical advantage can be calculated by dividing the **force arm** by the **resistance arm**.

$$\text{mechanical advantage} = \frac{\text{force arm}}{\text{resistance arm}}$$

The force arm is the distance from the axis to the force and the resistance arm is the distance from the axis to the resistance. This is shown in the next diagram.

In the example shown here, there is a mechanical advantage because the ratio is greater than 1, which means that the force required to move the load is less than the force of the resistance. In simple terms, this means that in this type of lever system, a greater weight can be moved with less effort. All second-class levers have a mechanical advantage greater than 1.

When the resistance arm is greater than the force arm, there is no mechanical advantage – the ratio is less than 1 – but the range of motion of the lever is increased. All third-class levers have a mechanical advantage of less than 1. A greater force is required, but it only needs to be applied over a very small distance to achieve a large range of motion of the resistance. This in turn increases the angular speed of the lever.



Force arm and resistance arm of a (second class) lever

Most lever systems in the human body are third class. The force arm of anatomical levers is often very short, as the force is applied where the muscle attaches to the bone (not in the muscle belly), close to the axis. This means that anatomical levers will have a mechanical advantage of less than one. Levers in the body are designed to increase the speed and range of motion of the lever – the arm or leg for example. This in turn increases the angular speed of the body part, but the force generated must be greater than the resistance force.

Mechanical advantage >1	Less effort to move a resistance
Mechanical advantage <1	Increased range of motion Increased angular speed

Lever length

Anatomical levers in the human body are often extended in sporting situations through the use of a racquet, bat or club. This increases the distance from the axis to the resistance so the resistance arm is longer than the force arm. A greater force is required to swing the club or bat, but the advantage is an increase in the range of motion, resulting in an increase in velocity. The increased velocity translates to a ball being hit or kicked further.

Skilled athletes are able to increase the length of the levers they are using to maximise the velocity of the club or racquet, the hand releasing the ball or the foot kicking the ball, so that the velocity of the hit, kicked or thrown ball is greater.

The photo below shows an Australian Rules football player kicking a football. Notice that her leg is fully extended to maximise the length of the lever. This in turn imparts a greater velocity to the ball. The same thing can be observed when a tennis player serves the ball; they are at full extension when they connect with the ball.

Getty Images/Michael Dodge

Tayla Harris of the Demons kicks the ball for a goal during a Women's AFL exhibition match between Western Bulldogs and Melbourne at Etihad Stadium on 16 August 2015 in Melbourne, Australia. Fully extending her leg when kicking allows for maximum lever length.

Junior tennis players often serve from the wrist; others extend their elbow rather than their shoulder. Coaches encourage juniors to reach up to hit the ball during the serve, which allows for extension of the arm, maximising the length of the lever.

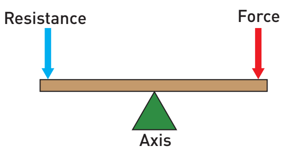
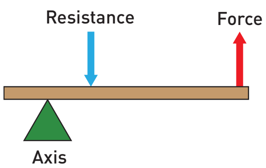
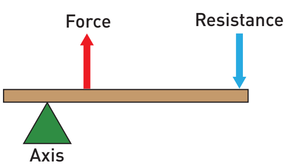
Children benefit from modified sporting equipment that is smaller and lighter than regular equipment. Longer levers can be more difficult to swing because of the length and greater mass. This increases the moment of inertia (see chapter 3, page 49). Increasing velocity is not as simple as increasing the lever length. Children will instinctively 'choke' a bat that is too big for them, which shortens the lever length, decreasing the moment of inertia and making it much easier to swing.

Image courtesy of Wilson Sporting Goods, www.wilson.com. Used with permission.

iStock.com/leventalbas

Modified sporting equipment increases the ability of a child to control the equipment, as shorter levers are easier to control.

TABLE 5.1 Summary of lever characteristics

Class	Arrangement	Direction of force vs resistance	Functional design	Mechanical advantage	Practical example	Human body example
1st	force – axis – resistance 	Resistance and force applied in same direction	Balanced movements (axis in middle)	= 1	Seesaw	Extending the head
			Speed and range of motion (axis near force)	< 1	Scissors	Overhead elbow extension
			Force motion (axis near resistance)	> 1	Crow bar	N/A
2nd	axis – resistance – force 	Resistance and force applied in opposite directions	Force motion (large resistance can be moved with relatively small force)	Always > 1	Wheel-barrow	Plantar flexing the foot to raise the body to stand on the toes
3rd	axis – force – resistance 	Resistance and force applied in opposite directions	Speed and range of motion (requires large force to move a relatively small resistance)	Always < 1	Catapult	Flexing the elbow

Adapted from Floyd, 2015

PRACTICAL ACTIVITY

LEVER LENGTH AND DISTANCE

AIM

To investigate the effect of lever length on the distance a ball will travel when hit

EQUIPMENT

Tennis balls, bat tennis bats, tennis racquets, markers, measuring tape and a large outdoor space

METHOD

1 Mark out a starting position from which to complete each trial.
2 Hit the tennis ball with your hand, using an underarm forehand action. Measure the distance the ball travels before it reaches the ground. Record your result. Repeat four times.
3 Repeat step 2 using the bat tennis bat and then the tennis racquet.
4 Record all your data in a table.
5 From your results, calculate the average distance travelled by the ball in each trial: hand, bat tennis bat and tennis racquet.

DISCUSSION

1 Which trial produced the greatest distance?
2 Explain why longer levers can hit the ball greater distances.
3 Golf clubs vary in length. From your findings, suggest reasons for the different club lengths used in golf.

REAL WORLD FOCUS

Levers in tennis


Alamy Stock Photo/PA Images

Australian tennis player Sam Groth uses his height to his advantage when serving. The extra length his height gives him is reflected in the length of his anatomical levers. Groth is tall – 193 cm – and has a big serve. He holds the world record for the fastest recorded serve, with a top speed of 263.4 km/h. This demonstrates the advantage of longer levers in generating velocity.

Elite players can extend the length of the lever not only with the racquet and by connecting with the ball with their arm fully extended, but also by making their spine the axis of rotation by rotating their body. This extends the length of the anatomical lever that is imparting the force.

CHAPTER CHECK-UP

1 An example of a second-class lever in the human body is the downward phase of a biceps curl. Draw a diagram labelling the axis, force and resistance. Explain the role of the muscle in this example.
2 Paddling a canoe is an example of which class of lever? What effect does sliding your hand down closer to the end of the paddle have on the functioning of the lever?
3 Push-ups can be a challenging exercise to perform. Using the principle of levers, explain how performing a push-up against a wall, on a bench and the on then ground will gradually increase the difficulty of the exercise.
4 Explain, in terms of levers, why a children's tennis, baseball, softball, golf or cricket coach should insist on modified equipment.

QUICKVID

If you did not watch this video in chapter 3 or 4, go to your student website via http://www.nelsonnet.com.au and use your login code. In the resources for page 105 is a video interview with Dr Elaine Tor, a biomechanist from the Victorian Institute of Sport, discussing the role of biomechanics in sport.

Video

QUICKVID

Watch a clear explanation and summary of levers in the human body by one of the authors. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 5, page 105 and choose the `interactive'.

Video

CHAPTER SUMMARY

- Equilibrium is a state of motion where there are no unbalanced forces or torques acting on the body. Equilibrium can be static or dynamic.
- Balance is the ability to maintain and control the equilibrium of the body in different situations.
- Stability is the body's ability to resist any changes or disruptions to its state of equilibrium. Stability is affected by mass, friction, base of support and centre of gravity.
- Levers consist of an axis, a force and a resistance. The positioning of each of these factors determines the mechanical advantage the lever will have.
- First-class levers have the axis between the force and the resistance.
- Second-class levers have the resistance between the axis and the force.
- Third-class levers have the force between the resistance and the axis.
- The human body is made up mainly of third-class levers. They are designed to increase the range of motion and speed of an object.
- The mechanical advantage determines the role of a lever. A lever with a longer force arm will have a mechanical advantage greater than 1 and increase the force output. A lever with a longer resistance arm will have a mechanical advantage less than 1 and increase the range of motion and speed of the lever.
- Longer levers have greater inertia and therefore are more difficult to swing. Junior sporting equipment is often modified to overcome this difficulty.

CHAPTER REVIEW

Multiple-choice questions

1 A lever designed to decrease the force required to move a load would be a
   - A first-class lever, where the force arm is shorter than the resistance arm.
   - B second-class lever, where the force arm is shorter than the resistance arm.
   - C third-class lever, where the resistance arm is longer than the force arm.
   - D both A and B

2 Stability is increased by
   - A lowering the centre of gravity, increasing the base of support and decreasing the mass of an object.
   - B lowering the centre of gravity, increasing the friction between the two surfaces and decreasing the mass of the object.
   - C positioning the centre of gravity towards the oncoming force, lowering the centre of gravity and increasing the friction between two surfaces.
   - D increasing the mass of the object, increasing the height of the centre of gravity and increasing the base of support.

Short-answer questions

3 How could a school athletics coach use the biomechanical principles associated with maximising stability to increase students' acceleration out of the blocks in the 100-metre and 200-metre sprint at the school athletics carnival?

4 Patrick is 13. His father gave him his old set of golf clubs to use to see if he likes golf. Why would using his father's old clubs be detrimental to the development of Patrick's skills?

5 Compare and contrast a standing sprint start and a crouched sprint start. Draw a diagram to show the relative bases of support, the position of the centre of gravity and the line of gravity.

6 Explain how a gymnast can increase their stability on landing.

7 Explain the biomechanical difference between a sit-up performed with your arms across your chest compared to a sit-up performed with your arms extended above your head.

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UNIT 3

ANALYSIS OF MOVEMENT AND ENERGY PRODUCTION

AREA OF STUDY 2

HOW DOES THE BODY PRODUCE ENERGY?

CHAPTER 6

THE THREE ENERGY SYSTEMS WORKING TOGETHER TO PRODUCE ATP

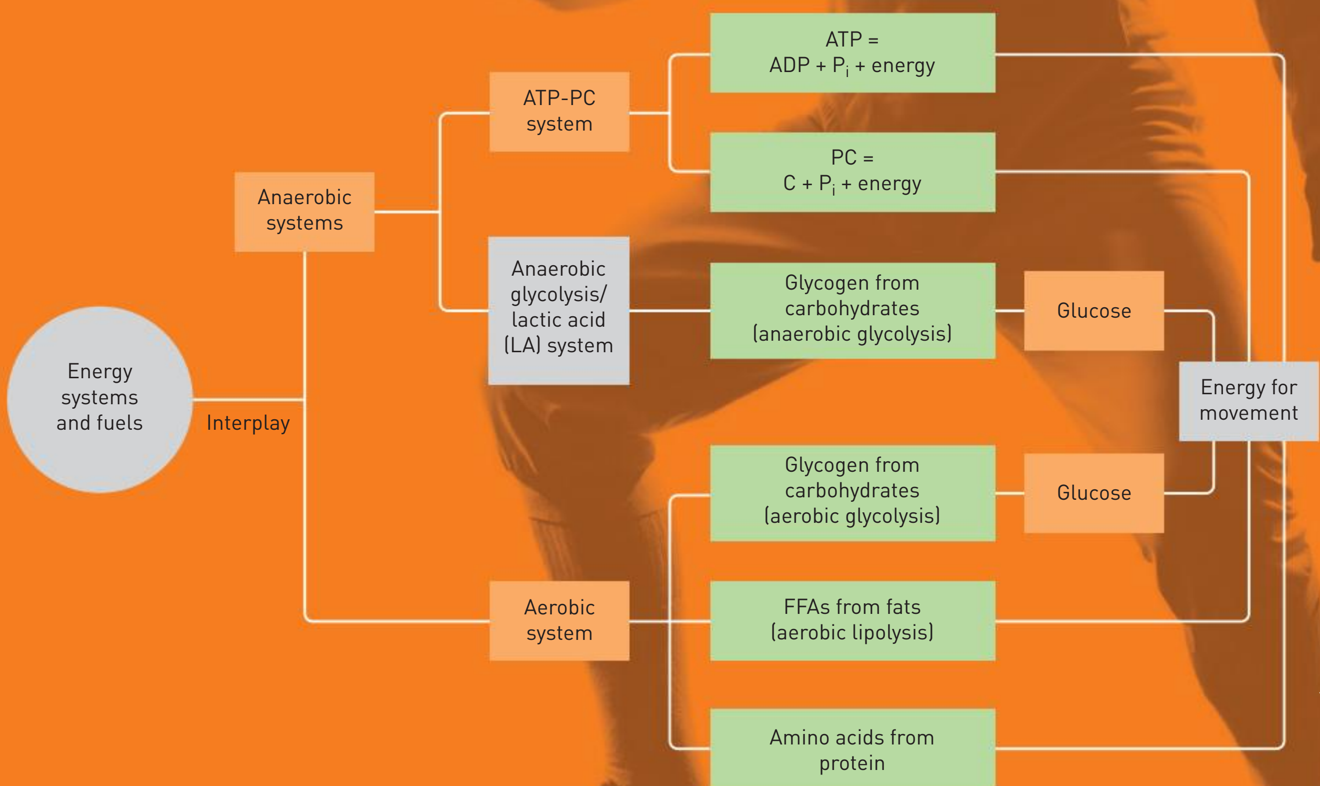
Key knowledge

- fuels (both chemical and food) required for resynthesis of ATP at rest and during physical activity, including the relative contribution of fuels at various exercise intensities
- characteristics of the three energy systems (ATP–PC, anaerobic glycolysis, aerobic system) for physical activity, including rate of ATP production, the yield of each energy system
- interplay of energy systems in relation to the intensity, duration and type of activity
- oxygen uptake at rest, and during exercise and recovery, including oxygen deficit, steady state and excess post-exercise oxygen consumption

Key skills

- participate in a variety of physical activities and describe, using appropriate terminology, the interplay and relative contribution of the energy systems
- perform, observe, analyse and report on laboratory exercises designed to explore the relationship between the energy systems during physical activity and recovery
- explain the changes in oxygen demand and supply at rest, and during submaximal and maximal activity

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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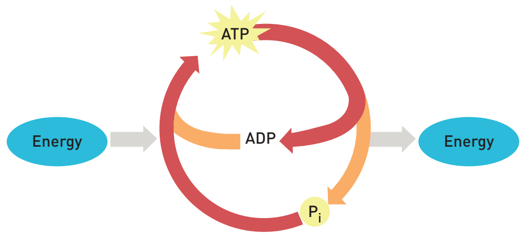
FUELS

Where do muscles get the energy they need for explosive movements such as a spike in volleyball or a rapid directional change in netball? How do muscles keep contracting for extended periods of time, allowing us to complete a 20-metre shuttle run or compete in a triathlon?

Energy is fundamental to the study of physical activity and sports performance. This chapter will give you a solid understanding of the sources of energy for muscular contraction – in particular, the role of **adenosine triphosphate (ATP)** and the associated chemical and food fuels used to recharge it. Every muscle contraction is due to adenosine triphosphate (ATP) splitting apart to produce energy, with **adenosine diphosphate (ADP)** being left over. ATP must be recharged for exercise to continue. To do this, chemical reactions using the body's available fuels add a phosphate group (P_i) back to ADP to make more ATP.

ATP is recharged via the three energy systems. All three systems work together to provide energy – this is known as the energy system **interplay**.

This chapter explains how the energy systems work together constantly to recharge ATP, allowing activities of varying intensity and duration to occur. ATP is recharged at a slow **rate** while sleeping, but while jogging this happens at a much quicker rate, by breaking down different food fuels.



ATP splits to release energy, and when energy is provided it is 'recharged'.

The food fuels

We eat foods to provide us with energy. The foods we eat need to be 'split' or broken down to recharge ATP. This is done via our three energy systems:

- the ATP–PC system } anaerobic
- the anaerobic glycolysis system } anaerobic
- the aerobic system.

Our food intake consists of three macronutrients: carbohydrates, fats and protein.

Carbohydrates (CHO)

Carbohydrates are the sugars and starches found in foods such as fruit, cereal, bread, pasta and vegetables. They are the body's preferred source of fuel, particularly during exercise.

Fats

Fats, found in butter, margarine, cheese, oil, nuts and fatty meats, act as a concentrated fuel storage in muscles and the body's adipose tissue. They are the body's main source of fuel at rest and during prolonged submaximal exercise.

Protein

Protein, found in meat, fish, poultry, legumes, eggs and grains, makes a negligible contribution to energy production during exercise (5–10 per cent in prolonged endurance events). It is used mainly for growth and repair, and as a 'last resort' fuel source.

Our digestive system breaks down carbohydrates to glucose, which is stored in the liver and muscles as glycogen. It breaks down fats to free fatty acids (FFAs) and triglycerides (stored as adipose tissue) and protein to amino acids, which are stored in muscles.

Water, minerals and vitamins are the other essential dietary ingredients. However, carbohydrates, fats and protein are the only sources of food energy or fuel. Table 6.1 shows the proportions of carbohydrates, fats and protein needed for a balanced diet that meets the needs of an average athlete.

After digestion and absorption, nutrients are carried away via the bloodstream surrounding the digestive system to the cells of the body. Some of this fuel is used immediately for energy production. The remainder is stored around the body, ready to be used at different rates depending on exercise intensity, duration and the availability of oxygen.

TABLE 6.1 Major food types: sources, fuel conversions and storage sites

Food fuel	Recommended daily intake (RDI) for a balanced diet (%)	Food fuel after conversion/ digestion	Storage
Carbohydrates Sugars and starches such as fruit, cereal, bread, pasta, rice, nuts and vegetables	55–60	Glucose	As glycogen, at the muscles and liver
Fats (triglycerides) Butter, margarine, cheese and full-cream dairy products, oils, nuts, fatty meats	25–30	Free fatty acids (FFAs)	As adipose tissue, at various body sites
Protein Lean meat, fish, poultry, legumes, eggs, lentils, grains, seeds, cheese and other dairy products, seafood	10–15	Amino acids	As muscle, at various body sites

Shutterstock.com/ifong

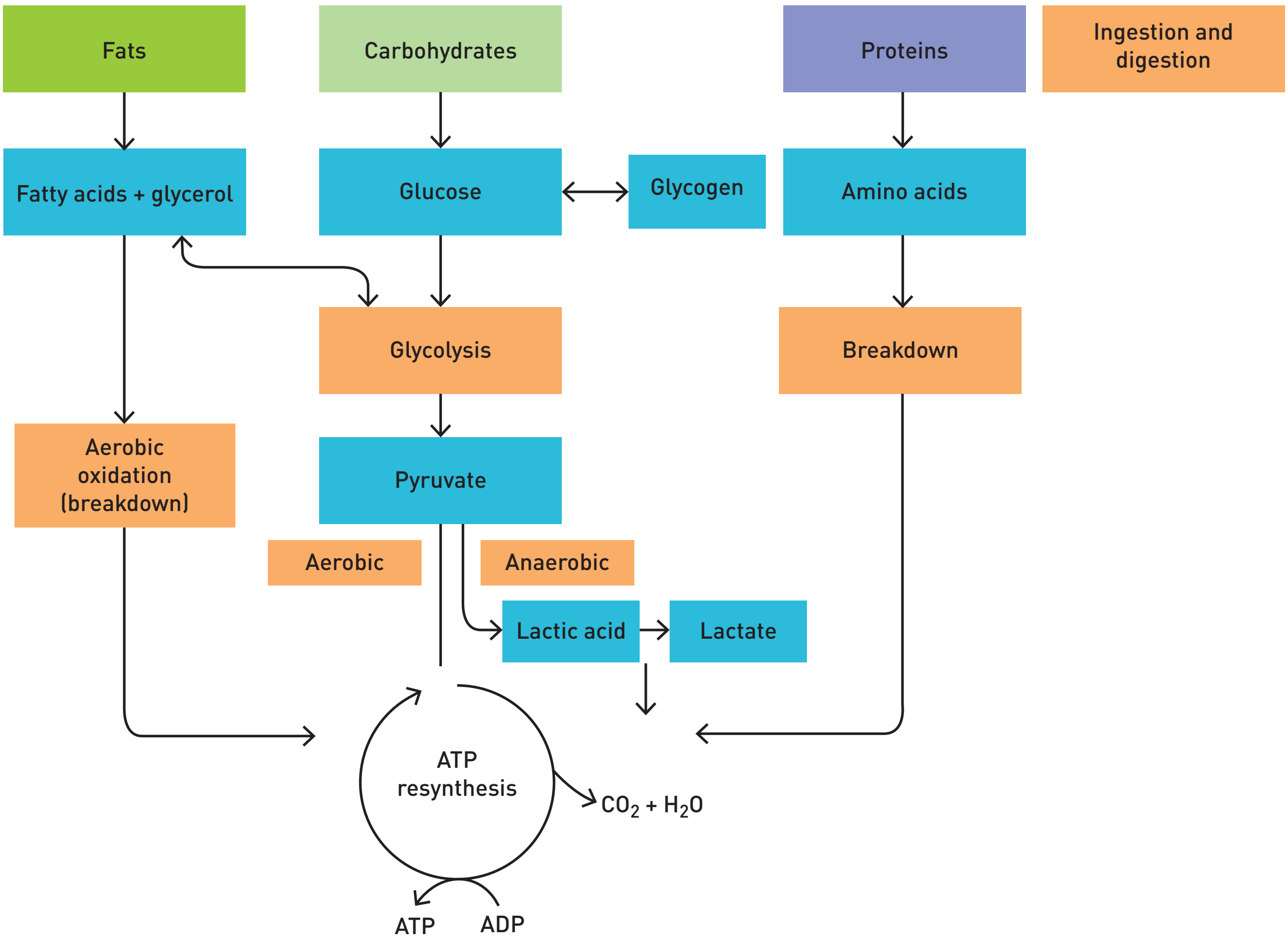
Which of these foods are high in carbohydrates, fats or proteins? Why would some athletes need a higher carbohydrate intake than others?

CHAPTER CHECK-UP

1 Provide three examples of foods not shown in the picture above that are high in carbohydrates, fats or protein.
2 Outline some sporting situations where the recommended carbohydrate intake would exceed levels recommended for a balanced diet.
3 Why would the food intake of competitors in a 20-kilometre run be very different from that of rugby players:
   a before the event (preparation)?
   b after the event (recovery)?
4 Produce a table listing foods that vegetarians could include in their diet to fulfil their carbohydrate, fat and protein requirements.

FOODS AS ENERGY SOURCES

Everything we eat is broken down and either used immediately, excreted or stored as chemical energy, which must be converted to mechanical energy so muscular contractions and movement can occur.



The food–energy path, from ingestion to the actual production of energy (ATP) that allows muscular contractions.

Adapted from: McArdle, Katch & Katch, 2015

Chemical fuels

Adenosine triphosphate

Adenosine triphosphate is the major source of energy that allows muscles to contract and cells to perform key functions. Put simply, no ATP means no energy for muscle contractions, resulting in fatigue.

ATP is a chemical fuel source. It consists of an adenosine molecule with three phosphates joined together in a row. Energy is released when one of the phosphates splits off, changing ATP into adenosine diphosphate (ADP) and an inorganic phosphate (P_i). Only a very small amount of ATP (enough to supply energy for 2–3 seconds of muscular work) is stored at the muscles, where it can be quickly accessed as needed.

ATP must be continually 'recharged' or resynthesised so that energy can be provided for longer periods of time. To rebuild ATP and create more energy in a form that muscles can

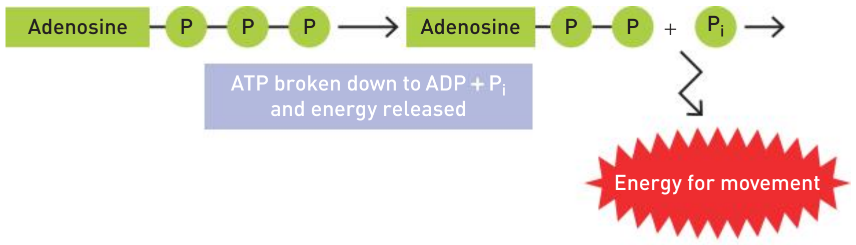
FYI

Recharging your phone is as simple as plugging it in, or putting energy back into it. Humans are exactly the same – when ATP has been depleted, it is instantly recharged by energy released from the breakdown of phosphocreatine or any combination of the three other macronutrients.

use, energy from the breakdown of **phosphocreatine (PC)** or nutrients (glucose, free fatty acids and amino acids) is used to rejoin ADP and inorganic phosphate (P_i). The three energy systems work together to ensure that ADP is re-synthesised into ATP using different fuel sources, and at different rates.

ATP is broken down and rebuilt many times to make energy available for muscular movement. It is resynthesised almost as quickly as it is broken down. The chemical reactions that turn the energy in ATP into energy that can be used in muscular contractions can be summarised as follows:

» Chemically, ATP is an adenosine nucleotide bound to three phosphates.
» When a cell needs energy, it breaks the bond between the second and third phosphate groups. This releases a large amount of energy, forming ADP and P_i (an inorganic phosphate).
» When the cell has excess energy (from the breakdown of PC or nutrients), it resynthesises ATP from ADP and P_i.

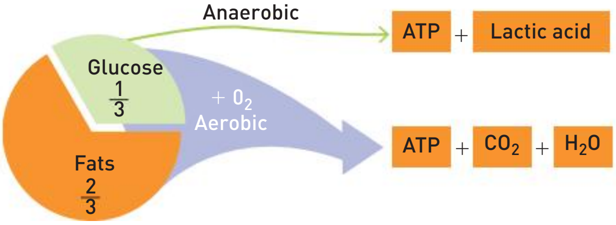


Energy release from the breakdown of ATP

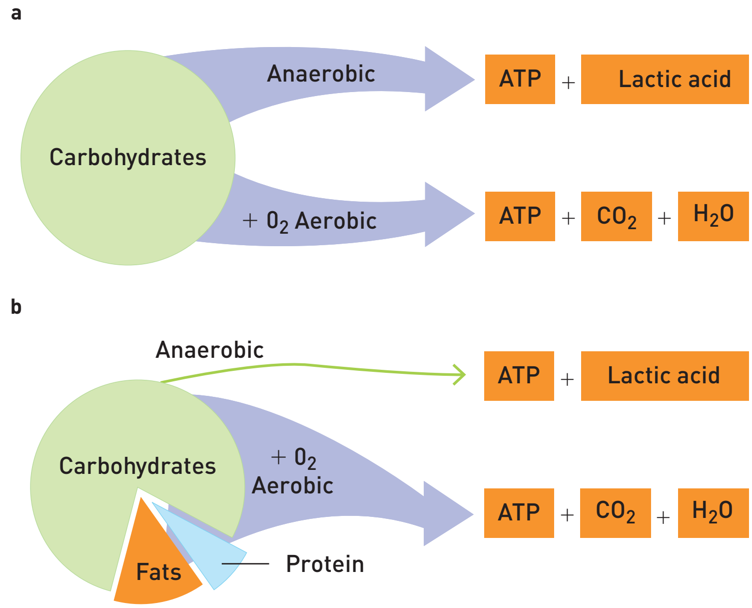
Fuel sources for physical activity

Glycogen (the form in which the body stores glucose) is the body's preferred energy source for exercise. Glycogen is broken down via a process called **glycolysis**. Each glucose molecule is split into two pyruvic acid molecules, and energy is released to form ATP, allowing more muscle contractions to occur. Under aerobic conditions with sufficient oxygen, the pyruvic acid enters the mitochondria and undergoes **aerobic glycolysis** to produce more ATP. When there is insufficient oxygen supplied (anaerobic conditions), the pyruvic acid transforms into lactic acid and then into lactate and hydrogen ions via **anaerobic glycolysis**.

At rest, the body shows a clear preference for fats as a food fuel over carbohydrates. The diagram below shows the 'mix' of both fats and carbohydrates contributing to energy production. At varying exercise intensities, food fuel sources will differ (see the two diagrams on page 113). Carbohydrate is the only source of energy used during maximal-intensity exercise (remember that PC is a chemical fuel, not a food fuel), whereas fats are used increasingly during prolonged submaximal or endurance activities. Once glycogen stores start to deplete during an endurance event (at approximately the two-hour mark), there will be a transition to fats as the major fuel source.



Food fuel sources at rest



Food fuel sources during (a) maximal and (b) submaximal activity

The contribution of carbohydrates, fats and protein to energy production

Carbohydrates

Energy for muscular contraction stems first from muscle glycogen and then liver glycogen. The level of carbohydrate intake varies according to the nature of the activity, with prolonged endurance activities requiring a **carbohydrate loading** regime, where as much as 80 per cent of the diet is carbohydrate.

It is important to have a carbohydrate-rich diet to increase glycogen stores. Glycogen stores facilitate high-intensity efforts via anaerobic glycolysis, as well as aiding endurance performance, which relies on the aerobic energy system. They also provide energy for PC restoration.

Recognition of the vital role that carbohydrates (specifically, glycogen and glucose) play in high-intensity exercise has been a major step forward in sports science and nutrition. The diets of athletes and sedentary individuals should be essentially the same, except that an athlete requires a greater energy intake. During anaerobic (high-intensity, short-duration) exercise, carbohydrates are the primary energy source once PC has been depleted. During aerobic (moderate-intensity, longer duration) glycolysis and exercise, energy comes from carbohydrates and then fats. Carbohydrates are preferred over fats during exercise because they require less oxygen to produce the same amount of energy.

Appropriate dietary preparation for an event must take into consideration the demands of the event, particularly the duration. Events lasting less than one hour require normal carbohydrate reserves. Events of a strenuous, intermittent nature or continuous events lasting around 90 minutes require well-filled glycogen stores, while prolonged endurance events of two hours or more require 'super-filled' glycogen stores obtained via carbohydrate loading.

Fats

Fats play an important role in the diets of both athletes and non-athletes. Fats act as a large energy store, and provide the source and transport medium for the fat-soluble vitamins A, D, E and K. Fats are stored throughout the body in fat cells (adipose tissue) and in skeletal

FYI

On average, an 80 kg person can store only 100 g of glycogen in their liver and approximately 400 g in their muscles (15 g of glycogen per kilogram of muscle). This would be sufficient to fuel a 25 km run! Approximately half of the body's energy for everyday activities is supplied by fat.

FYI

Aerobic glycolysis is the breakdown of glycogen when oxygen is present, and aerobic lipolysis is the breakdown of fats when oxygen is present.

FYI

One glucose molecule yields 36 to 38 ATPs in the presence of oxygen (aerobic glycolysis) but only 2 to 3 ATPs without oxygen (anaerobic glycolysis).

FYI

Complete oxidation of a glucose molecule results in a total of 36 ATP molecules, while complete oxidation of a triglyceride (fat) molecule yields 450 ATPs.

muscle, in the form of triglycerides. Triglycerides are broken down into free fatty acids, which in turn are broken down aerobically to provide energy for movement.

The transport of free fatty acids to muscle fibres is slow, and the breakdown requires a greater amount of oxygen than is needed to break down glycogen. This puts added stress on the oxygen transport and delivery system. Therefore, glycogen is the preferred fuel during exercise (especially where limited oxygen is available), but higher-intensity aerobic exercise predominantly uses carbohydrate as the preferred fuel.

In prolonged submaximal exercise, fat becomes an increasingly important energy source as glycogen is depleted. Even so, fat should not contribute more than 25 to 30 per cent of the body's total energy requirements. Despite the positive health benefits of exercise, athletes are still susceptible to the adverse health effects of diets high in saturated fat, such as obesity, cardiovascular disease and atherosclerosis.

FYI

Carbohydrate is a more efficient fuel source than fat when you consider the amount of ATP produced per unit of oxygen consumed. Six oxygen molecules are required to metabolise the 6 carbon atoms in glucose, producing 36 ATPs (6 ATPs per oxygen molecule), while 26 oxygen molecules are required to produce 147 ATPs from an 18-carbon fatty acid (5.7 ATPs per oxygen molecule).

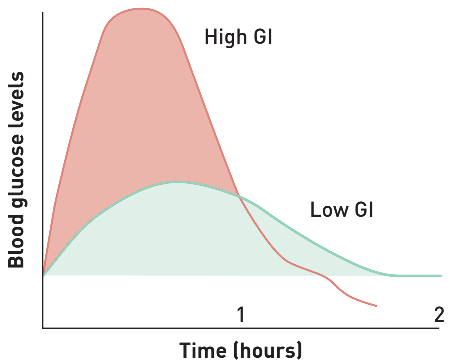
Protein

Protein is vitally important in the diet, as it forms the building blocks of tissue (growth and repair). All enzymes (which speed up chemical reactions) are proteins. Protein is also important in the synthesis of hormones and antibodies (the body's immune defence system). The basic structural units of proteins are amino acids.

Experts such as nutritionists, dietitians and sports scientists are divided on the protein requirements of athletes. Because protein is not normally used as an energy source, it should form only 12 to 15 per cent of the average diet – significantly less than the percentage of fats or carbohydrates. Protein is only used as an energy source in extreme circumstances (such as during extended-duration exercise) because large amounts of oxygen are required to break it down.

The conservative viewpoint is that the average diet supplies sufficient protein and essential amino acids to meet an athlete's requirements. Higher recommendations are based on the theory that amino acid requirements may be greater than originally estimated, and that endurance exercise significantly increases the turnover of protein. Many athletes consume more than 15 per cent of their diet as protein. For example, some athletes involved in high-contact sports such as rugby consume more than 20 per cent as protein, while for some weight- or power-lifters that figure is more than 30 per cent. However, there appears to be no real advantage to consuming more than 10 to 15 per cent. In fact, there may be some disadvantages, such as:

» the displacement of more carbohydrate-rich foods from the diet
» the excess fat intake associated with animal protein
» the additional nitrogen excretion, which increases urinary water loss (leading to dehydration and/or constipation).



Foods with a high GI are rapidly digested and absorbed, resulting in marked fluctuations in blood sugar levels. Low-GI foods, because of their slow rate of absorption, produce gradual rises in blood sugar and insulin levels, and have benefits during endurance performances.

Source: Baker IDI Heart and Diabetes Institute

The glycaemic index

Proteins and fats contain no carbohydrate and so have minimal effect on glucose production. They are considered to be 'low GI'; that is, they rank low on the **glycaemic index**. The glycaemic index is a ranking between zero and 100 describing how quickly the carbohydrate in a food is digested and absorbed into the blood. Foods are typically classified as being low, medium or high GI.

» **Low GI** = 55 or less
» **Medium GI** = 55–69
» **High GI** = 70 or higher

Our bodies take longer to break down foods that are high in fibre. Such foods are also considered to be low GI.

Sports drinks and foods with a high concentration of glucose (meaning they don't need to be broken down any further) raise blood glucose levels quickly, and so are considered to be high GI. Fruits (fructose) are slow to be broken down, as are most dairy products containing lactose, so these are low-GI foods. Sucrose has a medium release rate, so gets a moderate GI rating.

The following table provides examples of common foods and their lower and higher GI alternatives.

TABLE 6.2 Examples of common foods and their lower and higher GI alternatives

Food category	Lower GI	Higher GI
Bread 	» multigrain, sourdough, rye » pumpernickel » mountain oat, pita » fruit and grain » low GI white	» white » wholemeal » bagels and Turkish bread » crumpets
Breakfast cereals 	» untoasted muesli » rolled oats (porridge) » All-Bran, Guardian Special K, Sustain » Oat Brits » rice bran/oat bran	» Coco-Pops » quick oats » Cornflakes » Rice Bubbles » puffed wheat » Sultana Bran » Just Right
Rice 	» basmati (brown and white) » Doongara » long grain » wild	» jasmine » brown » white
Pasta and noodles 	» wheat pasta (white and wholemeal) » all noodles (not instant)	» canned spaghetti » potato gnocchi » corn and rice pasta » instant noodles
Grains 	» bulghur, barley » pearl couscous » buckwheat » quinoa » semolina	» couscous » polenta
Legumes and lentils 	» kidney beans, chickpeas, brown lentils, baked beans (all canned or dried)	» broad beans
Starchy vegetables 	» sweet potato (orange) » corn » Carisma potatoes	» potato – white, pontiac, sebago, desiree

Food category	Lower GI	Higher GI
Fruit 	» apples, apricots, bananas, berries » cherries, grapefruit, grapes » orange, kiwifruit, mandarin » mango, nectarines, peaches » pineapple, plums, tangelo	» canteloupe, watermelon » lychee (canned)
Milk and yoghurt 	» dairy milk & yoghurt » ice cream & custard » soy milk & yoghurt	» sweetened condensed milk » rice milk
Dry biscuits 	» Vita Wheat 9 grain » Ryvita multigrain	» rice cakes/crackers » puffed corn thins » water crackers
Extras 	» Snack Right biscuits » low fat ice-cream and custard	» plain sweet biscuits » sorbet and fruit-based gelato

Source: Baker IDI Heart and Diabetes Institute

Top to bottom: Shutterstock.com: evastudio; Robyn Mackenzie; Valentyn Volkov; Svetlana Kuznetsova; Richard M Lee; Galayko Sergey; Jiang Hongyan; Olga Miltsova; Mega Pixel; anitasstudio; M Unal Ozmen

The carbohydrate–fat 'fuel mixture' during prolonged endurance events

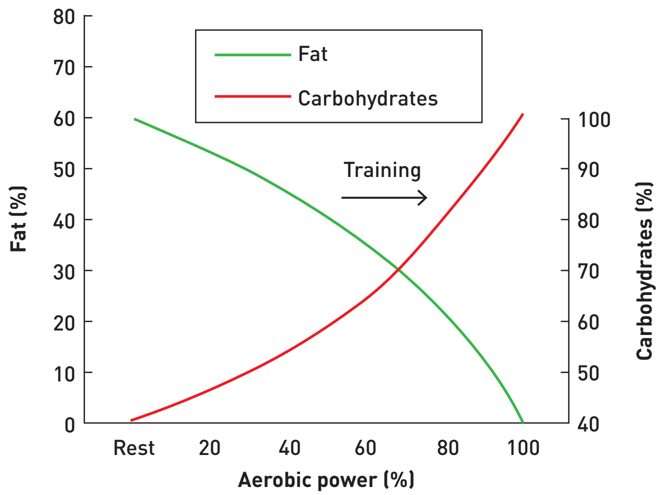
The graph on page 117 shows the increased reliance on fats as a fuel source as the intensity of exercise drops and the duration increases. During prolonged activities such as a marathon or triathlon, the body uses a mixture of carbohydrates and fats. In the early stages of the race, an athlete's body predominantly uses glycogen as a fuel source, but because fats are the preferred fuel under these conditions, the sooner the athlete can use free fatty acids as a fuel, the greater the capacity of the body to reserve glycogen for the later stages of the race, when the intensity tends to increase.

The athlete must try to conserve glycogen during the race to avoid 'hitting the wall'. Several factors contribute to this condition. Increased reliance on free fatty acids as a fuel (due to glycogen depletion) means the athlete requires plenty of oxygen. The heart must work harder to increase oxygen supply to the muscles. In addition, metabolism of fatty acids requires glucose.

The 'crossover concept'

The 'crossover' concept is a theoretical model that explains the balance of carbohydrate and fat usage during sustained exercise. The crossover point is the intensity at which energy from carbohydrates predominates over energy from fats, with further increases in intensity resulting in greater carbohydrate use and decreased fat **oxidation**.

Linked to the crossover concept, endurance training results in adaptations that increase fat oxidation during mild- to moderate-intensity exercise – this is known as **glycogen sparing**.



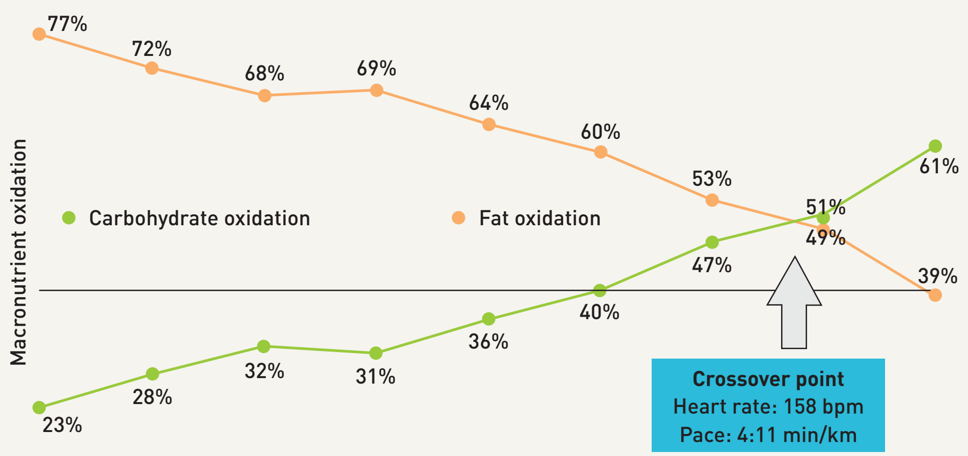
During aerobic training the crossover point shifts to the right and delays carbohydrates becoming the predominant fuel source during endurance events.

REAL WORLD APPLICATION

Fuel for marathons

The following graph shows the carbohydrate and fat usage for a runner completing an 80-kilometre ultra-marathon. At slower paces, he relied predominantly on fat to recharge ATP. At a pace of 4:11 minutes per kilometre and a heart rate of 158 bpm, he reached his crossover point, where he began relying more on carbohydrates than fat to recharge ATP.

The runner's goal would be to shift the crossover point to the right to preserve carbohydrates until later in the event. How could this be achieved?



Carbohydrate and fat usage for a runner competing in an 80 km ultra-marathon

Time (minutes)	24:00	28:00	32:00	36:00	40:00	44:00	48:00	52:00	56:00
Time (min.) to complete 1 km @ 1% grade	6:46	6:12	5:44	5:19	4:58	4:39	4:23	4:08	3:55
Heart rate	116	122	127	136	142	148	155	159	163
Perceived effort	2	4	4	5	5	6	6	7	8

Source: Courtesy of Andrew Skurka, andrewskurka.com

Fats as a fuel source

When liver glycogen is depleted and an athlete is unable to sustain blood glucose levels, **hypoglycaemia** sets in and the athlete again depends heavily on fat to supply energy. This can be quickly remedied by ingesting soluble sucrose (sugary drinks). Endurance athletes, via aerobic training, tend to increase their ability to use fatty acids for ATP resynthesis by increasing the number of **mitochondria** they develop, and by glycogen sparing.

As a result of the increased oxygen cost that comes from switching from carbohydrates to fats as the main fuel source, less oxygen is available to working muscles, and the risk of working anaerobically increases. This may explain why performers are forced to 'slow down' when fats are used during high-intensity activities, or used increasingly as the duration of an activity increases.

Table 6.3 shows that fats are a more concentrated source of energy than carbohydrates, but require more oxygen per ATP of energy produced.

TABLE 6.3 Energy availability and oxygen cost associated with the three main food fuels

Food fuel	Maximum energy (ATP per molecule)	Gross energy (kilocalories per gram)	Oxygen required (litres per mole of ATP produced)
Carbohydrates	36	4	3.5
Fats	3 × 147 = 441*	9	5.5
Protein	**	4	8.0

*One fatty acid molecule contains 147 ATP of energy and each triglyceride (fat) molecule contains three fatty acids.

**After nitrogen is removed (deamination at the liver or transamination at muscles), amino acids serve as a source for glucose and fatty acid synthesis. Some enter the citric cycle and add to energy production in this way.

CHAPTER CHECK-UP

1 Explain glycogen sparing and discuss how it can be beneficial to endurance athletes performing in events lasting longer than two or three hours. Make specific reference to the crossover concept.
2 Carbohydrate loading is one way of delaying the crossover from carbohydrates to fats in endurance events. How else can athletes delay this while training/competing?

CHARACTERISTICS OF THE THREE ENERGY SYSTEMS

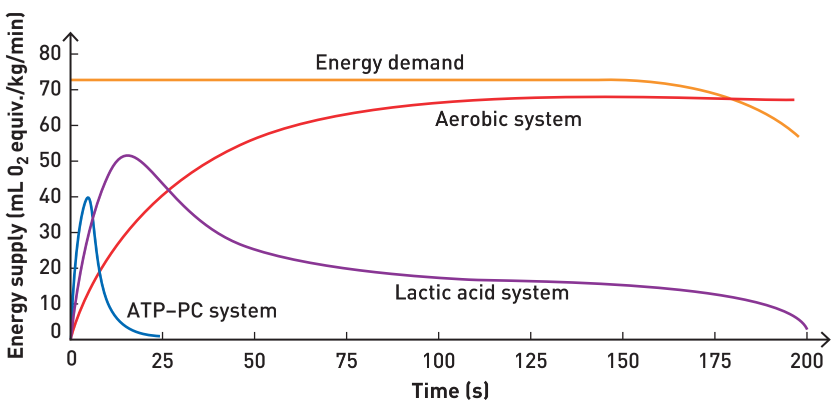
The three energy systems work together via the process of interplay to supply energy and rebuild ATP. All three energy systems are activated at the start of exercise, and their relative contribution is determined by the intensity and duration of the exercise. Which of the three systems operates depends on:

» the duration of the exercise
» the intensity of the exercise
» whether or not oxygen is present
» the depletion of chemical and food fuels during exercise.

The energy continuum

The energy continuum shows how the energy systems interact to provide energy for the resynthesis of ATP. It also highlights the predominance of each of the three energy systems according to the duration and intensity of the activity.

Each physical activity or sport requires a different percentage of energy from each energy system. Some activities/sports are mainly aerobic, while others are anaerobic, but most use a combination of all three energy systems.



Energy system continuum while cycling at 110% VO_2 max

At rest, our demands for ATP are low and can be met aerobically. But as we start to exercise, the demand for ATP increases quickly, especially during explosive or maximal activities. Because we cannot get oxygen to working muscles as rapidly as explosive activities require, our body calls on the two anaerobic systems to supply ATP in the early stages of exercise. However, if an activity is less intense and of longer duration, the aerobic energy system is able to supply most of the energy. Table 6.4 shows how intensity and duration influence the predominant system utilised to supply energy and the major fuels directly called upon to resynthesise ATP.

FYI

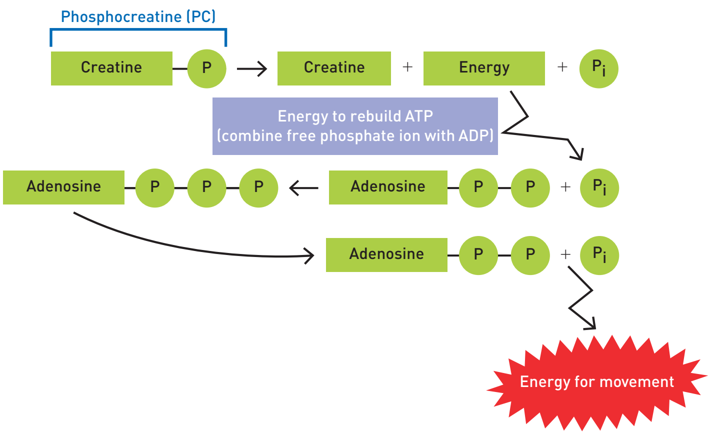
It is possible to work above 100% VO_2 max, but only when using an anaerobic energy system (usually the anaerobic glycolysis system) because PC has not had time to replenish. Sprinting maximally (on a track or bicycle) can push rates up to 200% VO_2 max, usually when the ATP–PC system has been depleted. This occurs if continuous activity lasts longer than 20 seconds or if breakaway sprints or surges suddenly increase intensity and the anaerobic glycolysis system increases its energy contribution by up to 400%.

TABLE 6.4 Dominant energy systems at various physical activity intensities and durations

Intensity	Total event duration	Dominant energy system	Food and/or chemical fuel
Rest	n/a	Aerobic	Glucose and free fatty acids (FFAs)
Submaximal	30 seconds	Aerobic	Glucose and FFAs
Submaximal	30 minutes	Aerobic	CHO
Submaximal	3 hours+	Aerobic	FFAs
Maximal	1–3 seconds	ATP–PC	Stored ATP
Maximal	5 seconds	ATP–PC	Remaining stored ATP–PC
Maximal	30 seconds	Anaerobic glycolysis	CHO
Maximal	75 seconds	50% ATP–PC and anaerobic glycolysis, 50% aerobic	CHO

The ATP–PC energy system

As explained earlier, the ATP–PC energy system produces energy by breaking down PC to resynthesise ATP through chemical reactions that do not require oxygen (anaerobic reactions). All activities that are carried out above 100 per cent **VO_2 max** depend on an anaerobic energy supply. If PC has not had time to replenish, this will be powered by the anaerobic glycolysis system.



Phosphocreatine breakdown to resynthesise ATP

The amount of ATP stored in muscles can supply energy for a maximum of 2–3 seconds. If activity is to continue, it must be constantly regenerated. As long as the use of ATP is balanced by its resynthesis, it is possible to continue performing at high intensity for a long period of time.

PC, like ATP, is stored in muscle cells and contains phosphate bonds which, when broken, provide large amounts of energy. PC splits into creatine (C) and inorganic phosphate (P_i). The energy that results is linked to the resynthesis of ATP. As ATP is broken down by muscular contractions, it is reformed from ADP and P_i just as rapidly, using the energy released by the breakdown of PC stored in muscles.

This is the most rapidly available source of ATP for muscles, because both ATP and PC are stored within muscles and don't depend on oxygen in the short term. Energy released by the ATP–PC system is exhausted very quickly, after only 6–10 seconds of intense muscular activity. PC is replenished within 3 minutes of the activity ceasing and a passive recovery being undertaken.

Summary of the ATP–PC energy system

- The ATP–PC system is anaerobic; it does not depend on oxygen being transported to working muscles to release energy.
- The system provides the most rapidly available source of ATP for energy because it depends on simple, short chemical reactions and the ready availability of PC in muscles. (PC is broken down to C and P_i.)
- The ATP–PC system is limited by the amount of PC stored in the muscles (about four times the amount of ATP). The more intense the activity, the more quickly PC is used to produce ATP.
- The stored PC lasts for about 10 seconds at maximal intensity, with larger muscles capable of storing slightly more (12 to 14 seconds' worth). When the PC stores are 40–50 per cent depleted (after about 5 seconds at maximal intensity), the anaerobic glycolysis system becomes the major producer of ATP.
- Once PC has been depleted, it can only be replenished when there is sufficient energy in the body. This usually occurs through the aerobic pathway or during recovery, once the activity has stopped.
- Once PC has been depleted at the muscle, ATP must be resynthesised from another substance – typically glycogen, stored in the muscles and the liver – via anaerobic glycolysis using the anaerobic glycolysis system.

The anaerobic glycolysis energy system

Anaerobic glycolysis refers to energy provided by the incomplete breakdown of glucose when oxygen isn't available. Theoretically, there is enough glycogen stored in muscles to maintain maximum effort for approximately 90 seconds, but maximal efforts can in practice only be sustained for about 20 seconds.

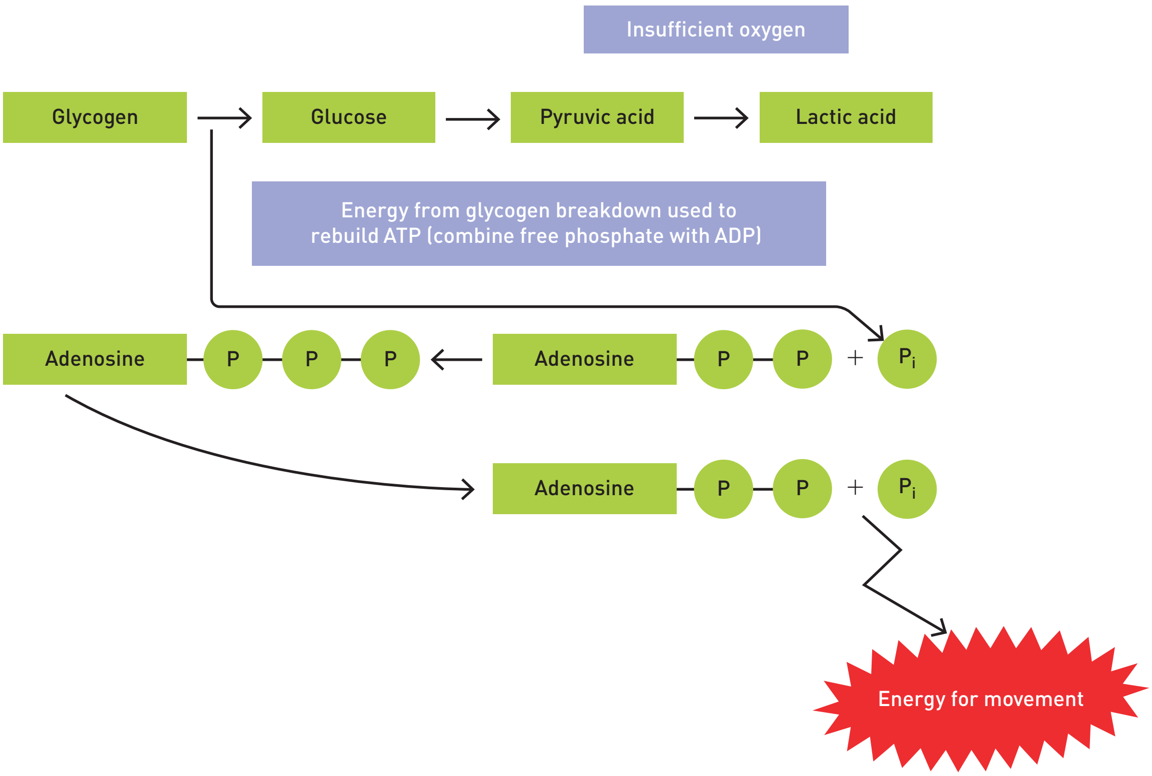
All the pyruvic acid produced during anaerobic glycolysis is converted into lactic acid (see diagram at top of next page). A by-product of this process is the production of hydrogen ions (H^+), which cause the muscle pH to fall (become more acidic), thereby inhibiting glycolysis. These hydrogen ions are responsible for the inability of muscles to contract maximally after a short period. This is a safety mechanism that prevents the cells being destroyed under extremely acidic conditions. The hydrogen ions combine with pyruvate to form lactate, which is then converted to glycogen and made available to release further energy. In other words, more ATP is produced when lactic acid is broken down to lactate and hydrogen ions (H^+), and more glycogen is resynthesised to again be used as a fuel when more ATP is required.

Although about 80 per cent of the lactic acid diffuses from the skeletal muscles and is transported to the liver to be converted back to glucose or glycogen, some hydrogen ions accumulate in muscle tissue, making muscle contraction painful and causing fatigue.

The **lactate inflection point (LIP)** refers to the moment when the body can just prevent the accumulation of hydrogen ions in the working muscles. This occurs when there is maximal lactate production being matched by maximal lactate removal – this is the maximal lactate steady state (MLSS). Beyond this point, lactic acid is produced faster than it can be oxidised or broken down, and lactate will accumulate in the muscles and move into the bloodstream. The point at which lactate levels begin to rise rapidly is known as **onset of blood lactate (OBLA),** and occurs at a level of about 4 mmol/L.

FYI

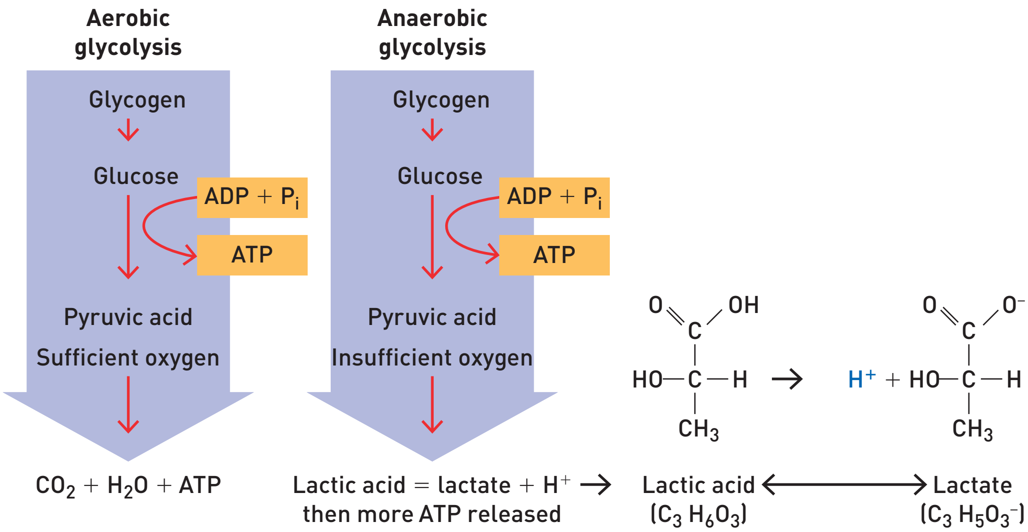
Bicarbonate soda (an alkali) has been shown to improve performance in events lasting 3 to 10 minutes, as it buffers some of the hydrogen ions produced during anaerobic glycolysis. This can cause gastric upsets, however, which sometimes outweigh the benefits.



Anaerobic glycolysis breaks down glycogen to re-form ATP without oxygen. This is how the anaerobic glycolysis system functions.

Summary of the anaerobic glycolysis energy system

- This system produces lactic acid, but is actually powered by glucose, which can be broken down (without oxygen) to provide energy (ATP). This is why it is called the anaerobic glycolysis system, rather than the lactic acid system.
- The system supplies ATP at a slower rate than the ATP–PC system because it requires longer and more complicated chemical reactions (about 12 of them).
- Like the ATP–PC system, the anaerobic glycolysis system supplies energy from the start of intense exercise. Peak power is usually reached between 5 and 15 seconds, and the system continues to contribute to ATP production until it fatigues, after 2 to 3 minutes.
- The system provides twice as much energy for ATP resynthesis as the ATP–PC system. It increases its ATP contribution if performance intensity exceeds the lactate inflection point. During maximal exercise, the rate of glycolysis may increase to 100 times the rate at rest.
- The system provides energy for longer during submaximal activities, when PC is depleted. Lactic acid accumulation also tends to be slower. This provides a 'stop-gap' until enough oxygen is transported to working muscles for the aerobic system to become the major energy contributor.



Aerobic versus anaerobic glycolysis. Note that for anaerobic glycolysis the lactic acid is broken down to lactate and H^+, and in doing so energy is released to rebuild ATP, which can then be used for more contractions.

The aerobic energy system

Aerobic glycolysis refers to energy provided by the complete breakdown of glucose when plenty of oxygen is available. The aerobic energy system produces energy by breaking down glycogen (preferentially during exercise), or free fatty acids (preferentially at rest), or amino acids (as a last-resort energy source) to resynthesise ATP.

Aerobic energy production takes more chemical reactions to produce ATP than either of the two anaerobic energy systems. The aerobic energy system produces ATP more slowly than the other systems, but can continue to supply energy for many hours, as long as sufficient fuel supplies exist. When oxygen supplied meets demand, the body is said to have reached **steady state**. This can occur at various levels up to the lactate inflection point.

When using the aerobic energy system, any accumulated lactic acid and other metabolites have the opportunity of being oxidised/removed or converted back into glycogen to again be used as an energy source. Fats are able to release more energy than carbohydrates in the presence of oxygen, but require greater amounts of oxygen to do so.

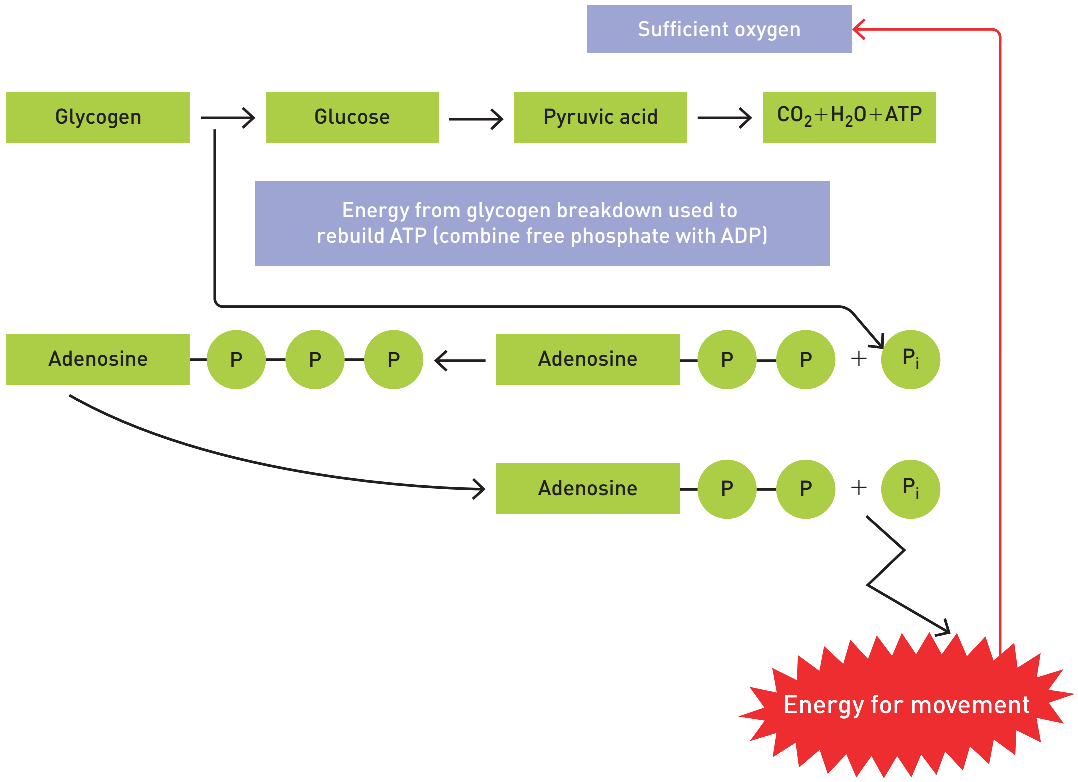
As a result of the increased oxygen cost when transitioning from carbohydrates to fats as the main fuel source, less oxygen is available to working muscles, and the risk of working anaerobically increases. Table 6.5 shows that after approximately 75 seconds of maximal-intensity exercise, the energy is being released equally by the aerobic and anaerobic systems.

After only 30 to 60 seconds of maximal exercise, oxygen uptake can be as high as 90 per cent of an athlete's maximum (90% VO_2 max). Thus, the aerobic system is very important in providing energy for extended high-intensity activities.

TABLE 6.5 Relative contributions of anaerobic and aerobic energy to maximal exercise

Duration of exhaustive exercise (seconds)	10	15	20	30	45	60	75	90	120	180
Anaerobic energy contribution (%)	94	88	82	73	63	55	49	44	37	27
Aerobic energy contribution (%)	6	12	18	27	37	45	51	56	63	73

Adapted from: Gastin & Le Rosignol, 2001



Aerobic glycolysis: the breakdown of glycogen with oxygen supply meeting oxygen demand

Summary of the aerobic energy system

- The aerobic system is the slowest system to contribute towards ATP resynthesis. It involves many more complex chemical reactions to release energy than the ATP–PC and anaerobic glycolysis systems.
- The system provides 30–50 times as much ATP as the ATP–PC and anaerobic glycolysis systems combined.
- It requires oxygen, which can be provided (90% VO_2 max) within 60 seconds.
- It preferentially breaks down carbohydrates rather than fats to release energy.
- Fats can produce more ATP than carbohydrates, but they require more oxygen to produce an equivalent amount of ATP.
- The aerobic system does not release toxic or fatiguing by-products and can be used indefinitely.
- It contributes significant amounts of energy during high-intensity or maximal activities lasting 1–2 minutes.
- The aerobic system is also activated at the start of intense exercise. Peak power from this system is usually reached between 1 and 2 minutes and will continue to be the major ATP contributor as the anaerobic glycolysis system decreases its contribution.

Comparing the three energy systems

The most obvious comparison to be made between the three energy systems is their energy production. A unit of measure for quantifying chemical compounds, called moles, is used to compare the amount of energy available from each of the three systems. One mole of ATP provides approximately 30 kilojoules of useful energy. As one mole equals 1000 millimoles, we have:

$$1 \text{ mol of ATP} = 1000 \text{ mmol of ATP} = 30 \text{ kJ of useful energy}$$

Energy production in the ATP–PC system

Within the body's total muscle mass there are between 570 and 690 millimoles of ATP and PC, which can provide about 15–20 kilojoules of useful ATP energy.

Energy production in the anaerobic glycolysis system

The anaerobic glycolysis system can potentially resynthesise 3 moles (3000 millimoles) of ATP from 1 mole of glycogen (180 grams). If all 180 grams of glycogen were broken down, 180 grams of lactic acid would be formed. Since the muscles and blood can tolerate only 60–70 grams of lactic acid before fatigue sets in, only 1.0 to 1.2 moles of ATP (1000 to 1200 millimoles) can actually be resynthesised. Note that 1000–1200 millimoles provides about 30–40 kilojoules of useful energy – about twice as much as via the ATP–PC system.

Energy production in the aerobic system

The aerobic system will, following hundreds of complex chemical reactions, yield a total of 38 moles of ATP from the breakdown of 1 mole of glycogen (or 87–98 moles of ATP from the breakdown of all the stores of glycogen in the muscles). A further 80–100 grams of glycogen (17–22 moles of ATP) is stored in the liver. Provided that exercise intensity is submaximal, approximately 13 times the amount of energy can be released aerobically as is possible anaerobically (from a given amount of glycogen) without the accumulation of fatigue-causing lactic acid.

TABLE 6.6 Key characteristics of the three energy systems

Characteristic	ATP–PC energy system	Anaerobic glycolysis energy system	Aerobic energy system
Alternative name (also known as)	Alactic system, phosphocreatine (PC) or creatine phosphate (CP) system, phosphagen system	Lactacid system	Oxygen system, aerobic glycolysis
Fuel source	Phosphocreatine (PC or PCr) or creatine phosphate (CP) (These are different names for the same chemical.)	Glycogen	At rest: FFAs At submaximal and maximal intensities: » CHO » Fats (when glycogen sparing and when glycogen stores are diminished) » Proteins (only under extreme conditions such as starvation, extended illness or depletion of CHOs and FFAs)
Intensity of activity	High intensity (>95% max HR)	» High intensity (>85% max HR) » Used for increases in intensity during long duration events when PC has not restored	» Resting » Submaximal intensity (<80% max HR)

Characteristic	ATP–PC energy system	Anaerobic glycolysis energy system	Aerobic energy system
Duration system is dominant during activity	Short duration 1–5 seconds	Intermediate duration 5–60 seconds	Long duration >75 seconds
Peak power	2–4 seconds	5–15 seconds	1–1.5 minutes
Amount of ATP produced	Extremely limited (0.7 ATP for every PC molecule)	Small amounts (2–3 ATP for each glucose molecule)	» Large amounts (endless) » Carbohydrates (38 ATP per glucose molecule) » Fats (441 ATP per triglyceride molecule)
Speed of production of ATP	» Explosive, instantaneous » Fast and simple chemical reactions	» Fast » Longer chemical reactions (12 of them) in the breakdown of glycogen compared to ATP–PC	» Medium » Complex chemical reactions » Oxygen availability delays maximum power » Fats slower to resynthesise ATP than CHOs
By-products	» Inorganic phosphates (P_i) » ADP and AMP*	» Lactic acid » H^+ ions » ADP	» CO_2 » H_2O » Heat
Total duration during activity	0–10 seconds	10–75 seconds	>75 seconds (The major contributor of energy for events of more than 75 seconds in total)

*Adenosine monophosphate

FYI

Swimmers can use up to four times the energy a runner would use to cover the same distance. This is because they use more muscles and more energy to keep their body buoyant and to overcome resistance to forward movement.

FYI

The aerobic energy system uses a combination of glycogen (aerobic glycolysis) and fats (aerobic lipolysis) – and sometimes proteins, in extreme circumstances – to produce ATP.

While the aerobic system clearly produces the most energy of the three systems (it has the greatest capacity to supply ATP), it is dependent on the body's ability to take in, transport and utilise oxygen. Note that this does not include the aerobic metabolism of fat or protein as an energy source. Metabolism of fat (and, in extreme circumstances, protein) provides an almost unlimited source of energy for submaximal activity.

Table 6.7 highlights the total possible amount of energy (yield) and the 'running time' or rate of depletion for various fuels when working at 75 per cent of maximum heart rate.

Table 6.7 confirms that when the aerobic system is activated and becomes the major energy contributor, it provides 50 times more energy (moles of ATP) than the ATP–PC and anaerobic glycolysis systems combined.

TABLE 6.7 Approximate reserve values and capacity from various fuels

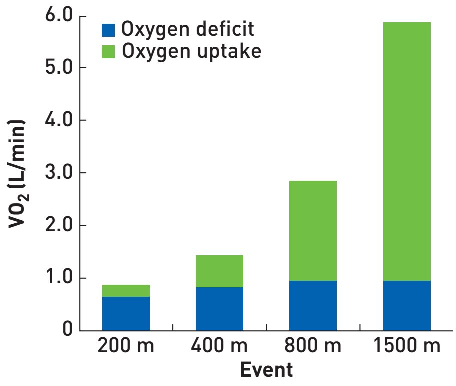
Fuel	Total stored energy (kJ)	'Running time' at 75% max HR (aerobic metabolism)
Stored ATP and PC	80	30 seconds
Blood glucose	360	5 minutes
Liver glycogen	1500	20 minutes
Muscle glycogen	6000	150 minutes
Plasma free fatty acids and triglycerides	180	2 minutes
Intra-muscular triglycerides	9000	120 minutes
Stored fat (adipose)	360 000	2–3 days
Protein	200 000	1–2 days

Notice in Table 6.8 that there is a trade-off between rate and yield for each of the energy systems. As the rate of ATP resynthesis increases, the yield (amount of ATP being produced) decreases.

TABLE 6.8 Rate of ATP production and yield of ATP for the three energy systems

Energy system		Fuel used	Rate of ATP (energy) production	Total amount of ATP (energy)
ATP–PC system		Phosphocreatine (PC) or creatine phosphate (CP)	Fastest 	0.7–1.0
Anaerobic glycolysis		Glucose	Fast 	2–3
Aerobic system	Aerobic glycolysis	Glucose	Moderate 	36–38
	Aerobic lipolysis	Fatty acids	Slowest 	147

THE ENERGY SYSTEM INTERPLAY OR CONTINUUM

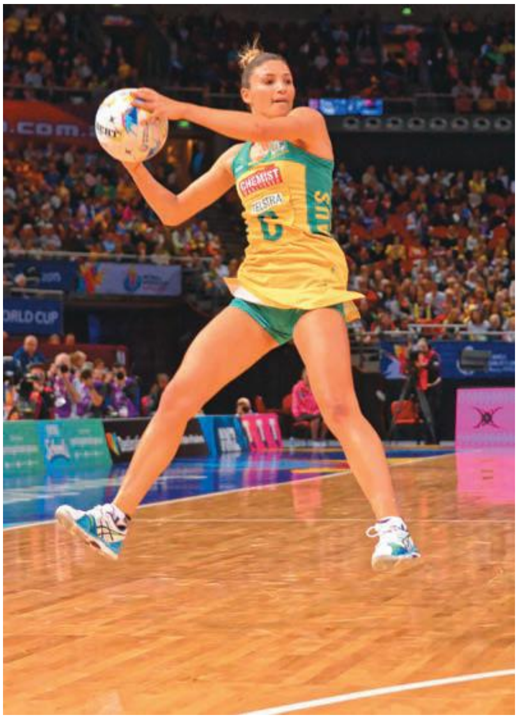


Oxygen deficit is associated with anaerobic ATP production and oxygen uptake is associated with aerobic ATP production.

Virtually all physical activities derive some energy from each of the three energy systems. The three systems contribute energy sequentially but in an overlapping way, depending on the type of activity and exercise demands – each system is best suited to supplying energy for specific types of events or activities. The energy systems do not simply turn themselves on and off when required. In fact, all three systems supply energy for ATP resynthesis during exercise. What differs is the relative importance and contribution that each system makes to rebuilding ATP and supplying energy.

The graph on page 119 showed how the three systems overlap and vary in their percentage contribution to energy/ATP production depending on the duration of the activity, providing an energy continuum. That is, the three systems all work together but vary the amount they each contribute at various stages of the activity. The longer the activity lasts, the more likely it becomes that the ATP–PC system will contribute less, unless it is given the opportunity to 'recharge', as occurs in most team sports and activities.

Alamy Stock Photo/Newzulu



Getty Images/Quinn Rooney

Athletes use all three energy systems, but in varying amounts, for (a) playing netball, and (b) marathon running. How might the ATP–PC system be used differently by the athletes in these two situations?

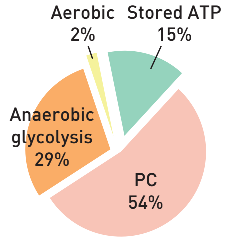
The column graph on page 128 also demonstrates the changing contributions from the aerobic and anaerobic systems as the length of an event increases.

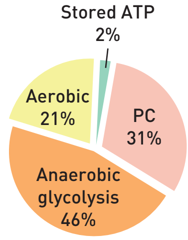
The examples shown above compare the energy system interplay or continuum during an intermittent team sport and a continuous activity. The notion of energy system interplay or an energy system continuum can also be reinforced when considering the energy sources of a 200-metre sprinter at two different stages of the race – 5 seconds and 20 seconds (finish).

As can be seen in the two pie charts, at the 5-second stage of the 200-metre sprint the predominant energy system is the ATP–PC system, which has the fastest rate of energy supply. The anaerobic glycolysis system is also working anaerobically but at a slower rate, because it takes longer to break down glucose than it does PC. The aerobic energy system contributes a very small amount of energy at this stage because the cardiovascular and respiratory systems cannot take up and transport large amounts of oxygen in such a short time.

The energy system contribution at the end of the race (the 20-second mark) is very different, with the anaerobic glycolysis system taking over as the predominant supplier and PC coming in second. PC depletion has been quite significant at this stage – the aerobic system is now contributing significant amounts of energy given that the cardiovascular and respiratory systems are now taking up and transporting much larger amounts of oxygen than at the 5-second stage of the race.

If the runner kept sprinting for another 200 metres, the aerobic energy system would keep increasing its contribution to energy production, almost taking over as the predominant producer of ATP by around the 50-second stage of the race.





Energy system interplay at the 5-second and 20-second stages of a 200-metre sprint

Examples of energy system interplay

Intermittent activity: Team sport: Netball

- Netball is characterised by repeated bouts of high-intensity action interspersed with periods of moderate activity and active rest (during play stoppages). When play starts, all three systems start contributing, but in the first 3–5 seconds most energy is derived from the ATP–PC system. At the same time, the anaerobic glycolysis system increases its contribution to energy production, but more slowly, due to the more complex chemical reactions required to break down glycogen. If efforts above 85 per cent of maximum heart rate (85% max HR) last for longer than 5 seconds, the anaerobic glycolysis system will increase its contribution.
- There is sufficient PC to 'power' efforts for up to 10 seconds, but each explosive burst will deplete the ATP–PC system. Restoration of PC will occur at very low intensities, but until a break of 60+ seconds occurs (e.g. quarter time), this system is unlikely to rebuild or restore PC. Increasingly high-intensity efforts will be driven by the anaerobic glycolysis system as the match progresses, especially for mobile players such as centres, wing attack or defence.
- The aerobic energy system supplies only a small portion of the energy needed during initial intense efforts, but its contribution increases as PC has less time to resynthesise, providing most of the energy during moderate activity after the 2-minute mark. It is critical for efficient recovery during stoppages, breaks and time on the bench. Once the aerobic system has established itself as the major ATP producer, it contributes more ATP than the anaerobic glycolysis system (which can only produce one-fifth to one-seventh as much ATP), even if high-intensity efforts are required.
- At the 5-second stage, the contribution from the three systems might be: ATP–PC 90 per cent, anaerobic glycolysis 5–7 per cent, aerobic 3–5 per cent.
- At the 2-minute stage, the contributions might be: ATP–PC 25 per cent, anaerobic glycolysis 15 per cent, aerobic 60 per cent.

Continuous activity: Individual activity: Marathon

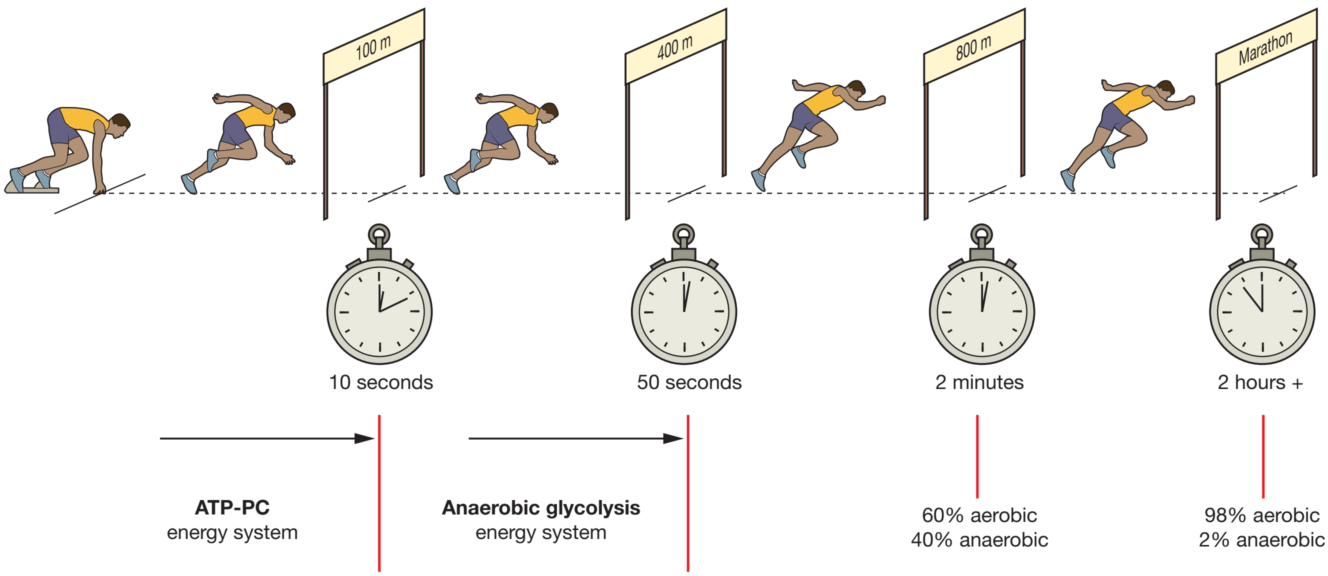
The marathon lasts for just over two hours at the elite level. At the start, all three systems supply energy, but at a slower rate than for someone who is working at a higher intensity, such as a netball centre. PC will be used at a slower rate and so will peak later (8–10 seconds). The anaerobic glycolysis and aerobic systems are also contributing to ATP production, and increase their contribution from the first step. However, because the activity will not exceed the anaerobic threshold in the early stages, the aerobic system quickly takes over as the major ATP producer.

» During any surges in the range where the anaerobic glycolysis system increases its contribution, it still cannot produce the same amount of energy as the aerobic system (2–3 moles ATP compared with 30–36 moles ATP). During surges, the anaerobic glycolysis system isn't the major ATP provider; rather, it is the system that provides the extra energy required to allow an increase in intensity or work output.

» Once PC is depleted it does not have the chance to replenish itself, so the ATP–PC contribution is limited to the first few seconds of the race. As well as being important to producing ATP during the race, the aerobic system also plays an important role in breaking down any metabolic by-products that accumulate when the anaerobic glycolysis system increases its contribution. It also converts any accumulated lactic acid back into glycogen to be used either aerobically or anaerobically.

» At the five-second stage, the contributions might be: ATP–PC 80 per cent, anaerobic glycolysis 15 per cent, aerobic 5 per cent.

» At the one-hour stage the contributions might be: ATP–PC 0 per cent, anaerobic glycolysis 5 per cent, aerobic 95 per cent.



There are two important work times that mark a shift in emphasis from one of the three energy systems to another:
(a) **10 seconds:** After 10 seconds of intense muscular activity the energy system providing the majority of the energy shifts from the ATP–PC system to the anaerobic glycolysis system.
(b) **60–70 seconds:** After about one minute of maximal intensity effort the shift is away from the anaerobic glycolysis system to the aerobic system.

The aerobic–anaerobic split

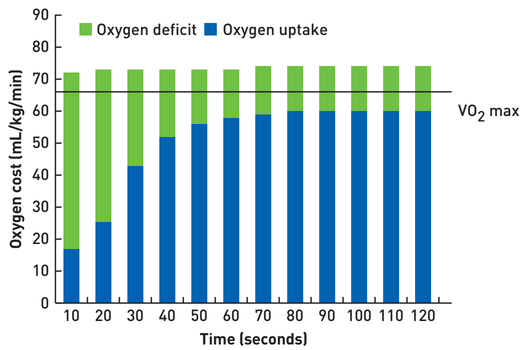
The aerobic–anaerobic split refers to how much the aerobic and anaerobic energy systems are involved in a particular activity. The aerobic–anaerobic split is determined by considering the key factors of intensity, duration (how far into the activity the event has progressed) and availability of fuels. For any activity, rather than considering the overall contribution of the three energy systems, it is probably more accurate to consider the energy system contribution and interplay at various stages of performance.

OXYGEN UPTAKE AT REST, DURING EXERCISE AND RECOVERY

Oxygen deficit

As we start to exercise, there is a period of time in which the body's oxygen demands exceed the supply from its systems. The body's respiratory, circulatory and cardiovascular systems cannot act quickly enough to satisfy the demand for oxygen. The amount by which the oxygen supply fails to meet the body's demand represents the **oxygen deficit**. While oxygen deficit continues, the body must obtain ATP from its anaerobic energy systems, which don't rely on oxygen.

For activities of short duration and high intensity, the body is unable to deliver sufficient oxygen quickly enough to meet the activity demands. This causes the body to rely on PC splitting (using the ATP–PC system) or anaerobic glycolysis (using the anaerobic glycolysis system) to supply ATP anaerobically. In the column graph on the right, the changes in height of the blue columns show that oxygen uptake increases very rapidly for about the first minute, and then levels off. The oxygen deficit is initially large but rapidly declines and also levels off.

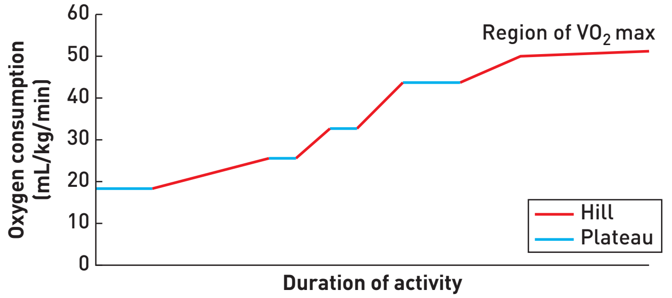


Oxygen uptake and oxygen deficit for an elite 800-metre runner during an event lasting approximately two minutes

Steady state

It is very difficult to sustain high-intensity workloads for longer than 30 seconds because of limitations of the two anaerobic energy systems: primarily, depletion of PC and accumulation of lactic acid, hydrogen ions and other metabolic by-products. Remember, at the commencement of exercise, all three energy systems contribute to ATP production, but the aerobic energy system calls upon many more chemical reactions to liberate ATP. This means it 'lags' in its ability to contribute large amounts of energy in the first 20 to 30 seconds of exercise.

Aerobic training will greatly speed up a person's ability to supply oxygen to working muscles, as well as extract it in larger amounts once it has been transported there. Oxygen consumption rises rapidly during the first minute or so of exercise until sufficient oxygen is taken up, transported and used to meet exercise demands. Once the performance becomes predominantly aerobic, and the aerobic energy system becomes the major supplier of ATP, steady state is attained. When the body is in steady state, oxygen supply equals oxygen demand and this contributes to lactate breakdown, removal and conversion back into useful forms. On any oxygen consumption graph, steady state will be represented by **plateaus** of



Oxygen consumption with increasing loads until VO_2 max is reached

unchanging oxygen demands. Periods of oxygen deficit will be represented by steep lines representing oxygen uptake (in a line graph) or by large increases in the heights of columns (in a column graph).

In the graph at left, repeated 'hills' of different grades, interspersed with plateaus, show changing intensities during surges or changing workloads until the VO_2 max is attained. VO_2 max is measured in millilitres per kilogram of body weight per minute (mL/kg/min). Table 6.9 shows VO_2 max figures for males and females who have had various levels of training to match their daily physical demands.

TABLE 6.9 Comparison of VO_2 maximums

Men	VO_2 max (mL/ kg/ min)	Women	VO_2 max (mL/ kg/ min)
Active	51	Active	46
National-level hockey	60	National-level hockey	52
National-level squash	60	National-level squash	52
AFL rover (15–16 on beep test)	65–70	Netball centre (10–12 on beep test)	48–55
National-level 400-metre swimmer	70	National-level 400-metre swimmer	60
International-level long-distance runner	74	International-level long-distance runner	63
Cross-country skiing	83	Cross-country skiing	68

Oxygen debt or EPOC

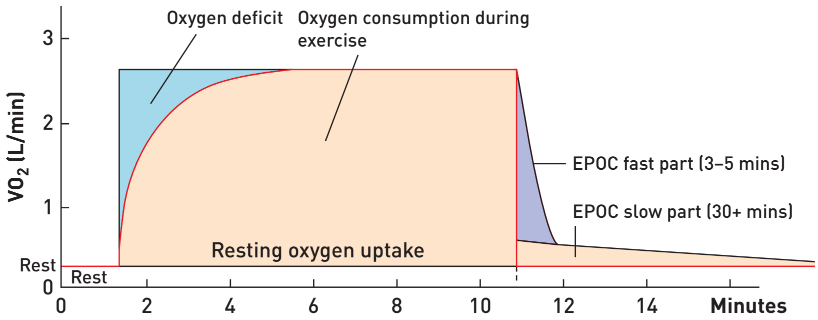
At the completion of exercise, the demand for ATP decreases dramatically. However, oxygen consumption is still higher than at resting levels. This is known as an **oxygen debt**, and typically occurs during the warm-down. Oxygen consumption is extended when an **active recovery** is undertaken, and assists in removal of metabolic by-products. Another term for oxygen debt is excess post-exercise oxygen consumption (**EPOC**).

Oxygen debt is defined as the volume of oxygen used during recovery from exercise that is in excess of resting oxygen consumption.

$$\text{oxygen debt} = VO_2 \text{ used during recovery} - \text{resting } VO_2$$

Exhausting, high-intensity exercise results in a larger oxygen debt than exercise at lower workloads or intensities. The oxygen debt can be further divided into two 'parts'.

The first (or fast) replenishment part is primarily involved in restoring phosphocreatine (PC). This takes approximately 2 to 3 minutes, in which time 2 to 3 litres of oxygen can be consumed. The second (or slow) replenishment part is primarily concerned with removal of lactic acid and H^+. This part is also concerned with various regulatory functions (see Table 6.10), and recovery time depends on usage and metabolic disturbances during activity. The greater the accumulation of lactic acid, the larger EPOC will be. It is also likely that an active recovery will be undertaken, which extends EPOC when compared to a passive recovery.



Oxygen debt and its two parts: fast and slow

TABLE 6.10 Recovery processes during EPOC or oxygen debt

Fast replenishment (3–5 minutes)	Slow replenishment (30+ minutes)
» ATP resynthesis » PC resynthesis » Restore oxygen to **myoglobin**	» Return core temperature to pre-exercise levels » Convert lactic acid to CO_2 and H_2O » Oxidation of H^+ ions » Convert lactic acid to glycogen, protein and glucose » Restore heart rate, ventilation and other body systems to pre-exercise levels

It is important to understand the relationship between exercise intensity and the related factors of oxygen deficit, steady state and oxygen debt. An activity that calls rapidly upon the anaerobic energy systems will have a large oxygen deficit, possibly a brief (or no) steady state and a large oxygen debt or EPOC. An activity performed at a lower intensity will have a smaller oxygen deficit, a longer steady state and a smaller oxygen debt.

Activities where steady state has been established and the anaerobic glycolysis system is called upon increasingly to supply ATP (such as surges or short sprints) contribute to oxygen deficit and so 'add' to the oxygen debt during recovery – essentially extending the slow-replenishment part. A person who has undertaken aerobic training will be able to consume a greater amount of oxygen during steady state, making the anaerobic energy system contribution proportionately smaller at an earlier stage of the activity or performance.

CHAPTER CHECK-UP

1 Other than at the commencement of performance, explain the circumstances under which an oxygen deficit occurs during activities.
2 When is it advantageous to prolong the oxygen debt?
3 What is the trade-off between fuel restoration and conducting an active recovery to facilitate metabolic by-product removal?
4 The oxygen deficit for the 800-metre and 1500-metre running events would be very similar. Briefly discuss how this can be possible.
5 Contrast the oxygen deficit and EPOC for two athletes (Athlete A is a trained endurance athlete whereas Athlete B is a 400-metre specialist) running side by side on treadmills set at the same speeds.

REAL WORLD FOCUS

Michael Johnson

Getty Images/Darren England

Michael Johnson, one of the world's greatest athletes

Sprinter Michael Johnson was born on 13 September 1967 and retired from athletics in 2001 at the top in his field. He is still considered one of the finest athletes to have competed in the modern era. He smashed the world record in the 200-metre sprint (19.32 seconds) and set an Olympic record in the 400-metres (43.49 seconds), becoming the first man to win the gold medal in both races in the same Olympic Games (at Atlanta in 1996). During his athletic career he was a two-time world champion in the 200 metres (1991 and 1995) and a four-time world champion in the 400 metres (1993, 1995, 1997 and 1999). He set the world record in the 400 metres (43.18 seconds) at the 1999 World Championships in Seville (Spain), and won the 400 metres in Sydney in 2000, becoming the only man in history to win the event in two consecutive Olympic Games.

Table 6.11 shows the breakdown of Michael Johnson's speed during his 400-metre run at the at Hayward Field, Oregon, prior to winning gold at his second Olympic Games in Sydney later that year.

TABLE 6.11 Breakdown of Michael Johnson's speed for 400 metres, Prefontaine Classic, 2000

Distance (m)	0	50	100	150	200	250	300	350	400
Time (s)	0	5.6	10.4	15.4	20.6	26.0	31.6	37.4	43.921
Speed (km/h)	–	32.3	36.82	36.3	34.43	33.3	32.2	31.2	27.5

In a Canadian study, fatigue during the 400-metre sprint was investigated by measuring muscle ATP, PC and muscle lactate before and after four experimental sprints (see Table 6.12). Note that after the 200-metre mark, the speed of running decreased, although PC was not totally depleted and lactate concentration was not at a maximum.

TABLE 6.12 Substrate and metabolite changes during a 400-metre sprint

First 100 metres		After 200 metres		End of 400 metres		
PC (mmol/kg)	Muscle lactate (mmol/kg)	PC (mmol/kg)	Muscle lactate (mmol/kg)	ATP concentration	PC concentration	Muscle lactate (mmol/kg)
by 15.8 to 8.3	to 3.6	to 6.5	to 8.3	by 27%	by 89%	to 17.3

Source: Hirvonen et al., 1992

CHAPTER CHECK-UP

1 In Table 6.12, why has muscle lactate doubled in the second half of the sprint (between 200 and 400 metres)?
2 Describe the rate of PC depletion when considering the first 200 metres and compare this with the rate of loss during the second 200 metres.
3 What is the rate of ATP production in the first 200 metres compared to the last 200 metres?
4 How do you account for the difference described in question 3?
5 Discuss the energy system contribution to ATP production at the 200-metre stage of the race and also at the end of the race/400-metre stage.
6 Why do physiologists often measure lactate build-up in the muscles in preference to blood lactate?

FYI

To maintain a running speed, it takes less energy to shorten your running stride and increase stride frequency than to lengthen your stride and reduce the frequency.

LABORATORY

ENERGY SYSTEM CONTRIBUTION DURING A MAXIMAL SPRINT

AIM

To investigate energy system contributions when running 140 metres at maximal effort.

EQUIPMENT

Measuring tape, 7 stopwatches

METHOD

1 Mark out a 140-metre track and position a student with a stopwatch at each 20-metre interval.
2 A starter signals the start of the activity by calling out 'go' and waving their arm. When this occurs, all students should start their stopwatches.
3 As the sprinter passes each 20-metre interval, the student at that interval should stop their stopwatch and keep the time on the display until it has been recorded (see results table below).
4 Share your times with at least two other members of your class for comparison.

RESULTS

Distance covered (m)	0	20	40	60	80	100	120	140
Time at this point (s)								

ANALYSIS

1 Plot a graph of distance (*y*-axis) versus time (*x*-axis) for your results and those of two classmates.
2 Mark on the graph any straight (or almost-straight) portions. Remember not to connect all points but rather to draw a 'line of best fit'.
3 Parts of the graph might be curved rather than straight. Draw a straight line of best fit for each of these sections as well.
4 Calculate the slope or gradient of the graph at the 5-, 10- and 15-second marks. (This represents the running speed in metres per second.) Remember that gradient = rise/run.

DISCUSSION

1 For your performance, were there any differences in the slopes (running speeds) at the 5-, 10- and 15-second marks?
2 At what point of the sprint did you slow down? How do you account for this decrease in running speed?
3 Comment on your performance in terms of energy system contribution (interplay) at different stages of the race, as well as the overall performance.
4 Compare your results with those of your classmates and discuss similarities and differences between energy system contributions.
5 Did any students maintain the same speed throughout the entire run? Briefly discuss what this means in terms of energy system contribution and performance.
6 Is there any link between performance in this sprint, energy system contribution and adaptations that may have occurred as a result of

participating in outside activities? (For example, did people who play netball differ from people who row, or did people who play hockey differ from those involved in athletics?)

Note: Make sure you revisit this data and discussion when you are considering fatigue mechanisms.

EXTENSION

Convert your running speeds into kilometres per hour and compare them with Michael Johnson's times up to the 150-metre mark (see Table 6.11 on page 134).

PRACTICAL ACTIVITY

ENERGY SYSTEM CONTRIBUTION DURING TEAM SPORTS

AIM

To explore the relationship between energy system contribution and participation in an activity requiring different intensities and duration throughout the performance

EQUIPMENT

Heart-rate monitors, equipment for chosen game (see method)

METHOD

The class should participate in a team game performed on a moderate-sized playing area, to allow for data collection, observation and class discussion. Recommended activities include netball, indoor soccer, basketball, indoor hockey, European handball and badminton.

The class elects one or more students to collect heart-rate data during the game. Ideally this should be obtained via a heart-rate monitor, or at regular intervals during the game, and recorded by someone on the sidelines. (See chapter 7 for more ideas on effective data collection and its uses.)

It would be good for more than one student to collect data on heart rate and intensity. This will allow comparisons between energy system contribution to the activity and different players and positions, and can also potentially introduce the notion of energy system adaptations to training and limits to energy systems.

DISCUSSION

During the activity, stop play every five minutes or so to discuss the following questions.

1 Which system is the major energy contributor at various stages of the game, and why? (The discussion should be linked to playing intensity and duration.)
2 Which foods or fuels would be responsible for supplying energy?
3 What limits the use of certain energy systems during the game? Does each player's level of training affect their energy system use?
4 How do the three energy systems work together (interplay) to supply energy during the game?
5 Does the energy system contribution differ for different types of players (for example, mobile versus 'fixed' positions)?
6 Which energy system is the major ATP producer during the break in play, and what is being recharged?

ANALYSIS

Analyse your collected data. Share the data among the class and plot a graph outlining heart rates during the activity.

The graphs should identify key points on the heart-rate axis such as the aerobic training zone, the lactate inflection point and the maximum heart rate. Use this information, as well as playing times, when discussing the energy system interplay for different class members.

CHAPTER CHECK-UP

1 Why does the body call upon the ATP–PC system when rapid and explosive actions are required?
2 Even though all three systems contribute to energy production, why does the anaerobic glycolysis system take longer than the ATP–PC system to peak?
3 How is it possible to use the anaerobic glycolysis system repeatedly during continuous exercise without recovery?
4 Describe the relative energy system contribution at the 40-second stage of an 800-metre race for an elite female athlete (total competition time: 2 minutes) compared with a female club-level runner (total competition time: 2 minutes and 30 seconds).
5 The graph on page 119 shows the energy-system interplay for a sprint cyclist. Why would the interplay of a 400-metre runner vary from that shown in the graph, assuming the same performance time was considered?
6 Describe the energy system contribution to the final 50-metre sprint at the end of a 1500-metre run.

Training the energy systems

One of the most important principles of training, which will be reinforced in later chapters, is **specificity**. Once activity or performance demands have been determined from a games analysis, it is imperative that these are replicated in training. The best training program will also focus on frequency, duration, intensity and progressive overload.

Training the ATP–PC system

Short-interval, sprint training and **plyometrics** are favoured methods to develop the capacity of the ATP–PC system. It is recommended that high- or maximal-intensity efforts lasting up to 10 seconds are followed by adequate time to allow full replenishment of PC. You will discover that a 10-second maximal effort will need to be followed by three minutes of passive recovery in order to fully (98 per cent) restore PC stores. A five-second maximal effort will require only 30 to 60 seconds of rest or recovery. This regime will have minimal input from the anaerobic glycolysis system and focus mainly on developing the ATP–PC system.

Alternatively, resistance or weight training can also be used, where maximal effort occurs up to five seconds. This would involve several repetitions with heavy weights, performed explosively, using muscle groups specific to actions observed during games analysis. Short sprint intervals with work periods of up to 10 seconds will require a work-to-rest ratio of between 1:3 and 1:5, depending on the intensity and the duration of the exercise bout. The closer the intensity is to maximal and to the 10-second 'limit', the more likely that the rest period will need to be five times that of exercise.

Training the anaerobic glycolysis system

The anaerobic glycolysis system's range of maximum energy production is 45–60 seconds during exercise that occurs at more than 85% max HR. Most coaches and physiologists recommend that any training sessions occurring above the anaerobic threshold (85% max HR) will improve the anaerobic glycolysis system. Research indicates that, out of the three energy systems, the anaerobic glycolysis system has the greatest capacity to improve with training. An elite performer can improve their anaerobic thresholds from 83–85% max HR during the off-season to 85–90% max HR during the competitive period, in approximately four months.

Repeated efforts of 30 to 90 seconds above anaerobic threshold, using a work-to-rest ratio of 1:3 or 1:2, will allow sufficient time for large amounts of lactate to be cleared and reconverted into more glycogen or oxidised and dissipated. When considering the work-to-rest ratio for training the anaerobic glycolysis system, your recovery time between exercise bouts will be double or triple the exercise time. The longer the exercise duration lasts above the anaerobic threshold beyond 75 seconds, the greater the contribution from the cardiovascular system and the aerobic energy system. Any work performed at or above the anaerobic threshold will promote increased lactic acid tolerance and delayed lactate inflection point.

Ideally, training to increase the anaerobic threshold should include a work-to-rest ratio of 1:1. Training intensities above the anaerobic threshold are almost totally driven by glycogen, so high-GI foods should be consumed immediately after training, and high-intensity training bouts should be 24 to 36 hours apart.

FYI

The lactate inflection point and onset of blood lactate (OBLA) are very much linked to the anaerobic glycolysis system. They respond primarily to anaerobic training and, to a lesser extent, aerobic training. If the lactate inflection point can be prolonged during physical activity, this will delay associated metabolic by-products from accumulating and causing deterioration in performance, as well as delaying the accumulation of lactic acid in the bloodstream.

Training the aerobic system

VO_2 max is largely inherited and depends on a highly developed aerobic energy system. Although it can be improved with training, it has much less capacity for improvement than the anaerobic energy systems. Any aerobic performer who can significantly increase their anaerobic threshold can perform at a higher intensity more efficiently. Remember, aerobic metabolism produces 20 to 30 times more ATP, without producing fatiguing metabolic by-products, but anaerobic ATP production results in fatiguing metabolic by-products such as inorganic phosphate and hydrogen ions.

Training for the aerobic system can be divided into high- or low-intensity bouts and can use continuous or long-interval training sessions. High-intensity aerobic training works best with interval training, which should range from about 80% to 90% max HR. Keep to a work-to-rest ratio of either 1:0.25 or 1:0.5. In other words, if you work for four minutes at 80% max HR you should rest for one minute before your next repetition, and if you work at 90% max HR, you should rest for two minutes.

The aerobic training zone falls between 70% and 85% max HR. Most lower-intensity aerobic training around 70–75% max HR should be performed continuously and for at least 30 minutes. Low-intensity aerobic training occurs at 'talking pace' – you should be able to talk easily during aerobic exercise.

TABLE 6.13 Training intensity, type of recovery and recommended work-to-rest ratio for the energy systems

Energy system	Training or exercise bout	Intensity	Work: rest ratio	Recommended recovery
ATP–PC	Up to 10 seconds	Maximal	1:3 → 1:5	Passive
Anaerobic glycolysis	10–90 seconds	>85% max HR	1:2 → 1:3	Active
Aerobic	Interval: about 2–3+ minutes	70–85% max HR	1:0.25 → 1:0.5	Active
	Continuous: about 30 minutes			Passive

CHAPTER CHECK-UP

1 What are the differences between short- and intermediate-interval training with reference to the three energy systems?
2 If the work-to-rest ratio is changed from 1:5 to 1:2 for interval training, what effect will this have on the repeated use of energy system(s) for subsequent repetitions?
3 What is the trade-off between performing an active recovery following increased energy contribution from the anaerobic glycolysis system, and resynthesis of PC to be used by the other anaerobic energy system?
4 Discuss how anaerobic training might be used to improve the performance of an endurance athlete such as a marathon runner or triathlete, despite these activities predominantly calling upon the aerobic energy system.

QUICKVID

Watch clear explanations of the energy system interplay at various intensities (continuous and interval), the concepts of rate and capacity, and aerobic energy production by one of the authors. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 6, page 139 and choose the 'interactive'.

Video

CHAPTER SUMMARY

- Carbohydrates, fats and proteins are broken down and used immediately or stored as chemical energy to allow muscular contractions and movement. Carbohydrates are the body's preferred source of fuel, while fat acts as a 'back-up' fuel and protein is used for growth and repair.
- Only a very small amount of ATP exists in the muscles, sufficient for a few maximal contractions (two to three seconds). To provide energy for longer periods, ATP is continually rebuilt or resynthesised from phosphocreatine (PC) or food fuel sources, almost as quickly as it is broken down.
- During glycolysis, each glucose molecule is split into two pyruvic acid molecules. Under aerobic conditions, the pyruvic acid enters the mitochondria and undergoes aerobic glycolysis to produce more ATP. Under anaerobic conditions, the pyruvic acid transforms into lactic acid and then lactate and hydrogen ions (H^+) via anaerobic glycolysis.
- Fuel sources differ at varying exercise intensities. Carbohydrates are the only source of energy during maximal-intensity exercise, and the primary source during anaerobic exercise, once PC has been depleted. During exercise, carbohydrates are preferred over fats, as they require less oxygen to produce energy. Fats are used increasingly as carbohydrates deplete. Protein is used for energy only in extreme circumstances, such as extended-duration exercise.
- The three energy systems responsible for the resynthesis of ATP are the ATP–PC system, the anaerobic glycolysis and the aerobic system. The first two are anaerobic systems. The three energy systems working together to supply energy is known as interplay.
- All three systems are activated at the start of exercise and their relative contribution is determined by the intensity and duration of the exercise, whether or not oxygen is present, and the depletion of chemical and food fuels during exercise.
- The ATP–PC system provides the most rapidly available source of energy because it doesn't depend on oxygen, but it is exhausted very quickly, after only 6–10 seconds of intense muscular activity. PC is replenished within three minutes of a passive recovery.
- All activities carried out above 100 per cent VO_2 max depend on an anaerobic energy supply. If PC has not had time to replenish, this will be powered by the anaerobic glycolysis system.
- At the lactate inflection point (LIP) maximal lactic acid production and maximal lactic acid removal are equal. This is sometimes referred to as the maximal lactate steady state (MLSS). At this point, no lactate accumulates and the aerobic energy system is providing most of the ATP and is the predominant system.
- Aerobic glycolysis is the breakdown of glucose when plenty of oxygen is available. The aerobic energy system produces energy by breaking down glycogen (preferentially, during exercise) or free fatty acids (preferentially, at rest) or amino acids (as a last-resort energy source) to resynthesise ATP.
- Peak power from the aerobic system is usually reached after 60–70 seconds. After approximately one minute of maximal-intensity exercise, the aerobic and anaerobic systems are releasing almost equal amounts of energy. The aerobic–anaerobic split or 50–50 mark occurs somewhere between 60 and 75 seconds, depending on the person's level of training.
- When using the aerobic energy system, any accumulated lactic acid and other metabolites have the opportunity of being oxidised/removed or re-converted back into glycogen to be again used as an energy source.

CHAPTER REVIEW

Multiple-choice questions

1 Which of the following best describes the energy system interplay or continuum?
  A The ATP–PC system provides the initial energy for activities, and is then taken over by the anaerobic glycolysis and aerobic systems.
  B All three energy systems supply energy continuously.
  C All three energy systems contribute to ATP production but, at any stage, one of them is the major contributor.
  D None of the above.

2 During submaximal activities lasting up to 30 minutes, the majority of the ATP is resynthesised by breaking down:
  A phosphocreatine.
  B glycogen.
  C free fatty acids.
  D proteins.

3 When switching from glycogen to free fatty acids as the major fuel source in a marathon, why must the performer slow down?
  A More oxygen is required to resynthesise ATP and less is available to working muscles.
  B More processes are required in breaking down free fatty acids, so ATP is resynthesised at a slower rate.
  C It is likely that the performance will increasingly start to become anaerobic.
  D All of the above.

4 Why does the ATP–PC system provide most energy at the start of an explosive or maximal activity?
  A It is impossible to release ATP using the aerobic system in such a short period of time.
  B It requires the smallest number of chemical reactions to break down PC and resynthesise ATP.
  C ATP is readily available at the muscle site.
  D All of the above.

Short-answer questions

5 Fats can provide more ATP than carbohydrates, yet they are not the body's preferred exercise fuel. Briefly discuss why this is.

6 a The lactate inflection point (LIP) or maximum lactate steady state (MLSS) is the point at which maximal lactate production equals maximal lactate removal. Outline three advantages an athlete gains by being able to increase their LIP.
  b Discuss any changes likely to be experienced in energy-system contribution to activity if a person's LIP increases from 85% to 90% max HR.
  c The LIP increases as an adaptation to aerobic training. How might participation in intermittent interval training affect a person's LIP?

7 a PC stored in muscles is depleted after only 10–15 seconds of activity. Discuss how athletes could increase their PC stores through training and diet.
  b Suppose that a 200-metre hurdler could use his ATP–PC system for 15–20 per cent longer than his opponents. Discuss the advantages to the hurdler in terms of energy production, fatigue and overall performance time.

8 Briefly discuss what is meant by the energy-system interplay or continuum. Use a sport of your choice to clearly demonstrate your understanding. (It is probably best to choose a sport that has varying intensities and duration of efforts.)

9 Discuss the energy system usage and food–fuel contribution to the running of a marathon. Assume the performer runs predominantly at 80% to 85% max HR, with the exception of uphill sections of the course, where the workload increases. The total time of the event is 2 hours and 25 minutes.

CHAPTER 7

ACUTE RESPONSES TO EXERCISE

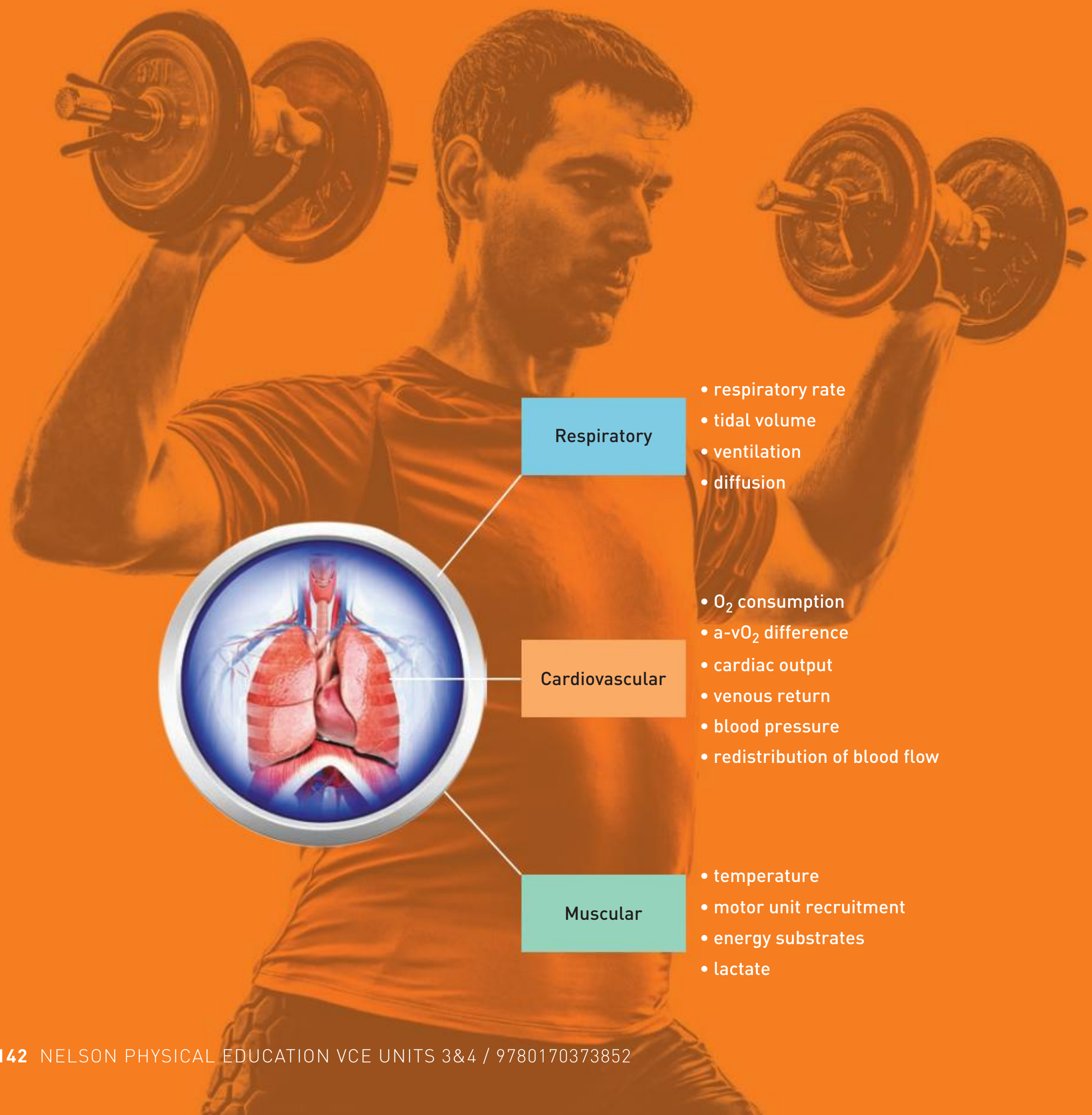
Key knowledge

» acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems

Key skills

» participate in physical activities to collect and analyse data on the range of acute effects that physical activity has on the cardiovascular, respiratory and muscular systems of the body

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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INTRODUCTION

When we start to exercise, a number of physiological changes occur in the body to meet the energy requirements of the activity. The respiratory, cardiovascular and muscular systems respond to meet the increased demand for energy. The initial responses of these three systems are called **acute responses**. The level of response depends on the intensity and type of exercise being undertaken.

ACUTE RESPIRATORY RESPONSES TO EXERCISE

The respiratory system is responsible for the delivery of oxygen to, and removal of carbon dioxide from, the cells of the body. At the beginning of exercise, receptors in the working muscles stimulate **ventilation (V)** by sending messages to the respiratory centres in the brain telling them to increase the volume and rate of breathing. When you start exercising, you will breathe more deeply and more often.

Ventilation

At rest, the amount of air we breathe in per minute varies from person to person. Depending on body size and gender, it can be anywhere from 4 to 15 litres. This can increase significantly during exercise, becoming 15 to 30 times greater than at rest. This increase in ventilation is a result of an increase in **tidal volume (TV)** and/or **respiratory rate (RR)**.

$$V\ (\text{L/min}) = TV\ (\text{L/breath}) \times RR\ (\text{breaths/min})$$

PRACTICAL ACTIVITY

MEASURING RESPIRATORY RATE

Breathing is an involuntary action – imagine what would happen if you had to think about every breath you take!

In this activity you will calculate your respiratory rate (RR) by counting the number of breaths you take, and predict your ventilation.

respiratory rate = number of breaths per minute

ventilation = tidal volume × respiratory rate

METHOD

Sit quietly and calmly in your chair and place your hand lightly on your abdomen. Close your eyes and count the number of times your hand rises and falls in one minute (your teacher will time you).

» Record your respiratory rate.

» With a partner, sit facing each other and for one minute try to breathe at the same rate as your partner.

» Record your respiratory rate.

RESULTS

Use a spreadsheet to record and calculate the results for this activity. Record the respiratory rate for everyone in the class. There is an Excel spreadsheet for you to use online if you wish. Go to http://www.nelsonnet.com.au, use your login code and navigate to this page.

Average tidal volume

Males	Females
600 mL	500 mL

Calculate the amount of air you breathe in or out in one minute based on the average tidal volume provided above.

Record the ventilation for each member of the class.

Calculate the average respiratory rate and ventilation for the class, for male students and for female students.

>

DISCUSSION

1 What is the range of respiratory rates in the class? Was it different or the same for males and females?
2 Suggest three factors that might affect respiratory rates.
3 Suggest a reason for the difference in tidal volume for males and females.
4 Describe what happened to your breathing when you were facing your partner. Did controlling your respiratory rate feel normal? Why or why not?
5 Predict what will happen to both respiratory rate and ventilation when you begin to exercise.

FYI

Respiratory rate changes when we pay attention to it, so it is difficult to measure our own respiratory rate accurately! The results you obtain in the 'Measuring respiratory rate' activity are likely to be between two and three times smaller than your actual respiratory rate at rest, because when we focus on our breathing it becomes slower and deeper.

Breathing to reduce stress

Being able to control our breathing is important for controlling stress and anxiety and promoting relaxation. This can be useful to athletes, particularly before competition.

Table 7.1 shows typical values for respiratory rate, tidal volume and ventilation at rest and during moderate and maximal exercise.

TABLE 7.1 Comparison of respiratory rate, tidal volume and ventilation at rest and during exercise

Condition	Respiratory rate (breaths/min)	Tidal volume (L)	Ventilation (L/min)
Rest	12	0.5	6
Moderate exercise	30	2.5	75
Maximal exercise	48	4.0	192

Weblink

Go to the Victorian Government's Better Health website to read an article on breathing to reduce stress. You can link direct via http://vcepe34.nelsonnet.com.au.

When exercise commences, increases in respiratory rate and tidal volume increase ventilation dramatically. This in turn increases the volume of oxygen in the lungs, which can then be transported to the working muscles. Any combination of alterations to tidal volume and respiratory rate can be selected to increase the available oxygen, but athletes choose a combination that seems natural to them. Instructing athletes to deliberately alter their breathing rhythm does not appear to improve performance, and the best combination is that which is automatically selected by the body.

At submaximal exercise intensities, ventilation increases rapidly at the start of exercise and then more slowly until it reaches a plateau. This occurs about four to five minutes into exercise. During light to moderate exercise, the relationship between ventilation and oxygen consumption is linear. At low exercise intensities, tidal volume and respiratory rate increase proportionally in order to increase ventilation.

In maximal intensity exercise, ventilation continues to increase until the exercise is stopped. At high intensities, tidal volume **plateaus** and any further increase in ventilation is due to further increases in respiratory rate. At progressively higher exercise intensities, the increase in ventilation is no longer proportional to oxygen consumption.

FYI

Ventilation increases immediately before exercise! This is most likely due to anticipation of the exercise that is about to be done.

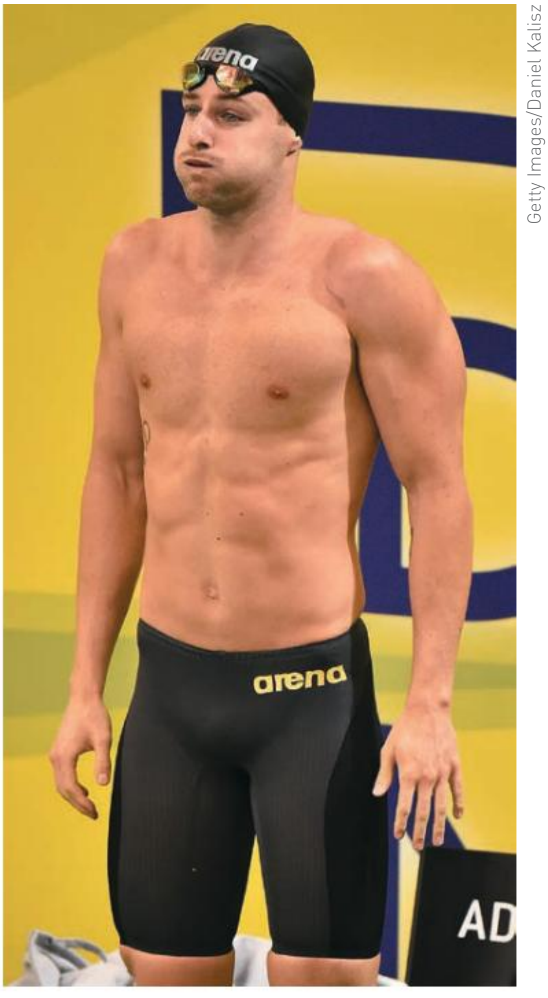
The point where ventilation is no longer increasing linearly with the increase in exercise intensity is called the **ventilatory threshold**. This threshold occurs at approximately 65–75 per cent of maximum oxygen consumption. Ventilation continues to increase non-linearly until the exercise has ceased, when it will decrease suddenly and then return to resting levels more gradually, as shown in the graph below.

Diffusion

Gas exchange occurs in the lungs at the alveolar–capillary interface and in the muscle at the tissue–capillary interface through **diffusion**. Diffusion of gases always occurs from an area of high pressure to an area of low pressure. Oxygen concentration in the lungs is high, so oxygen diffuses from the alveoli into the bloodstream (see below). Carbon dioxide levels in the blood are high, so carbon dioxide moves from the blood into the alveoli via a diffusion path.

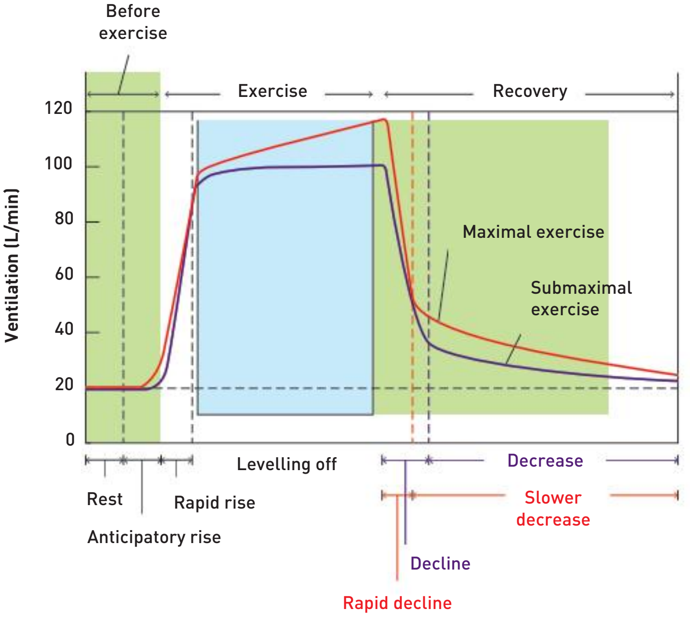
The opposite occurs at the muscle, where blood oxygen levels are high and muscle oxygen levels are low. Here, oxygen is diffused into the muscle while carbon dioxide moves out of the muscle and into the bloodstream (see below right).

During exercise, the diffusion capacity is increased (due to increased surface area of the alveoli and the muscle tissue) so that greater amounts of oxygen and carbon dioxide can be exchanged at the alveoli and the muscle. This means greater amounts of oxygen are available at the muscle and greater amounts of carbon dioxide (which have been produced as a by-product of aerobic energy production) can be removed.



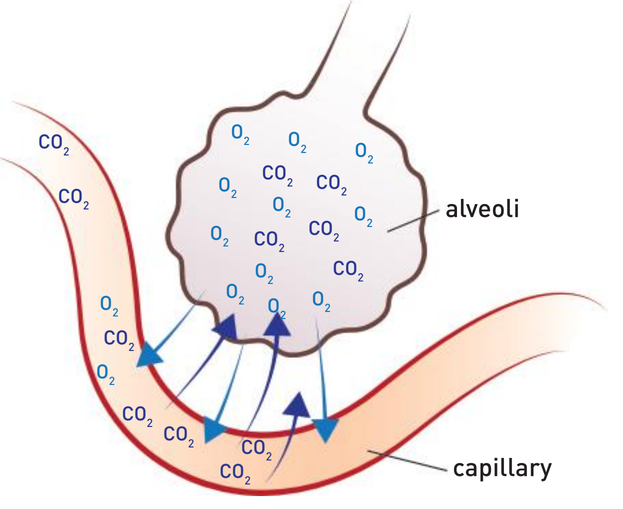
Getty Images/Daniel Kalisz

Athletes such as Australian swimmer James Magnussen focus on controlling their breathing when preparing to compete



Ventilation responses to submaximal and maximal exercise

Adapted from: Fox, Bowers & Foss, 1993



Oxygen and carbon dioxide are transferred between alveoli and the capillary network through diffusion.

CHAPTER CHECK-UP

1 What two factors contribute to changes in ventilation? Are these changes voluntary or involuntary? Explain.
2 Describe the relationship between respiratory rate, tidal volume and ventilation.
3 Explain the mechanisms responsible for the rapid rise, plateau and decrease in ventilation shown on the graph on page 145.
4 How does the respiratory system respond to the demands of submaximal and maximal exercise?
5 Why are the increases in respiratory rate, tidal volume and ventilation shown in Table 7.1 necessary when the body goes from rest to exercise?

CARDIOVASCULAR RESPONSES TO EXERCISE

The circulatory system (heart, blood and blood vessels) works to maintain optimal levels of functioning in all conditions, including at rest and during exercise. During exercise, the cardiovascular system needs to deliver greater amounts of oxygen and energy substrates to the working muscles in order to meet the increasing energy demands of the activity. The focus is on getting more blood to the working muscles to deliver oxygen and speed up the removal of carbon dioxide and other waste products. To do this, the cardiovascular system undergoes a number of changes.

Cardiac output

Cardiac output (Q) is the product of **stroke volume (SV)**, which is the amount of blood pumped out of the left ventricle of the heart per beat, and **heart rate (HR)**.

Q (L/min) = HR (beats/min) × SV (L/beat)

TABLE 7.2 Changes in SV, HR and Q in untrained and trained individuals at rest and during maximal exercise

Condition		Stroke volume (mL/beat)	Heart rate (beats/min)	Cardiac output (L/min)
Untrained	Rest	75	82	6.2
	Maximal exercise	112	200	22.4
Trained	Rest	105	58	6.1
	Maximal exercise	126	192	24.2

A more efficient circulatory system doesn't have to work as hard to provide the same cardiac output. A lower heart rate, together with an increased stroke volume, provides the same cardiac output as a higher heart rate and lower stroke volume but indicates a more efficient circulatory system. As shown in Table 7.2, for similar cardiac output in trained and untrained individuals the trained person had a significantly lower heart rate and a higher stroke volume, particularly at rest.

Cardiac output increases with work rate in order to increase the amount of oxygen delivered to the working muscles. When the body begins to exercise, both stroke volume and heart rate rise to increase the cardiac output of the heart. At rest, the heart will eject only about 40–50 per cent of the blood in the left ventricle. During exercise, a stronger ventricular contraction causes greater amounts of blood to be ejected, leading to an increase in stroke volume. Stroke volume increases to a maximum during submaximal workloads; any further increase in cardiac output is a result of an increase in heart rate.

Heart rate is the most important factor in increasing cardiac output during exercise. During submaximal exercise, heart rate will increase until the oxygen demands of the activity have been met. It will then level off, as the body has reached a steady state where oxygen supply equals oxygen demand. With increasing workloads, heart rate will increase linearly until maximum heart rate (max HR) is reached. Maximum heart rate can be estimated by:

max HR = 220 – age

FYI

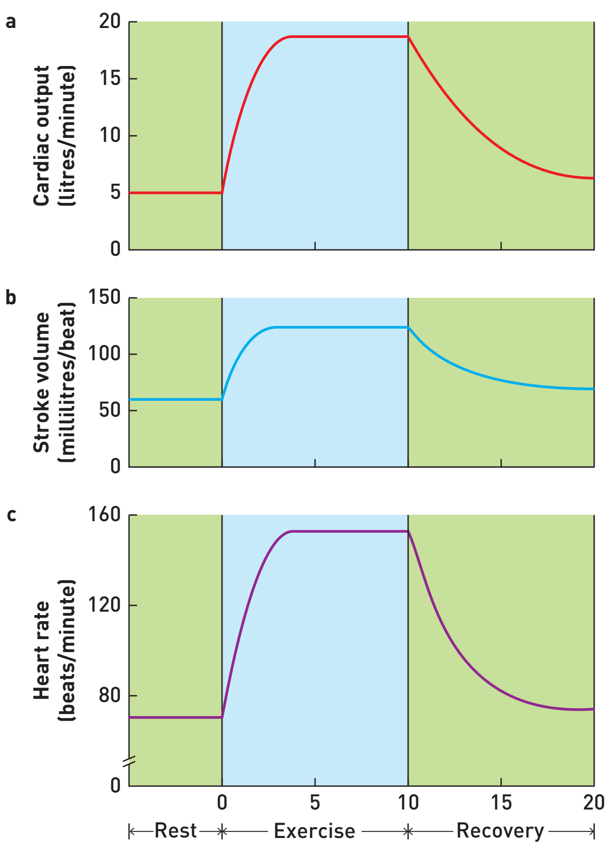
Women have lower stroke volumes than men, both at rest and during exercise, because they have smaller heart volumes.

INVESTIGATION

Much research has been conducted into calculating maximum heart rate. To find out how the findings from this research affect your max HR, go to http://vcepe34.nelsonnet.com.au and enter your age into the calculator. Why is it important to be able to calculate maximum heart rate?

Weblink

The graphs at right show the changes in heart rate, stroke volume and cardiac output during short-term, submaximal exercise. If the exercise duration continues past 30 minutes, heart rate will continue to increase but stroke volume will decrease. The changes in heart rate and stroke volume are equal in size but opposite in direction. Therefore, cardiac output stays the same to meet the demands of the exercise. Increasing blood flow to the working muscles is only part of the equation. Oxygen extraction by the muscles ensures that the cells are receiving adequate oxygen for energy production.



Changes in (a) cardiac output, (b) stroke volume and (c) heart rate during short-term, submaximal exercise

Adapted from: Fox, Bowers & Foss, 1993

LABORATORY REPORT

HEART RATE RESPONSE TO EXERCISE

AIM

To determine the change in heart rate in response to submaximal and maximal exercise

EQUIPMENT

You will need heart-rate monitors. (If not available, calculate heart rate manually for 15 seconds at either the **radial or carotid pulse**.)

METHOD

Submaximal exercise

1 Subjects sit quietly for 3–5 minutes. Record their heart rate (or take resting pulse manually).

2 Subjects complete 10 minutes of continuous exercise (e.g. running, cycling, step-ups).

3 Record subjects' heart rate after each minute of exercise in a results table, as shown below.

4 Subjects perform an active recovery (walking) until heart rate drops to below 100 beats per minute. Record heart rate at 1, 3 and 5 minutes post-exercise.

Maximal exercise

1 Record subjects' heart rate.

2 Subjects perform five maximal sprints (20 metres). Record heart rate at completion of last sprint.

You can fill in these tables online by going to http://www.nelsonnet.com.au and using your login to get to this page.

RESULTS

Heart rate (bpm) for maximal exercise		
Subject	Pre-sprint	Post-sprint
1		
2		
…		

Scaffold

Heart rate (bpm) for submaximal exercise														
	Pre-test	Continuous exercise									Recovery			
Subject	Rest	1	2	3	4	5	6	7	8	9	10	1	3	5	
1															
2															
…															

DISCUSSION

1 Graph the heart-rate responses for both submaximal and maximal exercise on the same axis. Describe the shape of each graph in terms of heart-rate changes.

2 Did heart rate increase more with maximal exercise or submaximal exercise? Explain your answer with reference to physiological responses to exercise.

3 Why does heart rate need to increase with exercise?

4 Compare your data with that of another person in the class. Explain any differences.

5 Predict (by drawing on the graph) the heart rate response of a highly trained triathlete to this same activity.

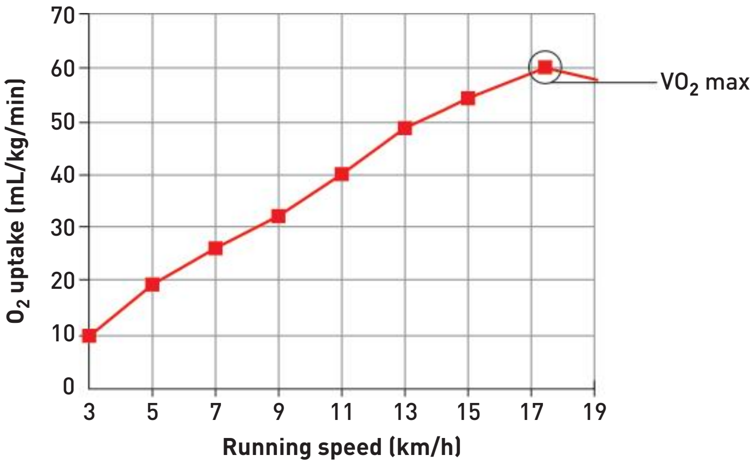
CONCLUSION

Write a conclusion based on your results and the discussion.

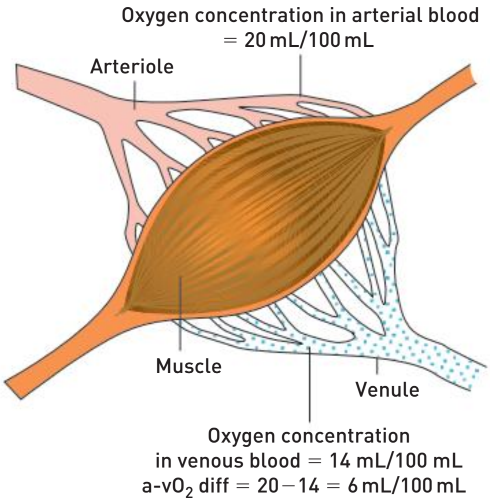
Oxygen consumption (VO_2) and arteriovenous oxygen difference (a-vO_2 diff)

Oxygen consumption is the volume of oxygen that can be taken up and used by the body. As intensity of exercise increases, so does oxygen consumption (see graph on page 149).

This is a direct result of an increase in cardiac output (as discussed earlier) and an increase in the **arteriovenous oxygen difference (a-vO_2 diff)** (see page 149). At rest, arterial blood releases as little as 25 per cent of its oxygen content to the tissues, and the remaining 75 per cent returns to the heart in venous blood. During exercise, the working muscles extract greater amounts of oxygen from the blood, increasing the a-vO_2 difference. While there is always some oxygen in the blood returning to the heart, when measured across a working muscle, oxygen extraction can approach 100 per cent.



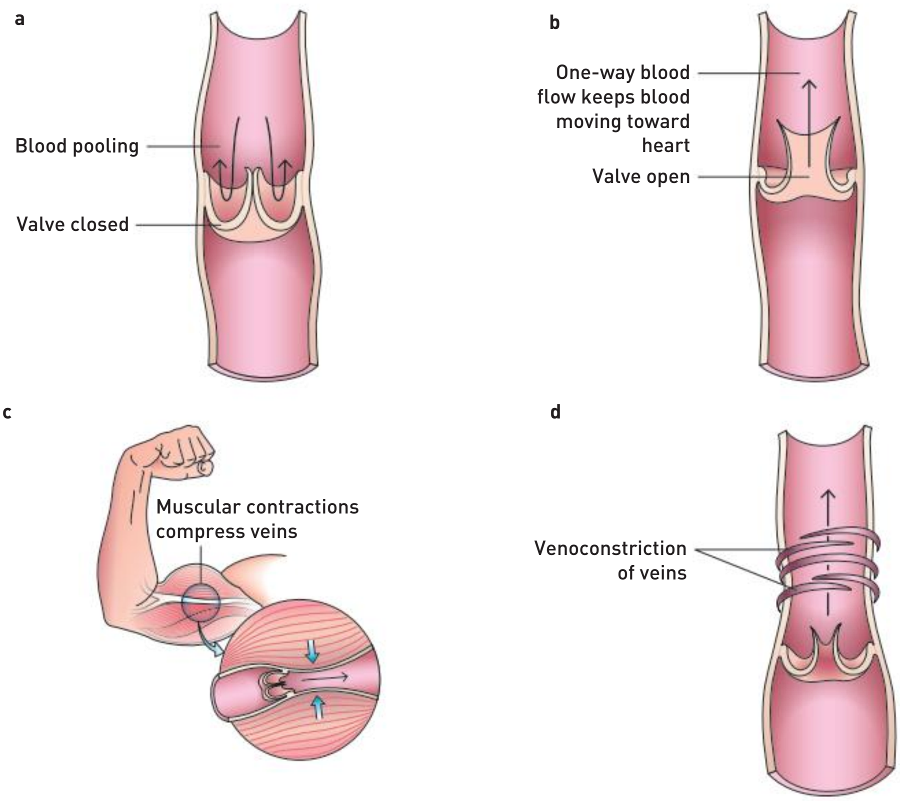
Oxygen consumption and exercise intensity



Arteriovenous oxygen difference

Venous return

The heart can only eject as much blood as it has in its ventricles, so it is important for an increase in cardiac output to be accompanied by an increase in **venous return**. During exercise, the venous return is increased via three mechanisms: the muscle pump, the respiratory pump and venoconstriction, or constriction of the veins (see below).



Processes for assisting venous return include (a) and (b) valves, (c) muscle pump and (d) venoconstriction

The muscle pump is a result of the mechanical pumping action caused by repetitive muscular contractions. When the muscles contract, the veins are squashed together and the blood in them is forced towards the heart. Valves in the veins prevent the blood from flowing backwards – veins are a one-way street. When the muscle relaxes, the veins fill with blood until the next contraction and the process continues, resulting in a 'pumping' action.

The respiratory pump uses a similar mechanical action to assist venous return. During inspiration (breathing in), the diaphragm increases abdominal pressure, and veins in the thorax and abdomen are emptied towards the heart. Then during expiration (breathing out), the process is reversed – the veins fill with blood ready to be emptied again. Venous return is promoted simply through breathing. During exercise, when venous return needs to increase, respiratory rate increases, which makes the pump more effective.

Venoconstriction is a reflex controlled by the central nervous system, and assists in venous return. Venoconstriction reduces the capacity of the venous system, forcing the blood in the veins to be pushed out towards the heart.

FYI

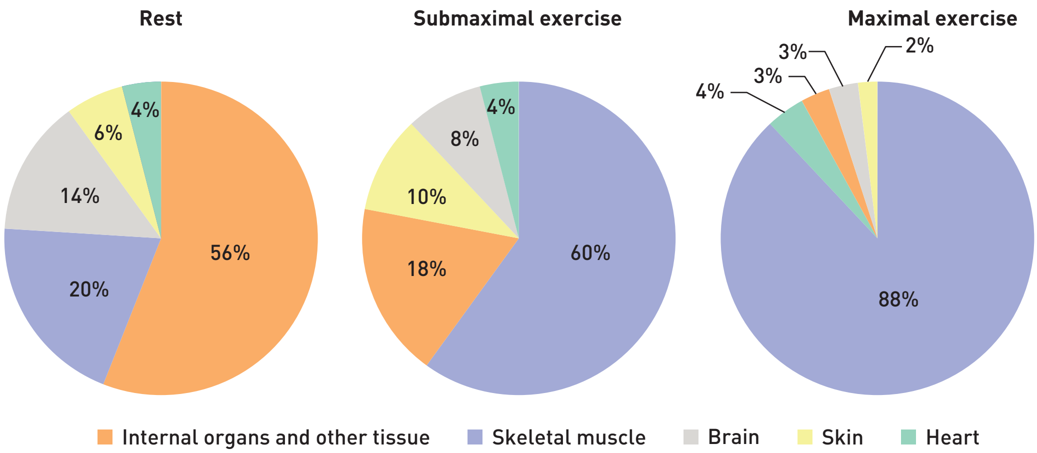
When the valves in veins collapse and allow blood to flow back towards the muscle, varicose veins are formed. Blood pools in the veins (usually in surface veins of the lower body), causing them to become stretched and painful.

Blood volume

During aerobic exercise, blood volumes decrease. Studies have shown that plasma volume can decrease by 10 per cent during prolonged endurance activities. Plasma volumes decrease rapidly within the first five minutes of exercise, but then stabilise. The size of the decrease depends on the intensity of the exercise, environmental factors (such as temperature) and the level of hydration of the individual.

Redistribution of blood flow

At rest, 80 per cent of blood is directed to the brain and internal organs. Cardiac output increases with an increase in exercise intensity. During submaximal exercise, 50–60 per cent of blood flow is redirected to the working muscles and approximately 10 per cent to the skin. During maximal exercise, nearly 80 per cent of blood flow is directed to the working muscles so that these muscles receive the greatest percentage of the cardiac output (see graphs below). This redirection is important to provide the oxygen and fuels needed for energy production and to remove the waste products from the working muscles. **Vasoconstriction** occurs in the arterioles supplying the inactive areas of the body, decreasing the blood flow, and **vasodilation** occurs in the arterioles supplying the working muscles, increasing the blood flow to these areas.

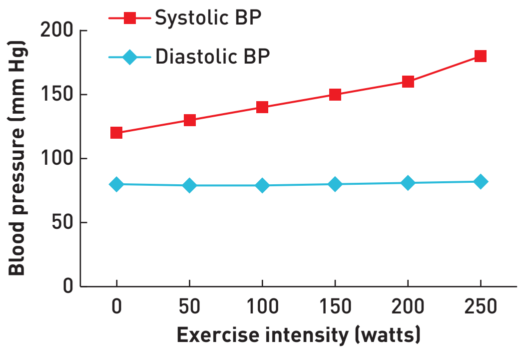


Distribution of cardiac output (a) at rest, (b) during submaximal exercise and (c) during maximal exercise

Adapted from Abernethy et al., 2013

Blood supply to the heart increases during exercise. Vasodilation of the coronary arteries assists in directing blood through these vessels to supply the heart muscle with the extra oxygen it needs.

Blood flow to the skin helps regulate body temperature through heat exchange with the environment. As exercise intensity increases, blood flow to the skin also increases, but as exercise approaches a maximum, blood flow to the skin decreases.



Blood pressure responses to continuous exercise of increasing intensity

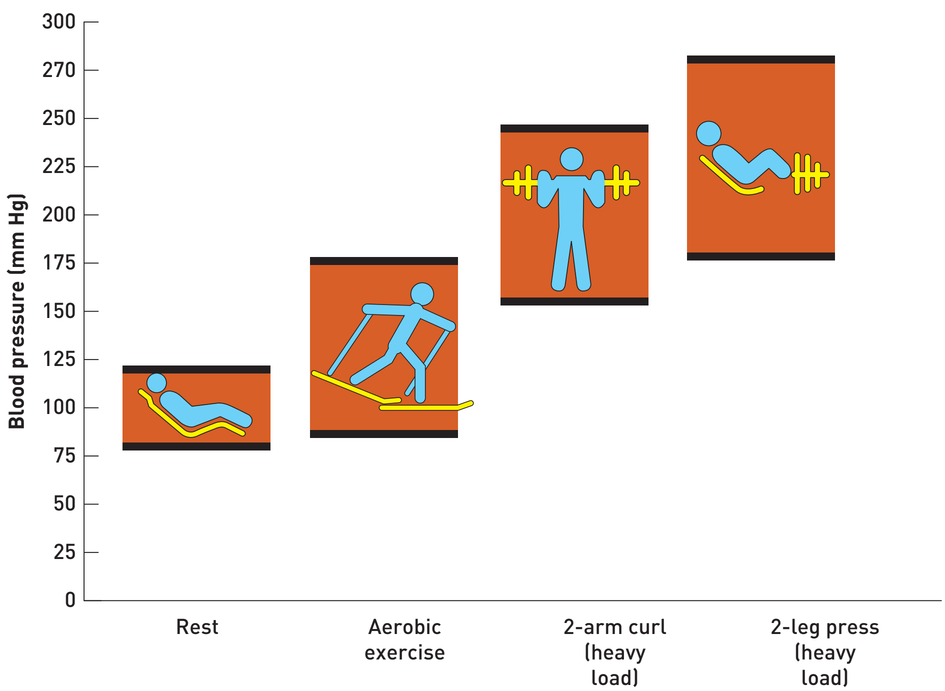
Blood pressure

During exercise, the increase in cardiac output results in an increase in blood pressure. Exercise that uses large muscle groups (such as running, cycling or swimming) affects **systolic blood pressure** more than **diastolic blood pressure** (see below). During these types of exercise, the arterioles supplying the active or working muscles will vasodilate (increase in diameter), resulting in more blood draining from the arterioles into the muscle capillaries. This minimises any changes to diastolic pressure. Strengthening exercises cause greater increases in systolic and diastolic blood pressures, but the changes in heart rate and cardiac output are less (see graph below).

As shown in the graphs on this page, blood pressure changes depending on the needs of the body. Blood pressure can be affected not only by exercise but by body position, breathing, emotional state and sleep. If blood pressure remains consistently high (hypertension), this can lead to serious conditions such as heart attacks and stroke. Blood pressure can be measured using an electronic blood pressure monitor (see at right) or taken manually with a sphygmomanometer.

Shutterstock.com/Serenethos

An electronic blood pressure monitor



Changes in blood pressure as a result of different exercise types

Adapted from: McArdle, Katch & Katch, 2015

LABORATORY REPORT

THE EFFECT OF POSTURE AND EXERCISE ON BLOOD PRESSURE

AIM

To investigate the effect of posture and exercise on blood pressure

EQUIPMENT

You will need a digital blood pressure monitor.

METHOD

1 Measure the blood pressure of each subject in the following positions: lying down, sitting and standing. Subjects should be in each position for 3–4 minutes before you take the blood pressure measurement.
2 Each subject completes a 400-metre run at a moderate to high intensity.
3 Measure the subject's blood pressure at the completion of the exercise.

RESULTS

Record the blood pressure readings for each member of the class in a table. You can fill in a table online, adding each class member's name in the column 'Subject'. Go to http://www.nelsonnet.com.au and use your login to get to this page.

Scaffold

Subject	Position			
	Lying	Sitting	Standing	Exercise
1				
2				
...				

DISCUSSION

1 Define systolic and diastolic blood pressure.
2 For each subject, was there any change in blood pressure for each different position?
3 Explain why blood pressure may vary depending on the position of the body.
4 What effect does exercise have on blood pressure?
5 Predict what might happen to blood pressure if the exercise was at maximal intensity.

CONCLUSION

Write a conclusion based on your results and the discussion.

CHAPTER CHECK-UP

1 Explain the relationship between cardiac output, stroke volume and heart rate.
2 Suggest why blood pressure increases more dramatically with resistance exercise compared with continuous exercise.
3 Adequate oxygen delivery is facilitated by increased blood flow and increased oxygen extraction. Outline the acute physiological responses that allow these two things to occur.
4 Provide an analogy to explain to another student how the vascular system redirects blood flow during exercise.

ACUTE MUSCULAR RESPONSES TO EXERCISE

In order for exercise to begin, the muscular contractions responsible for movement need to increase. All physical activity, exercise and sports require movement of the body. Whether the action is walking the dog, going for a run or kicking a football, the muscles involved need to be set in motion. The type of contraction, the force and the speed of contraction are controlled by the central nervous system; that is, the brain tells the body what to do. There are a number of mechanisms responsible for acute responses to exercise in muscles, including increased blood flow to working muscles, recruitment and activation of muscle fibres, lactate production and heat production.

Increased blood flow

As part of the redistribution of blood flow during exercise, blood is directed away from non-essential organs to the working muscles. During exercise, skeletal capillaries open up and serve three main purposes. They:

- allow increases in total muscle blood flow
- deliver large blood volume with minimal increase in blood flow velocity
- increase the surface area to increase diffusion rates.

So blood flow to the working muscles increases, allowing for greater delivery of oxygen to meet the metabolic demands of the exercise.

Recruitment and activation of muscle fibres

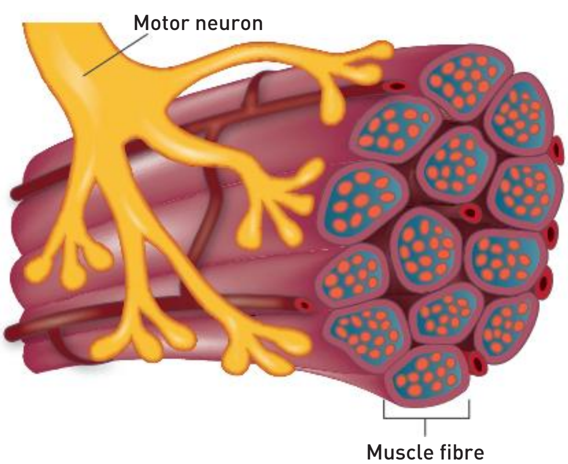
The central nervous system uses **motor units** to 'talk' to the muscles to control muscular contractions. During exercise, the amount of force developed in a working muscle increases. To do this, the brain can either increase the number of motor units recruited, or it can increase the frequency of messages sent to activate the motor unit. The acute response of the muscle fibres is based on need, or exercise intensity. Depending on the required strength and speed of the contraction, the number of motor units recruited and the rate at which they are recruited can be adjusted. Muscle fibre recruitment follows a set pattern called the size principle. Smaller, slow-twitch (ST) fibres that are slower to contract and generate less force are recruited first, followed by the fast oxidative glycolytic fibres (FTA), and then the larger fast glycolytic fibres (FTB) are recruited. While slow-twitch fibres are activated during all contractions and contribute to force production, depending on the intensity, duration and fatigue that occurs, FTA and FTB fibres may also be recruited. If a fast, high force output is required, ST, FTA and FTB fibres are activated rapidly, but still in order from smallest to largest. When a motor unit is activated, it will contract maximally or not at all, depending on the strength of the stimulus (this is the all-or-nothing principle). Increasing the frequency of the messages will also increase the force produced in the muscle.

Energy substrates

Adenosine triphosphate (ATP) is the immediate source of energy for all muscular contractions. When exercise begins, muscular contractions can be fuelled initially by the ATP stored in the muscles. However, this ATP is in relatively short supply and when it is used up, the muscles must then rely on energy substrates to fuel metabolism. Glycogen is used in both anaerobic and aerobic respiration to produce ATP. During exercise, **phosphocreatine (PC)** donates a phosphate to **adenosine diphosphate (ADP)** to resynthesise ATP.

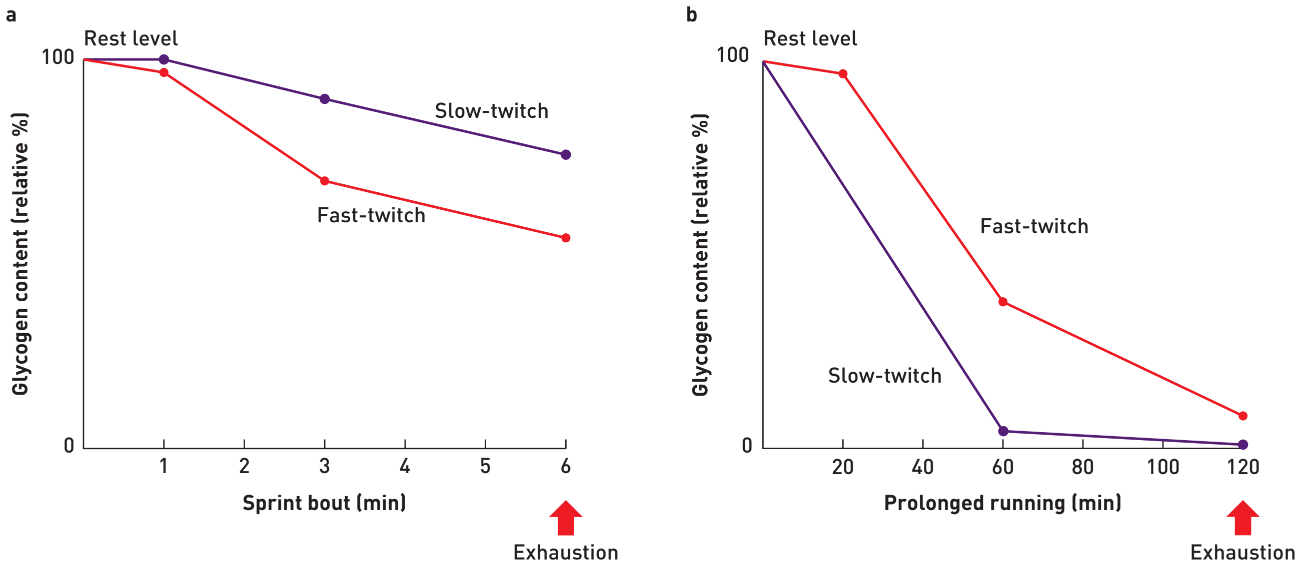
FYI

Small muscles over which we have fine control (e.g. hands and fingers) have fewer muscle fibres per motor unit than those required for gross motor skills such as running and jumping.



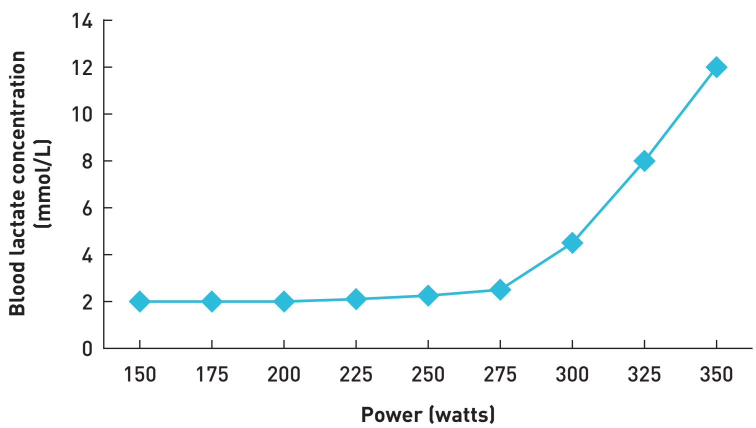
A motor unit is made up of the motor neuron and the muscle fibres it stimulates.

Exercise causes a decrease in all fuel levels within the muscle. ATP, PC and muscle glycogen levels all decrease, as does intramuscular triglyceride concentration. Glycogen content decreases more rapidly with endurance activities compared to high-intensity sprint activities, as shown in the graphs below. The preferential recruitment of slow-twitch (ST) fibres for endurance activities and fast-twitch (FT) fibres for sprint activities is determined by the characteristics of each fibre type (see Table 9.3, page 201). This is because high-intensity sprint events utilise FT fibres that rely more on stored ATP and PC as a fuel for energy production, while endurance events utilise ST fibres that use glycogen and fats. (Fuels required for physical activity were discussed in chapter 6.)



Glycogen content of muscle fibres during (a) sprint and (b) endurance exercise

Adapted from: Fox, Bowers & Foss, 1993



Blood lactate concentration remains stable until LIP is exceeded.

Lactate

Lactate is produced at rest and during exercise but remains relatively stable during submaximal exercise. At these intensities, the body is able to remove the lactate by oxidising it for energy production or converting it to glucose or glycogen in the liver at a similar rate to which it is being produced. Lactate levels increase exponentially once the exercise intensity exceeds the individual's **lactate inflection point (LIP)**. The lactate inflection point (LIP) is the last point where lactate entry into the blood and removal from the blood are balanced. At exercise intensities beyond the lactate inflection point (LIP), there is a steep rise in lactate (see graph at left) as the body is unable to clear the lactate as quickly as it is being produced. An individual's LIP varies depending on their level of training; in endurance-trained individuals, LIP occurs at higher absolute exercise intensities.

Body temperature

When exercise commences, there is an increase in the rate of metabolism required to produce ATP in the muscle. Heat is the by-product of the process of converting chemical energy (fuel) to mechanical energy (movement). An increase in the rate of reactions is accompanied by an increase in heat production, which causes body temperature to increase.

The body accommodates these changes by stimulating the sweat glands in the skin to produce sweat. Combined with the increased blood flow to the skin (as discussed earlier), these two mechanisms work to maintain a relatively constant body temperature. However, at high intensities, blood vessels vasoconstrict (rather than dilating, as they do in submaximal exercise), which hinders heat transfer to the skin and increases the risk of heat-related injuries during exercise.

Alamy Stock Photo/PA Images

Getty Images/Hamish Blair

What strategies are these athletes using to lower their body temperature and reduce the risk of heat injuries? What other measures could they consider using?

DATA ANALYSIS

SMALL-SIDED SOCCER GAMES

A recent study looked at the acute physiological responses of 16-year-old male soccer players for various small-sided soccer games. The study examined the differences in heart-rate response, blood lactate concentration and rate of perceived exertion (RPE) when playing 2 vs 2, 4 vs 4 and 6 vs 6 games of soccer. The pitch was adjusted for each game so that the area per player remained the same throughout the study. The study found that the 2 vs 2 game elicited a greater response in heart rate, blood lactate and RPE than either the 4 vs 4 or 6 vs 6. The results showed that when the number of people playing decreased, but the area per player was kept the same, the physiological and perceived workload increased.

Weblink

Follow this link to read how small-sided games have also been shown to be beneficial in AFL.

Scaffold

	Small-sided soccer games*		
Variable	2 vs 2	4 vs 4	6 vs 6
Game duration	24 minutes	24 minutes	24 minutes
Area per player	150 m^2	150 m^2	150 m^2
Pitch size	28 m × 21 m	40 m × 30 m	49 m × 37 m

* No goalkeepers and no offside rule

Measurements	2 vs 2	4 vs 4	6 vs 6
% maximum heart rate (max HR)	89 ± 4	85 ± 4	83 ± 4
Blood lactate (mmol/L)	6.7 ± 2.6	4.7 ± 1.6	4.1 ± 2
Rate of perceived exertion (RPE)	13.1 ± 1.5	12.2 ± 1.8	10.5 ± 1.5

Source: 'Physiological responses and time-motion characteristics of various small-sided soccer games in youth players', Hill-Haas SV, et al., *Journal of Sports Science*, 27 (1), Jan 2009, reprinted by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

METHOD

1 Divide the class into two equal teams and participate in a game of soccer using a full-sized soccer pitch.
2 After 10 minutes of play, record your rate of perceived exertion (RPE) using the Borg scale in Table 12.2 on page 289.
3 Divide the class into four equal teams and participate in a game of soccer using a half-sized soccer pitch.
4 After 10 minutes of play, record your rate of perceived exertion (RPE) using the Borg scale.
5 Divide the class into eight equal teams and participate in a game of soccer using a quarter-sized soccer pitch.
6 After 10 minutes of play, record your rate of perceived exertion (RPE) using the Borg scale.

DISCUSSION

1 Compare your ratings of perceived exertion for each game with the findings from the study. Were they similar or different? Provide reasons for your answers.
2 The data shows that in 2 vs 2-sided soccer games, players work at a significantly higher percentage of their maximum heart rate (max HR), their blood lactate levels are higher and they think they are working harder (RPE). Explain why these parameters would increase when playing numbers decrease but relative pitch size remains the same.
3 What conclusions can be made about the intensity of smaller-sided soccer games? Use examples from your results and the data to support your answer.
4 Suggest three reasons why a coach may use small-sided games during training.
5 Explain why exercise causes an increase in heart rate and blood lactate.

CHAPTER CHECK-UP

1 Identify and discuss the importance of the changes in skeletal capillaries that occur as a response to exercise.
2 Compare and contrast the energy substrate levels of a 100-metre sprinter and a marathon runner at the end of their events.
3 If motor units always contract maximally, explain how the body controls movements that require more or less force.
4 Lactate is present at rest and during submaximal and maximal exercise. However, it accumulates only at high exercise intensities. Discuss.
5 Explain the relationship between body temperature and redistribution of blood flow in the body as a result of continuous exercise.

Many of the acute responses to exercise discussed in this chapter contribute to increasing the availability of oxygen to the working muscles. Table 7.3 summarises the acute responses of the respiratory, cardiovascular and muscular systems that result in increased oxygen being taken in, delivered and utilised by the working muscles. The difference between resting levels and the increase as a response to maximal exercise are shown for a relatively fit individual.

TABLE 7.3 Acute responses to exercise in the respiratory, cardiovascular and muscular systems for a relatively fit subject

Response		Rest	Maximal exercise
Lungs	Respiratory rate (breaths/min)	12	30
Heart	Heart rate (beats/min)	70	190–200
	Stroke volume (mL/beat)	75	150
	Cardiac output (L/min)	5.2	28.5
	Blood flow distribution	20%	70%
Muscles	Oxygen extraction	5%	20%
	VO_2 (mL/kg/min)	3.5	60

Adapted from: Corbin et al., 2008

SUMMARY OF ACUTE RESPONSES TO EXERCISE

Table 7.4 summarises the acute respiratory, cardiovascular and muscular responses to submaximal and maximal exercise.

TABLE 7.4 Acute responses to submaximal and maximal exercise

Respiratory	Cardiovascular	Muscular
↑ Ventilation *(non-linear increase beyond 65% VO_2 max)* ↑ Tidal volume *(plateaus at high intensities)* ↑ Respiratory rate ↑ Diffusion	↑ Heart rate ↑ Stroke volume *(maximal at submaximal levels)* ↑ Cardiac output Blood pressure: ↑ Systolic *(greater increase with high intensity, resistance exercise)* Diastolic *(no change at submaximal intensities)* ↑ Venous return ↓ Blood volume (plasma) ↑ a-vO_2 difference ↑ Oxygen consumption *(increases with increasing intensity)*	↑ Motor unit recruitment ↑ Blood flow to working muscles ↑ Body temperature ↓ Intramuscular substrate levels: ATP, CP *(greater decrease at maximal intensity)* Glycogen, triglycerides *(greater decrease at submaximal intensity)* ↑ Lactate production *(greater at maximal intensity)*

↑ = increase
↓ = decrease

LABORATORY REPORT

ACUTE RESPONSES TO EXERCISE

AIM

To collect and analyse data relating to the range of acute effects that physical activity has on the cardiovascular, respiratory and muscular systems of the body

EQUIPMENT

You will need a spirometer, thermometers, heart-rate monitors (if not available, take heart rate manually for 15 seconds at either the carotid or radial pulse) and blood pressure monitors (automatic) or a stethoscope and sphygmomanometer (manual).

METHOD

1 Record subjects' pre-exercise levels for heart rate, blood pressure, body temperature, respiratory rate and tidal volume. To measure respiratory rate, place one hand on the diaphragm and breathe normally for one minute, counting the movements of your hand. To measure tidal volume, use a spirometer and exhale normally after a normal inhalation.
2 Complete 10 minutes of continuous exercise (such as running, walking briskly, cycling, step-ups).
3 At the conclusion of the activity, record all parameters in a table, as shown below. You can fill in a table online by going to www.nelsonnet.com.au and using your login.

Scaffold

RESULTS

	Heart rate (beats/min)	Blood pressure (mm Hg)	Temperature (°C)	Respiratory rate (breaths/min)	Tidal volume (L/breath)
Pre-exercise					
Post-exercise					

DISCUSSION

1 Compare and contrast the data recorded pre-exercise and immediately post-exercise. Provide reasons for any differences observed.
2 Explain how changes in the heart rate, respiratory rate and tidal volume lead to an increase in oxygen to the working muscles.
3 If the submaximal exercise was replaced by maximal exercise, what effect would you expect this to have on blood-pressure readings? Explain your answer.
4 Discuss the role of redistribution of blood in maintaining a constant body temperature during exercise.

CONCLUSION

Write a conclusion based on the data and discussion.

CHAPTER SUMMARY

- Acute responses are immediate physiological responses to exercise.
- The body responds to the demands of exercise by making a number of short-term physiological changes to the cardiovascular, respiratory and muscular systems. Once exercise is stopped, these three systems return to pre-exercise levels.
- Exercise places increased demands on the body's need for oxygen to meet the rising energy demands of the activity.
- Ventilation increases prior to the beginning of exercise and continues to rise to meet the oxygen demands of the exercise.
- Increases in ventilation are a result of an increase in tidal volume, respiratory rate, or both.
- At submaximal exercise intensities, ventilation will increase linearly with oxygen consumption (VO_2) until a steady state (plateau) is reached.
- At maximal intensities, ventilation increases until the exercise is stopped.
- Diffusion occurs from an area of high pressure to an area of low pressure. In the lungs, oxygen diffuses across the alveolar–capillary interface. In muscle, it diffuses across the tissue–capillary interface.
- Respiratory responses to exercise include increased respiratory rate, ventilation, tidal volume and diffusion.
- Acute cardiovascular responses to exercise include redistribution of blood flow, decreased blood volume and increased cardiac output, stroke volume, heart rate, blood pressure, venous return, oxygen consumption and arteriovenous oxygen difference (a-vO_2 diff).
- When exercise begins, muscular contractions increase to enable exercise to occur.
- Acute muscular responses to exercise include decreased energy substrates and increased blood flow to working muscles, motor unit recruitment, blood lactate levels and body temperature.
- Acute responses of the cardiovascular, respiratory and muscular systems increase the amount of oxygen delivered to working muscles.
- The body's responses to exercise are primarily responsible for increasing the amount of oxygen delivered to and used by the working muscles.

CHAPTER REVIEW

Multiple-choice questions

1 Acute responses to exercise include
   A a decrease in blood volume, an increase in oxygen consumption and an increase in intramuscular energy substrates.
   B a decrease in oxygen consumption, a decrease in blood volume and a decrease in intramuscular energy substrates.
   C an increase in the a-vO_2 diff, an increase in oxygen consumption and an increase in blood flow to working muscles.
   D an increase in oxygen consumption, a decrease in intramuscular energy substrates and an increase in blood volume.

2 The mechanism responsible for increased blood flow to the working muscles is
   A diffusion.
   B vasoconstriction.
   C vasodilation.
   D an increase in blood volume.

Short-answer questions

3 Discuss the changes in intramuscular energy substrate levels as a result of two different sporting events. Provide specific examples to support your discussion.

4 Describe the relationship between the acute responses to submaximal exercise in the respiratory, cardiovascular and muscular systems.

5 Outline the acute responses that assist the body in maintaining constant temperature and describe two practical strategies that athletes could use to assist in this process.

6 It is not possible to have an increase in cardiac output and a decrease in venous return. Discuss.

CHAPTER 8

ENERGY SYSTEM FATIGUE AND RECOVERY MECHANISMS

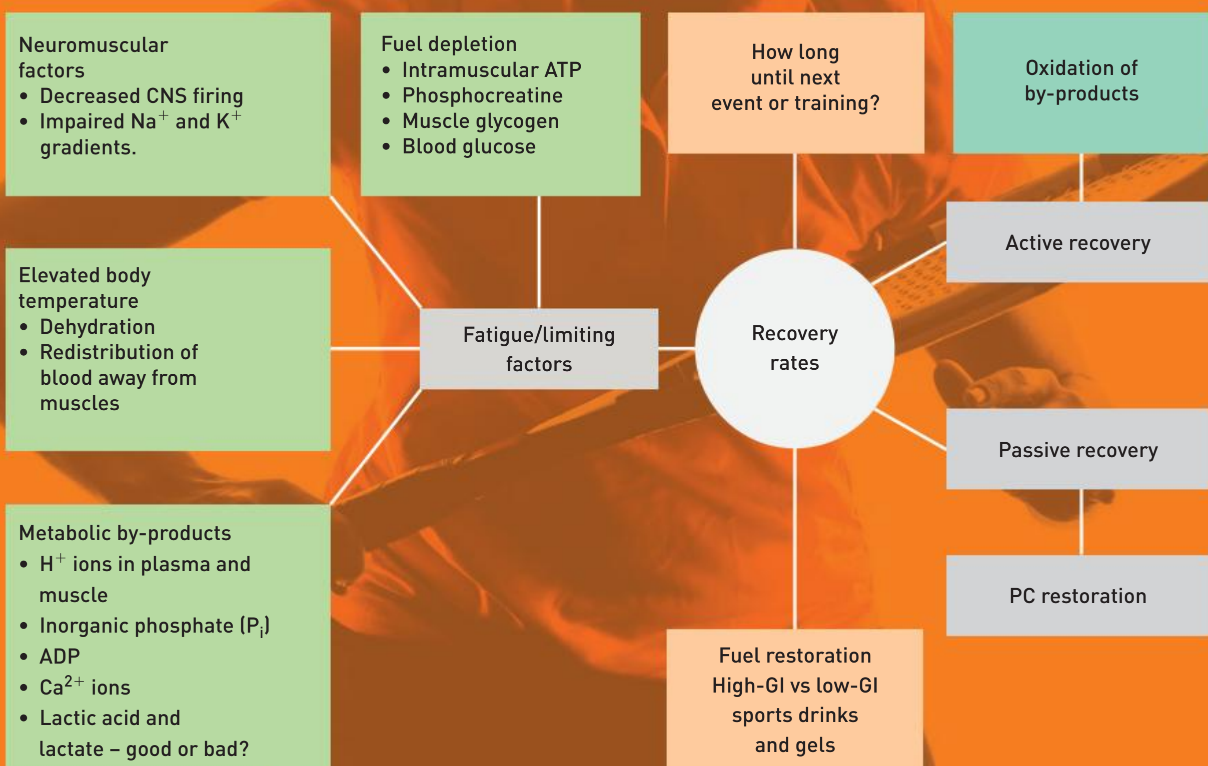
Key knowledge

- characteristics of the three energy systems
- fatigue/limiting factors and recovery rates associated with active and passive recoveries
- nutritional and rehydration recovery strategies including water, carbohydrate and protein replenishment

Key skills

- explain the fatiguing factors associated with the use of the three energy systems under varying conditions
- explain and apply relevant nutrition and rehydration strategies to enhance recovery

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



iStock.com/OSTILL

INTRODUCTION TO FATIGUE

Muscle fatigue is best defined as an exercise-induced reduction in the ability of muscle to produce force or power. Recent findings suggest that fatigue is task-dependent and can vary for different tasks. Factors such as exercise duration and intensity, types of muscular contractions, physical fitness or conditioning, age, diet and environmental conditions can all play a significant role in determining when performances will start to deteriorate.

The onset and rate of development of fatigue depends on:

» whether the activity is intermittent or continuous
» muscle fibre type being used: fast- or slow-twitch fibres (slow-twitch fibre types are more 'fatigue resistant')
» types of muscular contractions occurring: concentric, eccentric or isometric (isometric contractions more quickly cause fatigue)
» intensity and duration of the activity (fatigue is more rapid with high-intensity or anaerobic work)
» level of fitness or training adaptations the performer has developed (longer training adherence often reduces fatigue).

FATIGUE: LIMITING FACTORS

Fatigue can be caused by many factors that occur as exercise continues. In the same way that energy system interplay sees one system providing most of the ATP required for muscle contractions at any one time, fatigue mechanisms see one factor contributing most to fatigue. This chapter focuses on the three energy systems covered in chapter 6 and related fatigue factors, rather than the psychomotor mechanisms that might be responsible (see page 172).

Fatigue causes a reduction in both muscle force and shortening velocity; together, these also bring about reduced muscular power.

$$\text{power} = \text{force} \times \text{velocity}$$

Power is concerned with the intensity of exercise that can be sustained. Performers are also likely to experience slower muscle relaxation rates and increased rating of perception of effort (RPE), which is a very subjective measure. There are two sites where fatigue occurs:

» in the central nervous system (**central fatigue**), which occurs when muscular function is decreased due to central nervous system (CNS) impairment
» at the muscle (**peripheral fatigue**), which occurs when muscle function is disrupted because of internal muscle processes.

Central and peripheral fatigue mechanisms can occur simultaneously. Many researchers describe three levels of fatigue, as shown in Table 8.1.

Current understanding of fatigue mechanisms suggests that the key factors shown in Table 8.2 contribute to fatigue, either by themselves or together.

This chapter will focus on the metabolic causes of fatigue, the effects of high-intensity exercise by-products on peripheral fatigue, and the speed at which homeostasis is achieved post-exercise via passive and active recovery strategies.

TABLE 8.1 Levels of fatigue

Level of fatigue	Causes, signs and symptoms	Fatigue indicator (out of 10)	Examples
Local	Fatigue is experienced in a muscle or group of localised muscles. This tends to occur if the same muscle group is called upon repeatedly during training (without sufficient recovery) or performance. Muscles often feel heavy, tingling pain or cramp.	2–4	After completing a weight station (e.g. eight bench presses at 80% of the repetition maximum) or in biceps or triceps after a game of squash or badminton.
General	Fatigue tends to occur after completing a full training session or competitive game of e.g. football or netball. Performers feel that all their muscles are 'weakened' and sometimes experience psychological fatigue.	6–8	After completing a circuit session or a 'full-on' game of hockey.
Chronic	An unhealthy breakdown of the immune system, caused by overtraining (poor training program design), inappropriate recovery strategies and/or excessive competition demands. Chronic fatigue is dangerous. It is often accompanied by increased susceptibility to illness or infection, persistent muscle soreness and reduced motivation.	10	Diagnosed as chronic fatigue syndrome (CFS) or sometimes glandular fever.

TABLE 8.2 Key factors contributing to fatigue

Fuel depletion	Accumulation of metabolic by-products	Elevated body temperature	Neuromuscular events
» Intramuscular ATP » Phosphocreatine (PC) » Blood glucose » Muscle glycogen	» Hydrogen ions (H^+) in plasma and muscle » Inorganic phosphate (P_i) » Adenosine diphosphate (ADP) » Calcium ions (Ca^{2+})	» Very high core temperatures » Increased dehydration rate » Blood redistributed to assist cooling » Elevated blood pressure » Decreased plasma levels » Electrolyte imbalance/loss	» Decreased 'firing' of the central nervous system

ENERGY SYSTEMS AND FATIGUE

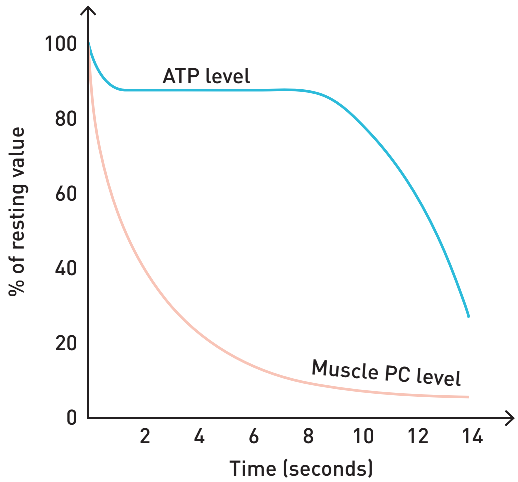
In chapter 6 you learnt that adenosine triphosphate (ATP) is constantly being broken down and resynthesised/recharged to provide the energy required for muscle contractions. Anaerobic energy is required when high-intensity and relatively short-duration actions are being performed, and the ATP–PC system and anaerobic glycolysis systems provide most of that energy. But for prolonged and repeated efforts fuelling local and cardiovascular endurance, the aerobic energy system predominates.

Fuel depletion

Because all three energy systems work together to rebuild ATP and provide energy for activities, any drop in their primary fuel sources will contribute to fatigue – the greater/faster the fuel depletion, the sooner fatigue sets in. We basically have a chemical fuel (PC)

FYI

Research has indicated that the central nervous system plays a protective role in preventing serious muscle damage by reducing the intensity and frequency of signals in response to biofeedback from the muscle cells.



ATP and PC depletion during maximal work

and three food fuels (carbohydrates, fats and proteins) that we call upon to rebuild ATP. In fact, some researchers have discovered that in the latter stages of prolonged maximal efforts such as at the end of a 200-metre sprint, rates of ATP breakdown can exceed rates of resynthesis so ATP depletion itself contributes to fatigue, even if only for short periods of time.

Phosphocreatine (PC) provides rapid but short-lived energy that typically powers high-intensity, short-duration efforts such as sprints up to 100 metres, explosive and powerful jumps, throws and hits. In the absence of PC being replenished during passive recovery (see page 175), ATP needs to be recharged by the breakdown of glucose, which takes longer, meaning contractile force and speed also decrease. Because blood glucose occurs in higher levels than PC, it can be used for longer to rebuild ATP.

Lowered blood glucose levels are associated with reduced rates of carbohydrate oxidation, increased use of fats and the onset of fatigue. Lowered blood glucose levels and reduced carbohydrate oxidation also contribute to the depletion of liver glycogen levels, and ultimately a change from carbohydrates to fats as the predominant food fuel for recharging ATP. When this occurs there is a significant drop in work rate due to the greater time and effort required to break down fats compared to carbohydrates.

Glycogen depletion becomes a significant factor for events lasting over one hour. Carbohydrate is the only source of energy during maximal-intensity exercise, but fats are used increasingly during prolonged submaximal or endurance activities. Muscle glycogen provides the first fuel source during aerobic activities. As this fuel is depleted, the muscles use glycogen stored in the liver. Once this runs low, they look to blood-borne fats and then stored fats. The rate at which glucose is broken down to resynthesise ATP decreases markedly when the body switches over to fats as the major ATP producer (at the two- to three-hour mark in extended endurance events). This generally means the aerobic system is compromised during endurance events lasting longer than 90 minutes, such as distance running or triathlons.

Muscles obtain glucose either directly from foods, or from amino acids and lactate via **gluconeogenesis**. Glucose obtained from these two primary sources either remains soluble in the body fluids or is stored as glycogen, mainly in the liver and muscles. Total glycogen stored in muscles is about three to four times the amount stored in the liver. Glycogen stored in the liver is the body's main reserve of blood glucose levels.

The rate of energy production from aerobic use of carbohydrate is 50–100 per cent faster than from the aerobic use of fat. This is due to the more complex chemical reactions and greater amounts of oxygen required for breaking down fats. Using fats when glycogen becomes depleted leads to fatigue. The body needs to have some glycogen left in order to break down fats. You may wish to look back at the 'crossover concept' in chapter 6 (see page 117).

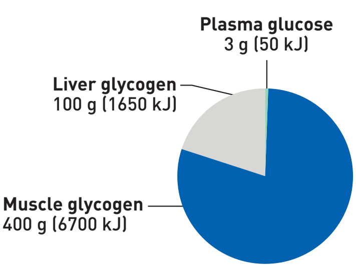
Protein can also be used as a fuel source, but only in extreme performance conditions lasting over five hours. Although not primary energy substrates, amino acids from protein breakdown are used as 'tertiary' fuels during muscular work. Exercise duration, muscle and liver glycogen levels, and fat stores all affect the use of protein to fuel contractions. Oxidation of amino acids for fuel within skeletal muscles is increased during prolonged exercise and when muscle glycogen and fat stores are both running low. Protein may contribute

FYI

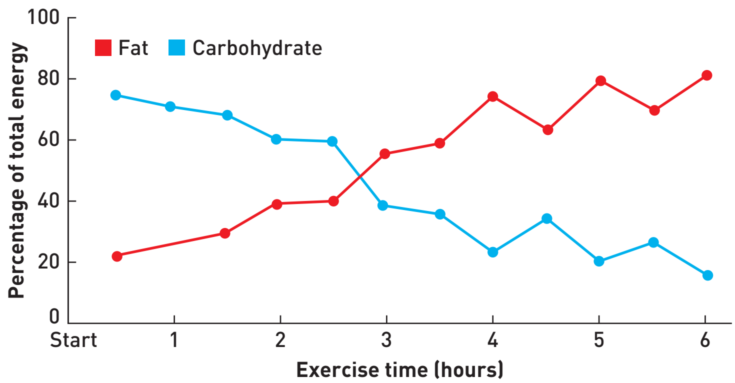
Creatine supplementation at sufficient dosages will increase the total muscular creatine pool in most individuals within two days. However, the improved work output is likely to be the result of more rapid CP resynthesis during recovery.

FYI

Depletion of muscle glycogen is generally accepted as the primary cause of fatigue during endurance events such as triathlons and marathons, although this may take 2 hours or more while exercising at 70% of VO_2 max or higher.



Distribution of carbohydrate energy in an average, 80-kilogram athlete. Total carbohydrates is 503 g (8400 kJ) up to 10 per cent of the energy needs in extended endurance events, such as the Hawaii Ironman Triathlon. Proteins take longer to break down than fats and carbohydrates and have a high associated oxygen cost (the amount of oxygen required to break down a substance).



Carbohydrate and fat use versus exercise time

Adapted from: McArdle, Katch & Katch, 2012

Accumulation of metabolic by-products

The two anaerobic energy systems are responsible for the accumulation of most metabolic by-products. Metabolic by-products tend to be associated with high-intensity work and often, but not necessarily, low recovery time in between repeat efforts. During rapid breakdown of ATP and PC (remember that these are two different fuel sources), there are increased levels of adenosine diphosphate (ADP) and inorganic phosphate (P_i) within working muscles, both resulting in decreased muscle contractile force.

Increased ADP levels can reduce force and slow relaxation in muscles by adversely affecting their contractile myofilaments and Ca^{2+} uptake into the sarcoplasmic reticulum. Similarly, increases in P_i concentration at muscles also reduce contractile force and Ca^{2+} release from the sarcoplasmic reticulum. When intramuscular P_i increases, the number of cross-bridges in weakly bound states increases, thus reducing contractile force.

The sliding filament theory explains how muscular contractions occur.

QUICKVID

This video clip explains clearly how muscles contract using the sliding filament theory. Go to http://vcepe34.nelsonnet.com.au and find this page.

Weblink

In order for a skeletal muscle contraction to occur:

1 **there must be a neural stimulus.** A nervous impulse stimulates the **sarcoplasmic reticulum** to release calcium into the muscle cell.

2 **there must be calcium in the muscle cells.** The calcium binds with troponin, which allows the actin and myosin to form cross-bridges. Using ATP as energy, the cross-bridges contract, shortening the muscle.

3 **ATP must be available for energy.** Stimulation of the sarcoplasmic reticulum then stops, and calcium is pumped back into it, breaking the link between actin and myosin. This causes the muscle to relax.

Events that cause lower or restricted brain signals reaching the muscles, impaired Ca^{2+} release, and/or impaired ATP availability will be associated with fatigue and decreased muscle contractions.

FYI

Improving LIP requires training the aerobic energy system, whereas improving lactate tolerance requires training the anaerobic glycolysis system. Because they involve very different energy systems and associated fibre types and metabolic processes, improving one of these variables will occur independently of the other and will not result in any associated improvements.

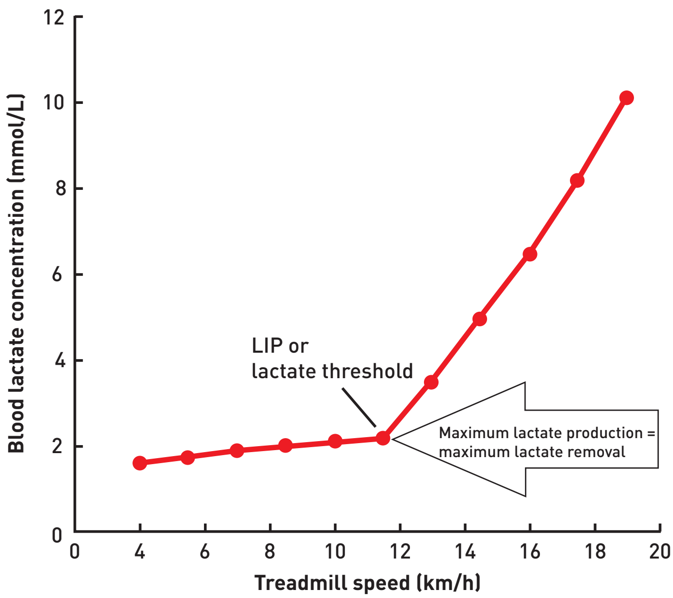
Lactic acid, lactate and H^+ ions

It has long been thought that when the anaerobic glycolysis system is the predominant energy system, the cause of the 'burn', pain and ultimately reduced muscle contractile force and fatigue is lactic acid. However, more and more physiologists are now investigating ways lactic acid can be used to improve performance, and it is being viewed more as a 'friend' than a 'foe'.

Lactic acid – good guy or bad guy?

Lactic acid has long been considered a waste product responsible for causing major fatigue in performers. Lactic acid is often blamed for **DOMS** and fatigue. However, the latest thinking is that lactic acid is an important and useful energy source that can be used to enhance performance. To get a better idea of its role in fatigue, it's worth exploring the links between energy systems, performance and the production of lactic acid.

Lactic acid is continuously being produced and removed, even at rest. Ultra-endurance athletes such as marathon runners and triathletes can have near-resting lactic acid levels following training and competitions, despite feeling exhausted. During low- to moderate-density exercise its production increases, but this is matched by its removal, showing no significant overall increase. Lactate production increases in proportion to our exercise rates and at some point, a rate or workload will be reached at which lactate accumulates. This occurs just above the **lactate inflection point (LIP)** and is usually triggered above 85 per cent of maximum heart rate (85% max HR) depending on conditions and training. It is at this point that the rate of lactate production exceeds the rate of lactate removal.



The lactate inflection point is sometimes referred to as the maximum lactate steady state (notice the 'flat' lactate line until inflection) or the lactate threshold. This is the maximum intensity athletes can still be working aerobically at without any build-up of lactate and H^+.

Once the LIP is exceeded, ventilation rapidly rises (see chapter 7). This point is easily determined when conducting VO_2 max tests in a laboratory. Athletes can have the same VO_2 max readings, but the athlete with the higher LIP, sometimes referred to as maximal lactate steady state (MLSS) or lactate threshold, will have a superior ability to keep working aerobically without accumulating H^+, thereby delaying the onset of fatigue. Training LIP is discussed in chapter 15 (page 349).

As explained in chapter 6, glycogen is our preferred energy source for exercise. Via **glycolysis**, each glucose molecule is split into two pyruvic acid molecules, and energy is released to form adenosine triphosphate (ATP), which then allows more muscle contractions to occur.

Anaerobic glycolysis results in the formation of pyruvic acid and hydrogen ions (H^+). A build-up of H^+ will make the muscle cells acidic and interfere with their operation, so carrier molecules (NAD) remove the H^+. The NAD^+ is broken down to NADH, which deposits the H^+ at the electron transport gate (ETG) in the mitochondria, to be combined with oxygen to form water (H_2O). If there is insufficient oxygen, NADH cannot release the H^+ and hydrogen ions build up in the cell. To reduce this rise in acidity, pyruvic acid combines with H^+ to form lactic acid, which then breaks down to lactate and H^+. Some of the lactate diffuses into the bloodstream, taking some H^+ with it as a way of reducing the H^+ concentration in the muscle cell.

The increase in hydrogen ions and subsequent acidity of the internal environment is called **acidosis**. Acidosis can be caused by reactions other than lactate production. Increased lactate concentration, although not the cause, coincides with acidosis and remains a good indirect marker for the onset of fatigue. Lactate production may delay the onset of acidosis, because lactate combines with hydrogen ions and moves them from the cell to the blood.

FYI

The lactic acid 'burn' results from the build-up of H^+ and consequent reduction in pH. Muscle contractions become impaired and the low pH stimulates the free nerve endings in the muscle, which we feel as a burning sensation.

Training accelerates lactate clearance, reduces lactate accumulation at any given workload and results in a greater level of lactate accumulation during maximal effort. However, high concentrations of blood plasma acidosis may impair performance by reducing the central nervous system drive to muscles.

The lactate shuttle model

This simplified model summarises the process described above.

» As we exercise, glycogen is broken down and pyruvate is formed.

» When insufficient oxygen is available to break down the pyruvate, lactate and H^+ are produced.

» Lactate and H^+ enter the surrounding muscle tissue and are then transported to the blood.

» The muscle cells and tissues receiving the lactate either break it down or use it in the creation of glycogen.

» The glycogen remains in the muscle cells until more energy/ATP is required.

As physical activity continues, lactate is a critical element in producing energy and may help to prolong submaximal activity. Evidence suggests that aspects of lactate production improve athletic performance.

The diagram below shows how insufficient oxygen availability forces aerobic glycolysis to become anaerobic glycolysis. Note that the pathways are identical up until to the point where glucose is broken down to pyruvic acid. Lactic acid and lactate are also very similar in structure, but the hydrogen ions split off from lactic acid to produce lactate provide more energy for ATP resynthesis. Hydrogen ions can be broken down (up to and including the lactate inflection point) or accumulate once LIP has been surpassed.

When lactate accumulates and severe blood acidosis occurs, fatigue tends to follow quickly. This is because increases in the cell or blood acidity compromise important contractile and metabolic functions, as indicated in Table 8.3.

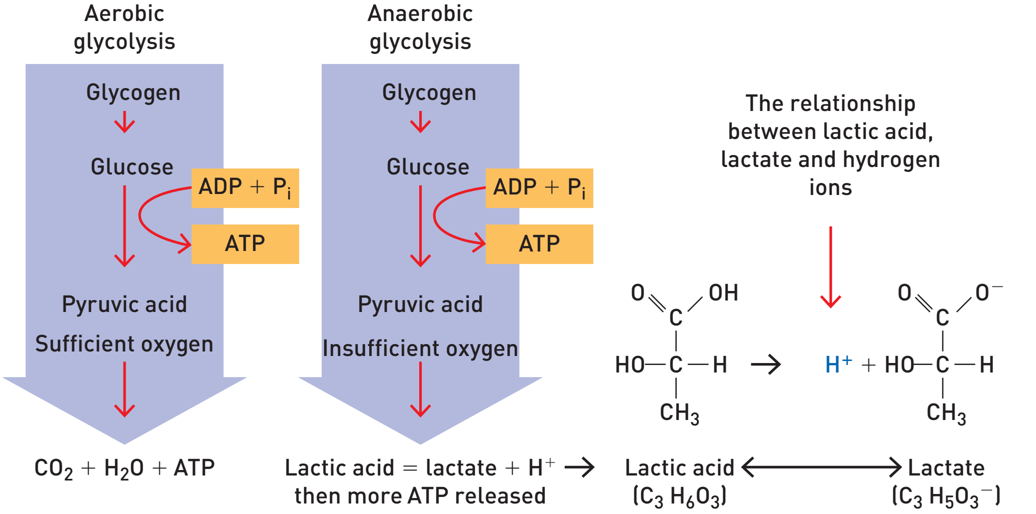
An active recovery clears lactate more quickly than a passive recovery, but it may also further deplete glycogen stores. Many athletes use active and passive recoveries together in order to decrease lactate levels while allowing glycogen resynthesis. See the diagram in chapter 6, page 123.

FYI

Lactic acid and lactate are two different substances. Lactic acid is produced during anaerobic glycolysis but quickly breaks down and releases hydrogen ions (H^+). The remaining compound combines with either sodium (Na^+) or potassium (K^+) ions to form lactate. A performer's blood lactate is measured in pinprick tests during training, not their lactic acid.

Getty Images/Alexandre Simoes

Lactate testing can be performed during testing of accumulation of fatiguing by-products and changes in blood pH. What use do coaches make of the data?



The similarities between aerobic and anaerobic glycolysis and the differences between lactic acid and lactate

TABLE 8.3 Probable H^+ contribution to fatigue

Probable muscular effects	How fatigue occurs
Reduced rates of glycolysis	Decreased rates of glycolysis lead to slower muscle contractions and possible increased use of fats as predominant fuels responsible for rebuilding ATP
Inhibited excitation–contraction coupling	H^+ may compete with Ca^{2+} at the actin/myosin binding site as pH decreases with increased H^+ levels
Reduced cross-bridge cycling	Myosin ATPase activity is reduced as pH is lowered, which slows ADP release and cross-bridge cycling

REAL WORLD APPLICATION

How lactic acid really works: The science of fatigue and lactate

Image courtesy of Jeff Gaudette

Coach Jeff is a 2:22 marathoner and has been a running coach for the past seven years. 'I love coaching and I have a passion for translating highly technical training theory to the schedules of the runners I coach.'

by Coach Jeff

There's a lot of fuss in the running world about lactate. Or, depending on who you ask, lactic acid.

It's been blamed for fatigue, soreness, overtraining, and probably more, but until recently, the phenomenon of lactate accumulation during intense exercise was poorly understood.

This week's article will dispel some of the myths about lactate, lactic acid, and how they relate to exercise and fatigue.

How lactic acid got a bad reputation

The association of lactic acid and its negatively-charged ionic form, lactate, with fatigue during exercise has a long history.

During the course of a prolonged and intense effort, muscles lose power. The growing fatigue with exercise can be resisted for a while through great concentration and mental effort, but eventually everyone succumbs to fatigue.

Early physiologists studied the origins of muscular fatigue using electric impulses sent to muscles from dissected frogs. Even these dismembered muscles fatigue after a while, proving that there is a chemical component to fatigue. When these muscle fibres are analysed, they show a high concentration of lactate and acid (hydrogen) ions. Therefore, physiologists concluded, the reason for muscular fatigue during exercise is accumulation of a compound called lactic acid.

This theory remained more or less unchallenged for much of the 20th century. It was only after the body's energy supply systems were subjected to rigorous biochemical accounting that some discrepancies turned up. For one thing, the body doesn't actually produce lactic acid, just the negatively-charged ion, lactate. 'Acid' (hydrogen ions) is indeed produced, but not from the exact same biochemical step.

Furthermore, the ratio of lactate to hydrogen ions produced during exercise isn't 1:1, as you would expect if lactic acid was being produced. These ambiguities led to a reexamination and eventual overhaul of the 'lactate paradigm' in the early 2000s, spearheaded by Roger Robergs.

The real science behind lactate

Robergs, an accomplished biochemist, took a hard look at each step in the metabolic process that turns sugars (glucose in the blood and glycogen in the muscles) into energy when you exercise.

Most runners have heard the following story about energy pathways: Aerobic respiration turns sugars into fuel using oxygen, and doesn't have any harmful by-products. Anaerobic respiration, which doesn't kick in until you're operating past your aerobic limit, can generate energy from sugar without using oxygen, but results in waste products – lactate and acid.

Robergs and others showed that this common understanding has some flaws. It turns out that anaerobic respiration functions all the time, turning sugar into a compound called pyruvate, releasing some hydrogen ions at the same time. Aerobic respiration

>

works to clean up the pyruvate, using oxygen to burn the pyruvate into carbon dioxide and water, which can be exhaled. The aerobic process also consumes acid (hydrogen ions), which retards the buildup of acid in the muscles.

The generation of lactate is actually a side reaction: when excess pyruvate and acid start to accumulate (when the rate of anaerobic respiration overtakes the aerobic system's ability to remove the waste), the body uses a pyruvate molecule and a hydrogen ion to create lactate, another way in which it can slow down the buildup of acid. The lactate can also be shuttled out of the muscles, into the blood, and burned in other areas of the body for more energy.

Practical implications of our new understanding of fatigue

All of this biochemistry is jolly interesting to a physiologist, but are there any practical applications of all this? We can take a few lessons from this right off the bat:

- a better understanding of the biology of fatigue only reinforces the concept that your aerobic strength is a huge factor in your performance. While your body has various mechanisms to buffer the acid produced during high-intensity efforts, all of these are limited. Only increasing your aerobic fitness will allow you to substantially increase how far and how fast you can run.
- Additionally, recognising that lactate has a greater role than simply causing fatigue allows you to better understand the place of high-intensity workouts at or faster than the 'lactate threshold'. These workouts aren't just running hard for the sake of running hard – they train your body to produce, process, and burn lactate (as a fuel!) at a greater rate. This can improve your stamina over short and medium-duration races like the 5k and 10k.
- Finally, there is still the inescapable fatigue that comes with acid overload. There really is no getting around this in shorter races. You can run hard interval workouts and races to improve your ability to buffer the acid produced when running at very fast speeds, but everyone is ultimately limited by the acidity in their muscles and blood.

So, is there such a thing as 'lactic acid production' during exercise? Not really. Your body certainly produces acid during exercise, and it produces lactate as well. But it's the former, not the latter, that's the main culprit for fatigue.

Regardless, it will likely still be a long time before we stop hearing about lactic acid buildup and so on. The fuss about terminology might be overblown, but understanding the real mechanisms at work when we run hard and get tired can help understand the purpose and importance of the various workouts you use in training.

Source: © Runners Connect, Inc. www.runnersconnect.net. Reproduced with permission.

Questions

1 The article mentions that growing fatigue through 'exercise can be resisted for a while through great concentration and mental effort'. Discuss how elite athletes might be able to use this to keep performing while H^+ accumulates, whereas non-trained athletes are more likely to stop.

2 Once 'lactate is shuttled out of the muscles' it can be used to produce more energy. How is this possible?

CHAPTER CHECK-UP

1 List the metabolic consequences of supplying ATP via the phosphocreatine energy system.

2 Why don't H^+ ions accumulate when we are performing at jogging pace?

3 Explain how the depletion of PC contributes to slower muscle contractions.

4 Why are lactate levels tested regularly during training sessions by physiologists, fitness advisors and coaches?

5 Explain how aerobic training reduces lactate accumulation at any given workload and yet results in a greater level of lactate accumulation during maximal efforts.

Fatigue and the aerobic energy system

So far we have focused on fatigue related to the predominant use of the two anaerobic energy systems – the ATP–PC system and the anaerobic glycolysis system. The aerobic energy system has a slower rate than the anaerobic energy systems and is more likely to be used in activities requiring less than 85% max HR effort, which are likely to be extended/endurance in nature. We have linked fuel depletion, and switching from carbohydrates to fats as the predominant fuel source, as factors that are only likely to occur when the aerobic system predominates. Additionally, the following fatigue factors are likely to occur during activities calling predominantly upon the aerobic energy system and lasting longer than 20–30 minutes:

» elevated core temperatures
» increased rate of dehydration
» redistribution of blood to assist cooling
» decreased plasma levels
» elevated blood pressure
» electrolyte imbalance
» decreased 'firing' of the central nervous system.

Elevated core temperatures

Normal core body temperature ranges from 36.5–37.5 °Celsius. It is important to maintain a balance between heat production and heat loss in order to stay within this range and sustain normal physiological functions. It is common for body temperature to rise during prolonged training or competition in conditions such as high heat and humidity, or during the acclimatisation phase for these. If heat production exceeds heat loss, then body core temperature will rise, and **hyperthermia** may result.

Heat production and loss

Approximately 20 per cent of the oxygen consumed during exercise is converted to mechanical work, and the remaining 80 per cent ends up as heat, the major metabolic by-product of extended endurance activities. To counter this during exercise, our bodies tend to lose heat via evaporation, with sweat produced to cool the body. In warm environments, evaporation is the main mechanism for heat loss, and when temperatures rise above 36 °C it is the only effective mechanism. High air temperatures combined with high humidity levels greatly reduce heat loss, increasing the likelihood of hyperthermia occurring.

Table 8.4 reveals that losing 2–3 per cent of body weight through sweating will result in impaired **thermoregulation**, aerobic capacity, muscle endurance and neuromuscular coordination. Left unchecked, continued sweating will result in greater decreases in muscle function, as well as decreases in anaerobic power and muscular strength. If more than 6 per cent of body weight is lost via sweating, the person may lose consciousness, and their core temperature may rise close to 40 °C.

As core temperature rises, sweat rates increase and blood is redistributed away from working muscles to the skin's surface to maximise evaporative cooling. This means less blood, oxygen and fuels flow to working muscles, which may contribute towards aerobic exercise becoming increasingly anaerobic. Less wastes are removed from muscles and fatigue at muscles greatly accelerates. These factors contribute to decreased sweating rates and a drop in the body's ability to cool, increasing the risk of rising core temperatures.It is easy to see how one factor causes others to spiral towards increased core temperatures.

TABLE 8.4 The relationship between weight loss via sweating and effects on the body

Weight loss (%)	Effects on the body
1–2	Increase in core body temperature
3	Significant increase in body temperature
5*	Significant increase in body temperature with a definite decrease in aerobic ability and muscular endurance Possible 20–30% decrease in strength and anaerobic power Susceptibility to heat exhaustion
6	Muscle spasms & cramping
10+	Excessively high core body temperature Susceptibility to heat stroke Heat injury and circulatory collapse with aerobic performance

*With a 5% body weight loss, an athlete will need at least five hours to rehydrate

Source: Alabama Cooperative Extension System, *Sports Nutrition For Young Adults: Hydration*, Keith, RE and Wade, L 2003. Available from http://www.aces.edu/pubs/docs/H/HE-0749/HE-0749.pdf

Where does the 'water' in our sweat come from? Increased sweat rates cause decreases in blood plasma volumes. To counteract this, both the heart rate and cardiac output increase to maintain the blood supply to working muscles. Decreased plasma volumes also reduce the amount of blood that flows to the muscles and the skin, affecting performance as described above. As discussed in chapter 7, vasodilation and vasoconstriction of blood vessels respectively increase blood flow to areas of need and decrease it to areas not requiring as much oxygen, blood and fuels. Vasodilation occurs when core temperatures increase, with the capillaries beneath the skin dilating to release excess heat from the body. This also causes the sweat glands in the skin to produce sweat, which then evaporates on the skin, cooling it. Unfortunately, blood flow to working muscles is reduced via vasoconstriction, and essential fuel supply and waste removal are also restricted, resulting in fatigue.

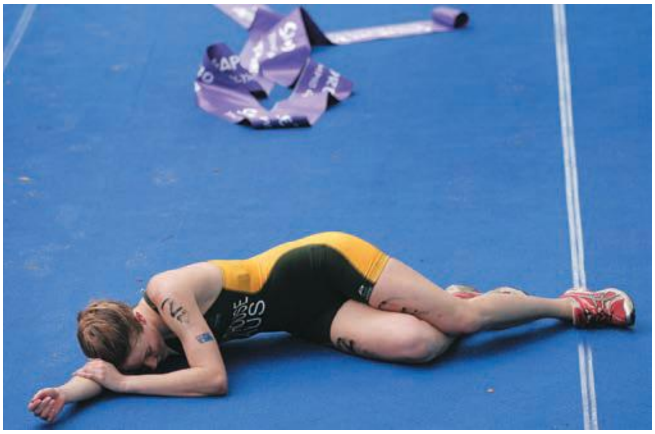
It is therefore easy to understand how a significant increase in body core temperature (hyperthermia) can affect both the central and peripheral processes involved in producing contractile forces and contribute to fatigue.

FYI

Males have an average of 5 litres of blood and females 4.5 litres of blood in their cardiovascular system. Most of the blood (55%) is made up of plasma, the fluid part of the blood. Plasma contains more than 90% water, which is freely exchangeable with the water of body cells and other extracellular fluids. This water is available to maintain normal hydration of all tissues.

Alamy Stock Photo/Michael Kemp

Water sprays during fun runs and marathons can help to maintain core temperatures within acceptable ranges. Would this strategy be effective in a high-humidity environment?



Getty Images/Adam Pretty

An exhausted athlete with severe fatigue crosses the finish line at the end of a triathlon and collapses. Why do running intensities slow dramatically at the end of such an event?

Central governor

In 1997, Tim Noakes, professor of Exercise and Sports Science at the University of Cape Town, suggested that there is a **central governor mechanism** in the brain that acts as a safety valve, contributing to fatigue as a means of protecting the body. This mechanism mostly occurs when the aerobic energy system predominates, as is the case in endurance activities and repeat high-intensity bouts spaced over an extended period of time.

Noakes' theory states that the power output by muscles during exercise is continuously adjusted according to calculations made by the brain regarding a safe level of exertion. These neural calculations factor in earlier experiences of strenuous/endurance exercise, the planned duration of the exercise, and the body's present metabolic state. The brain adjusts the number of skeletal muscle motor units that are stimulated, a control that is subjectively experienced as fatigue. Because this process occurs automatically, it cannot be overridden.

Neuromuscular factors

Decreased CNS 'firing'

Many sports and exercise physiologists have supported Noakes' theory and found that when the brain detects fatigue, it sends weaker signals to working muscles in an effort to reduce intensity and slow down their work rate. This means less electrical stimulation of the muscles, resulting in less forceful and less frequent muscle contractions. This can be considered a self-protection mechanism of the body.

Nerve fibres don't connect directly to muscles. There is a gap (synaptic cleft or neuromuscular junction) across which a neurotransmitter substance, acetylcholine (Ach) travels. As the intensity of exercise increases, a point is reached where Ach release slows down. This means there is less electrical stimulation crossing the gap – and less muscle stimulation, too. If the Ach is not given sufficient time to rebuild, the muscles will contract less forcefully (and in some cases, not at all). Nervous fatigue is a decline in the ability of a nerve to sustain a signal, resulting in lower stimulation of the associated muscles.

Recent research has suggested a more metabolic effect likely to be causing fatigue that stems from the brain's function being compromised. ATP gets broken down to ADP + P_i and the ADP gets further broken down to AMP (adenosine monophosphate) and ammonia (NH_3^+). This is taken up by plasma and the brain, which in turn needs to synthesise glutamine from glutamate in order to remove the ammonia. Accumulation of ammonia in the blood and brain during exercise could also negatively affect CNS function, leading to fatigue both here and at the muscles. When the body buffers the ammonia, pyruvate is also depleted, resulting in decreased contractile forces.

Loss of electrolytes

Electrolytes are salts that control cell membrane stability and carry the electrical charges needed for muscle contractions caused by nerve impulses. When we sweat, electrolytes play key roles in keeping water balanced both inside and outside cells so that our muscles and organs can continue to function optimally. Without electrolytes, nerve cells cannot communicate with each other or perform these essential functions. Performance calling upon the aerobic energy system will be compromised if elevated body temperatures occur, resulting in increased sweat rates and loss of electrolytes.

FYI

Sodium losses in sweat are greater than those of any other electrolyte.

TABLE 8.5 Major electrolytes and their roles

Electrolytes	Functions
Sodium and chloride	Sodium is one of the principal positive ions in the body's fluid and is found primarily outside the cells (extracellular). Chloride, also extracellular, is a negative ion and works closely with sodium in regulating body-water balance and electrical impulses across the cell membrane.
Potassium	Potassium is the main electrolyte inside the body's cells (intracellular) and is stored in muscle fibres with glycogen. Potassium performs a key role by helping to transport glucose into the muscle cell. It also interacts with sodium and chloride to control fluid and electrolyte balance and conduct nerve impulses. When glycogen breaks down to supply energy for your workouts, muscle cells are depleted of potassium.
Calcium	Calcium assists contraction and relaxation of muscles, nerve conduction, hormone secretion, enzymatic reactions and blood coagulation. Calcium is central to the synthesis and breakdown of muscle glycogen and liver glycogen.
Magnesium	Magnesium is present in every cell in your body and forms part of 300+ enzymes involved in nerve impulse transmission, muscle contraction, and ATP (or energy) production. While calcium is essential for muscle contractions; magnesium helps muscles relax, so both work together to delay fatigue.

Source: Based on Sally Warner, *The Complete Electrolyte Story: Theoretical and Practical Approaches*, Victory Nutrition, 2005

INVESTIGATION

Click on http://vcepe34.nelsonnet.com.au to view the Gatorade Sports Science Institute website. Go to the 'Sports Nutrition' section and choose a tab related to any of the fatigue factors considered so far. After reading a couple of articles and findings, write a short report outlining the factor considered, its physical effects on muscle contractions and suggested recovery strategies. Swap your report with a classmate.

Weblink

Delayed onset muscle soreness (DOMS)

Delayed onset muscle soreness (DOMS) is a normal response to unaccustomed exercise or heavy eccentric work. It is normally felt 24–48 hours after exercise. DOMS occurs as the result of microscopic muscle tears incurred during eccentric contractions or unfamiliar actions. The body adapts and heals the injury, which leads to muscle growth. Technically, DOMS is considered to be a muscular condition rather than a fatigue factor.

There are various ways to alleviate DOMS, such as:

» warming up before exercise and cooling down afterwards
» staying hydrated (this allows your kidneys to eliminate damaged muscle protein)
» using a foam roller as part of your cool-down
» performing an active recovery.

Shutterstock.com/Sebastian Gauert

Foam rollers allow self-massage and improved blood flow to assist recovery and decrease pain associated with DOMS. Active recovery on static bikes also helps alleviate symptoms associated with DOMS.

FYI

Muscles are made up of slow- and fast-twitch fibres. Slow-twitch fibres are predominantly fuelled by the aerobic energy system and are preferentially recruited during low-intensity and endurance-linked activities. Fast-twitch fibres are predominantly fuelled by the PC and anaerobic glycolysis energy systems, and are best suited to explosive/short-duration and high-intensity activities. This will be further investigated in chapter 9.

Before considering recovery strategies, take a moment to link the fatigue factors considered so far to the three energy systems, as shown in Table 8.6.

TABLE 8.6 The three energy systems and major associated fatigue factors

Predominant energy system	Likely causes of fatigue when system predominates
ATP–PC	Accumulation of ADP and P_i Depletion of ATP and PC
anaerobic glycolysis	Accumulation of H^+ (hydrogen ions)/Working above LIP or MLSS Lactic acid is no longer thought to contribute to fatigue. It is now regarded more as a positive performance enhancer.
aerobic	Depletion of blood glucose → muscle / liver glycogen → fats Decreased neural firing/motor unit recruitment CNS/brain self-limiting mechanisms Elevated core temperature leading to: » dehydration and increased sweat and loss of electrolytes » blood flow away from muscles to skin

CHAPTER CHECK-UP

1 What role does potassium play in muscular contractions, and what happens when it is reduced via high sweat rates?

2 For each of the following events or training conditions, clearly identify the depletion of one major fuel that contributes to fatigue.
   a 100-metre sprint (track event <10 seconds)
   b 100-metre swim (approximately 50 seconds)
   c Australian Rules football match (rover covering 18 km)
   d Short-interval training (work = 60 seconds, rest = 120 seconds)
   e Triathlon (approximately 4.5 hours)
   f Swimming the English Channel (18 hours)

3 Discuss two disadvantages associated with switching from carbohydrates to fats as the main fuel source in any endurance performance lasting longer than three hours.

4 How does the accumulation of H^+ resulting from intermediate interval sprinting contribute to decreased muscle force?

5 How might an athlete avoid hyperthermia if they were about to compete in their first Oxfam Trailwalker 100-kilometre event?

RECOVERY RATES

Recovery aims to return the body to pre-exercise conditions and, in doing so, reverse the effects of fatigue. Efficient recovery strategies will enhance adaptations to exercise loads, as well as preparing the performer for subsequent training or competition. Insufficient recovery will delay the removal of fatiguing factors and any possible adaptations, as well as taking performers into the dangerous area of overtraining, associated overuse injuries and immunodeficiency-related illnesses.

We will now consider each of the key fatiguing factors and suggest the most appropriate recovery strategies. Most coaches stress the importance of an active **cool-down** following training and competition, but in some cases this actually delays, rather than aids, the recovery process. This is another example of needing to match the recovery strategy to the most likely cause(s) of fatigue.

Active recovery vs cool-down

From a scientific or physiological perspective, an active recovery refers to the cool-down that occurs immediately after a training session or competition. What many coaches and personal trainers consider to be an active recovery is an easier or 'lighter' workout, compared to the normal training routine/plan. Typically, this active recovery would be done on a rest day from training.

Why not simply do nothing on rest days?

Some people believe that active recovery helps maintain your body's metabolic pathways of recovery, and that light exercise doesn't add to training stress or compromise recovery. For some, an active recovery provides psychological benefits – the person feels better and more positive with regular, daily exercise.

Daily exercise is not appropriate or recommended if it feels uncomfortable and is stressful, however. Active recovery days should only be undertaken as a person's fitness levels and adaptations increase. For example, a professional soccer player going for a run on a rest day will still be able to train at full capacity the next day, and the active recovery will most likely be of benefit to their overall wellbeing. However, for someone who is just starting a training program, exercise on consecutive days could add to their body's stress and outpace their ability to adapt to the previous training session.

If doing low-impact/low-intensity exercises on rest days makes you feel better, an active recovery day is a good choice. But, if it adds to your pain or stress levels, you should avoid active recovery until your body becomes more accustomed to training. For the purposes of this chapter, active recovery is applied immediately after a training session or competition.

Refuelling

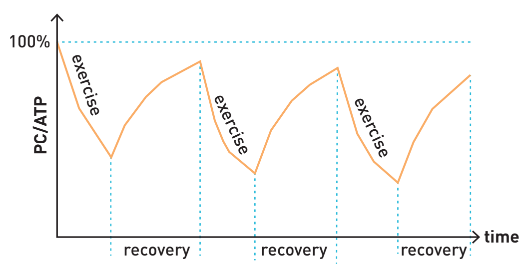
Intramuscular ATP stores deplete totally within 2 seconds of being activated. They are resynthesised quickly by breaking down other fuels in order of ease and availability. For high-intensity actions, this would lead to the breakdown of PC and muscle glycogen, both anaerobically. Endurance events would primarily rely on muscle and liver glycogen, and ultra-endurance events on fats, when carbohydrates were depleted (see Table 6.7 on page 127).

Phosphocreatine

Phosphocreatine (PC) is restored extremely rapidly as soon as rest or recovery commences, and is facilitated by a **passive recovery**. Recovery needs to be either total rest or exercise at an intensity low enough not to call upon PC, because this will hinder recovery rates. Most PC is restored during the rapid part of the oxygen debt, with 70 per cent being restored in the first 30 seconds of recovery. It can take up to 10 minutes to restore PC to pre-exercise levels. The body replenishes PC from two sources:

1 The liver produces PC from amino acids.
2 Dietary creatine is obtained from red meats or creatine monohydrate supplements.

Low pH (caused by accumulation of hydrogen ions) will slow PC restoration, as will low oxygen supply during recovery. This is why having a high aerobic capacity can actually benefit anaerobic performances as well, and why many teams focus on building this up during pre-season training. These restoration rates assume total muscle depletion. If a muscle contracts forcefully for only a few seconds, not all of the stored PC will be drained, so less resynthesis time is needed. This is very important when calculating the rest times required during short- and intermediate-interval training. Sometimes, athletes wanting to train their anaerobic glycolysis system will deliberately not allow time for full PC replenishment in an effort to minimise its contribution.

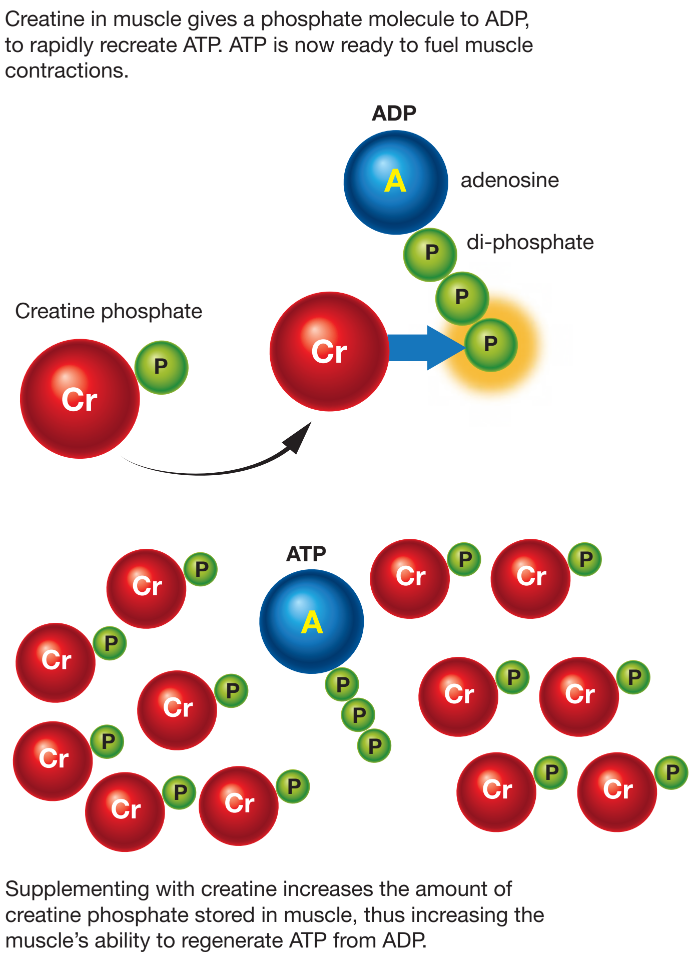


PC depletion and restoration during 4-second sprints with 15 seconds rest, conducted by a netball centre player (not to scale)

TABLE 8.7 PC restoration rates following a passive recovery (assumes PC depleted by more than 95 per cent)

Recovery time	Muscle phosphagen restored
30 seconds	70%
60 seconds	75%
90 seconds	93%
120 seconds	95%
150 seconds	97%
180 seconds	98%
10 minutes	100%

Dietitians have found that creatine supplementation increases the rate of PC restoration, as well as increasing the amount stored at muscles. Athletes calling primarily upon the ATP–PC system should strongly consider this strategy.



Blood glucose and muscle glycogen restoration

The body uses glucose at a rate of about 1 gram per minute during moderate exercise (60% max HR) and at a slightly higher rate during high-intensity exercise (85% max HR). Carbohydrates should be consumed during exercise lasting longer than 1 hour, after which time more than 60 grams of carbohydrate would have been metabolised and converted to energy.

TABLE 8.8 Suggested carbohydrate intake for athletes undertaking various training loads

Training situation	Daily carbohydrate intake (g/kg of body weight)
Daily refuelling needs for training programs less than 60–90 minutes per day of low intensity	5–7
Daily refuelling for training programs greater than 90–120 minutes per day	7–10
Daily refuelling for athletes undertaking extreme programs of 6–8 hours per day	10–12+
Carbohydrate loading for ultra-endurance events (triathlon)	7–10

Adapted from: Australian Institute of Sport, 2013

TABLE 8.9 Glycogen restoration rates for different 'wait times' before ingestion takes place

Post-event glycogen intake (high-GI)	Glycogen returns to pre-exercise levels
Within 1 hour	55% restored in next 5 hours 100% restored within 24 hours (1 day)
1–2 hours	100% restored within 24–48 hours (2 days)
5+ hours	Up to 5 days

The effects of glycogen depletion can be minimised by ensuring adequate stores are achieved before training or competition. This might involve carbohydrate loading four or five days before competition. During both training and competition lasting more than 60 minutes, **hypertonic sports drinks** should be consumed to lessen the amount of glycogen drained from the liver. These drinks have two functions: they keep performers both hydrated and well-fuelled. Alternatives to sports drinks include sports gels and sports bars. Whole foods that are high in carbohydrates may not be practical, or might cause gastric upsets.

Aside from maintaining high blood glucose levels during performance, it is critical to replenish used glycogen as quickly as possible during recovery. Muscles are able to store greater amounts of carbohydrates within the initial couple of hours following exercise.

Exercise makes muscles more responsive to insulin, which results in greater uptake of glucose from the blood by muscles. This improved insulin response only lasts for about 30–45 minutes following exercise, so that's the 'window' sports dieticians often refer to as being critical for replacing carbohydrates. High-GI foods should be consumed as soon as possible after events to ensure rapid restoration of muscle glycogen (first) and liver glycogen (second).

Physiologists have found that consuming protein and carbohydrates together prolongs this window of insulin sensitivity. This accelerates muscle glycogen replenishment and increases glycogen stores for the next exercise session by stimulating insulin release (Ivy et al., 2002). This recovery strategy also contributes to improved muscle repair after high-intensity bouts or extended endurance efforts. Consuming carbohydrates and proteins together means the release of insulin from the carbohydrate reduces muscle protein breakdown, and the amino acids from the protein increase muscle protein synthesis.

To repair and build muscle, athletes must refuel with high-protein foods immediately after exercise, especially after resistance training. It is recommended that they consume 30–40 grams of protein that includes 3–4 grams of leucine per serving to increase muscle protein synthesis. Whey is an optimal post-workout protein because of its amino acid composition and the speed of amino acid release into the bloodstream. Athletes also need to eat protein regularly throughout the day after training/performance in order to stimulate protein synthesis for up to 48 hours after exercise. Post-workout nutrition shakes help rehydrate athletes while providing both carbohydrate and protein.

FYI

Bananas are a good source of potassium and carbohydrate. Have you ever wondered why a tennis player will often eat a banana close to the end of their matches in the third, fourth or fifth set?

FYI

The Australian Institute of Sport (AIS) recommends that performers consume 1–1.5 grams of high-GI foods per kilogram of body weight in the first 30–45 minutes after exercise. There is no significant difference between the benefits of solids and liquids, but most athletes seem to prefer liquids.

INVESTIGATION

Weblink

1 Protein plays an important role in muscle repair and rebuilding. Conduct online research into some other functions protein plays in recovery.

2 While conducting your investigation, compare the diet of an athlete who predominantly calls upon their aerobic energy system with that of an athlete who is involved in activities predominantly driven by the two anaerobic energy systems. Present your findings in a side-by-side table.

Summary: Carbohydrate and protein intake pre- and post-training

» A carbohydrate/protein snack provides an excellent combination of nutrients to optimise post-exercise muscle protein balance. Examples of suitable snacks include:
  - yoghurt and cereal bar or banana
  - sports protein bar
  - liquid meal supplement
  - cereal and milk
  - cheese or tuna sandwich.

Alamy Stock Photo/epa european pressphoto agency b.v.

Elite cyclists are provided with carb top-ups by team support members at regular intervals during a competitive stage. What should this cyclist consume in the 24 hours following their cool-down to assist their recovery?

» Only a small amount of protein post-exercise is required to increase muscle protein synthesis.

» For athletes aiming to increase muscle mass, a pre-exercise protein/carbohydrate snack appears more important than a similar post-exercise snack

» It is important to consider individuals' tolerances to food prior to exercise.

» Foods that contain protein should be consumed 45 to 60 minutes before exercise to allow for digestion and absorption.

» 'Real' foods may provide a better source of amino acids to aid muscular repair post-exercise because they are released slowly into the body.

» Alcohol post-exercise is likely to impair muscle protein synthesis.

Adapted from: Cox, 2006

Carbohydrates that the body does not use as fuel are stored as glycogen in the muscles and liver. However, if these stores are full, excess carbohydrates have nowhere to be stored so they are converted to fats. This typically happens when athletes reduce their training loads but do not modify their carbohydrate intake. With decreased activity levels during a sport's off-season, players' carbohydrate intake should be reduced to avoid an increase in body fat percentage. As well as having their carbohydrate intake monitored, elite performers undergo regular skinfold tests to ensure their body fat percentage remains within agreed levels.

Rehydration

Post-exercise hydration should aim to reverse any fluid loss incurred during training or competition/performance. Rehydration should include water to restore hydration, carbohydrates to replenish glycogen stores, and electrolytes to speed rehydration.

Professional athletes rarely drink only water in order to return to their pre-effort physiological state. Including carbohydrates in the rehydration solution may improve the rate of intestinal absorption of sodium and water, and aid in replenishing the glycogen stores.

A high rate of fluid consumption during the first two hours of post-exercise rehydration is known to increase plasma volume significantly, resulting in a rapid return to pre-exercise level. Professor Louise Burke, Head of Sports Nutrition at the AIS, suggests that to achieve rapid and complete recovery from dehydration, athletes should drink 1.5 litres of fluid for each kilogram of body weight lost. Hydration (before, during and after performance) greatly enhances performance, maintenance of constant core temperatures and recovery. Most sports beverages contain additional flavouring to cover up the salty taste caused by the high sodium content.

Electrolyte or sports drinks are excellent for quick electrolyte replacement. With so many of these drinks on the market, it is important to read the label carefully. Choose a drink that is not too high in sugar in order to avoid gastrointestinal discomfort and dehydration. Many sports drinks contain as much sugar as soft drinks. If you are not undertaking regular, high-intensity exercise, drinking these drinks may cause weight gain.

FYI

To determine how much fluid to drink in order to rehydrate effectively and quickly, athletes should weigh themselves before and after training/competition. For each 100 grams lost, 150 mL of fluid should be consumed in the first hours of recovery.

Metabolic by-products

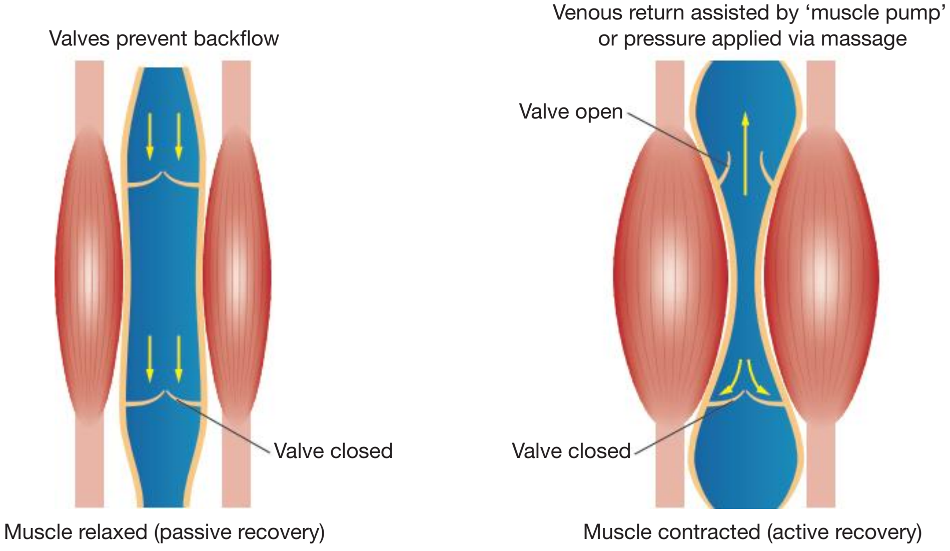
We have seen that large amounts of hydrogen ions (H^+) accumulate when the LIP or MLSS is exceeded. In most cases this corresponds to exercise intensities around 85 per cent of maximum heart rate (85% max HR), but aerobic conditioning can cause this to shift up to 90% max HR. This is another good reason to develop the aerobic energy system and aerobic capacity during off-season and pre-season training.

The more quickly H^+ ions can be removed from muscles, the more quickly performers will recover. An active recovery is recommended for the following reasons:

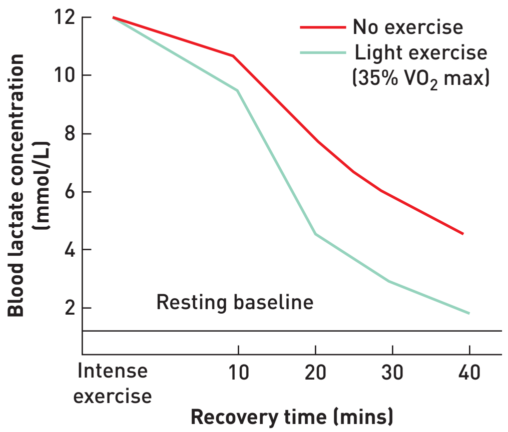
» It maintains higher oxygen levels than if the person were to simply sit or lie down, which speeds up removal of the lactate that would otherwise impede recovery.
» It creates a 'muscle pump', whereby muscles press on blood vessels surrounding the active or working area. This pump increases the rate of oxygen supply and waste removal via the circulatory system.

FYI

Although lactic acid is no longer thought to be the cause of fatigue, it is still tested as an indirect measure of hydrogen ion levels. (H^+ levels can be measured directly, but this is very expensive.)



Effect on blood flow with passive vs active recovery and massage



Passive recovery compared with an active recovery and the effects on blood lactate removal

» It prevents **venous pooling**. This commonly occurs during a passive recovery following high-intensity activity where large amounts of blood are supplied to working muscles. This blood tends to remain or 'pool' around muscles for longer periods than it would if muscles were to actively squeeze on surrounding blood vessels, promoting venous return to the heart.

Although massage is generally considered to be a passive recovery strategy, a muscle pump can be created when muscles are squeezed and massaged. However, this doesn't have any added benefit (compared with rest) in terms of an associated higher oxygen presence. The graph at left compares a passive recovery with an active recovery and the effects on blood lactate removal.

Contrast bathing (hot and then cold showers or baths) leads to increased removal of H^+ ions. With **vasodilation** and **vasoconstriction** being repeated many times, contrast bathing is more a venous pump than a muscle pump, and should be considered in conjunction with an active recovery.

TABLE 8.10 Passive versus active recovery in removal of H^+ ions

	Passive recovery (rest)	Active recovery (same activity at reduced intensity)
Minimal removal time	1 hour	30 minutes
Maximal removal time	2 hours	1 hour

Other by-products

Inorganic phosphate (P_i) and adenosine diphosphate (ADP)

As already discussed, immediate or explosive energy comes from the chemical process of breaking down ATP into two simpler chemicals: ADP and P_i. Creatine (C) binds with the phosphate in your body to form PC. When PC splits and energy is liberated, ADP and P_i bond to form more ATP. This tends to occur more quickly when both phosphate and oxygen are available to ensure rapid PC resynthesis, so a low-level active recovery is advisable.

If ADP begins to accumulate in muscle, then an enzyme is activated in the muscle to break down phosphocreatine (PC) in order to restore ATP levels (PC + ADP → ATP + C). For this reason, a passive recovery would see quicker removal of accumulated ADP than an active recovery. The creatine released from this reaction is converted to creatinine and excreted in the urine.

Addressing neuromuscular factors

Decreased CNS 'firing' is our body's safety mechanism or 'shut-down valve', designed to protect us from overworking. This means the only real recovery strategy for this is rest (passive recovery), which stops acetylcholine (Ach) from being broken down. In trained endurance athletes, plasma choline concentrations can be halved during training or competition. These reductions in blood choline could lead to a reduction in Ach synthesis. However, dietary meals high in cholines might increase the resynthesis of Ach.

Impaired sodium–potassium pump function can restrict muscular contractions. Potassium works with sodium to balance the fluids and electrolyte levels in the body. Most of the sodium in your body is stored outside your cells, while most of the potassium is stored inside them. Their different concentration levels mean that potassium constantly wants to get out and sodium wants to get in. When the movement of potassium is blocked, both muscle and nerve activity can be affected.

It is important that we replace lost sodium and potassium, as well as other key electrolytes such as calcium and chloride, which are essential in order to keep rebuilding ATP. Larger amounts of electrolytes are consumed during moderate to vigorous physical activity (such as engaging in sports activities or working out at the gym, compared with walking from class to class).

CHAPTER CHECK-UP

1 List three different types of athletes who would benefit from creatine supplementation.
2 Explain how the use of foam rollers could facilitate the removal of H^+ ions from leg muscles.
3 Apart from muscle rebuilding and repair, why is it important for athletes to consider consuming high-protein concentrates following a training session/competition?
4 Discuss a strategy that Tour de France cyclists might consider to reduce the amount of fats their bodies use in the production of energy when riding.
5 Discuss the best way for a sprinter to recover PC during a short-interval training session.
6 How might the recovery conducted by a sprinter doing intermediate interval training be different to that of a teammate doing long-interval training?

QUICKVID

Video

Watch clear explanations of the lactate threshold, lactate tolerance and links to fatigue; and the cross-over effect and fuel depletion by one of the authors. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 8, page 181 and choose the 'interactive'.

CHAPTER SUMMARY

- Fatigue is an exercise-induced reduction in the power-generating capacity of a muscle, and an inability to continue the activity. The onset and development of fatigue depends on the type, intensity and duration of activity, the type of muscular contractions and the performer's level of fitness.
- Fatigue may be local, general or chronic. Central fatigue occurs when central nervous system (CNS) impairment decreases muscular function. Peripheral fatigue is when impaired internal muscle processes disrupt muscle function at the muscle site.
- Fatigue can be caused by many factors (multifactorial). Key factors are fuel depletion, accumulation of metabolic by-products, neuromuscular interruptions and elevated body temperature. One of these will be the most significant contributor to fatigue and this is mostly linked to the predominant energy system being called upon for the activity.
- PC depletion occurs during high-intensity, short-duration activities.
- Accumulation of inorganic phosphate (P_i) occurs rapidly during high-intensity exercise or performance bouts and leads to decreased contractile force production. It reduces the amount of calcium that can be released and is associated with the slowing of muscle contractions.
- The accumulation of hydrogen ions (H^+) leads to muscle pH decreasing, slowing enzyme activity and the breakdown of glucose and decreasing muscle function.
- Using fats when glycogen is depleted leads to fatigue. Fats take longer to break down and require more oxygen than carbohydrates, which means less oxygen is available for muscles to use. The body needs to have some glycogen left in order to break down fats.
- Lactic acid is a useful energy source and may help to prolong submaximal activity. Evidence suggests that blood lactate is a useful indirect marker for the onset of fatigue, but does not itself cause fatigue and may in fact be beneficial to performance.
- As core temperature rises, sweat rates increase and blood is redistributed to the skin's surface to maximise evaporative cooling. Less blood, oxygen and fuels flow to working muscles, and aerobic exercise may become increasingly anaerobic. To counteract decreases in blood plasma volumes, both heart rate and cardiac output must increase to continue supplying oxygen to working muscles.
- PC restoration is facilitated by a passive recovery (total rest or low activity) but slowed by low pH and low oxygen supply. Many teams focus on building high aerobic capacity during pre-season training as this can benefit anaerobic performances as well.
- Co-ingestion of carbohydrates and proteins has multiple benefits to both aerobic and anaerobic athletes in terms of recovery.
- The more quickly H^+ ions can be removed from muscles, the more quickly performers will recover. An active recovery maintains higher oxygen levels, creates a 'muscle pump' (which increases the rate of oxygen supply and waste removal via the circulatory system) and prevents venous pooling.
- Massage is a passive recovery strategy but provides some benefits from the 'muscle pump' when muscles are squeezed. Foam rollers have become popular because they allow athletes to 'self-massage' and improve recovery rates. Contrast bathing creates a 'venous pump' and should be considered in conjunction with an active recovery.
- It is important to replace lost sodium and potassium (and other key electrolytes such as calcium and chloride) to allow uninterrupted transfer of nerve impulses and keep rebuilding ATP. Increased amounts of electrolytes should be consumed during and after moderate to vigorous physical activity.

CHAPTER REVIEW

Multiple-choice questions

1 Accumulation of H^+ ions will contribute to fatigue by
   A restricting blood flow to working muscles.
   B interfering with glycolytic and oxidative enzymes.
   C increasing muscle pH.
   D all of the above.

2 An active recovery is often used following training or competition because it
   A delays DOMS.
   B keeps oxygen levels above resting levels and creates a muscle pump.
   C facilitates the electrolyte balance between active and passive transportation.
   D prevents cramps during recovery.

3 Elevated body temperature will contribute to fatigue by
   A contributing to a muscle meltdown.
   B increasing plasma levels and decreasing blood pressure.
   C decreasing oxygen availability to the cardiac muscle.
   D causing blood to be redirected to the skin's surface.

Short-answer questions

4 A hockey player is showing clear signs of 'slowing down' during the last quarter of her match.
   a List three factors likely to be contributing to the player's fatigue, outline their effects on her performance and summarise strategies that could minimise these effects.
   b Outline three dietary strategies the player should use at the completion of the game to maximise her return to pre-game conditions, ensuring that she will be in her best condition to train effectively in two days' time.

5 Accumulation of H^+ ions see a rapid decrease in work-rate. Briefly discuss two ways this can be:
   a prevented from occurring
   b removed as quickly as possible once they accumulate at the muscle site.

6 Discuss why a sports nutritionist would suggest that a marathon runner considers having a high carb/protein recovery shake immediately after a 20-kilometre training run, despite this causing significant muscle breakdown (catabolism).

7 Rafael Nadal has consistently been a top-five tennis player in the world over the last 10 years. Nadal's sweat rate was measured at 1.45 litres per hour.
   a Briefly discuss how a sweat rate as high as this could lead to decreased performance for Nadal.
   b If Nadal were to become dehydrated, what symptoms may he experience?
   c Nadal is often seen drinking a coloured drink during the change of ends. This is a specialised electrolyte drink prepared by his dietitian. Outline the importance of ensuring the electrolytes Nadal loses through sweat are replaced.

8 For a sport of your choice, discuss factors that might contribute to fatigue during either competition or training. Your response should clearly indicate how fatigue might have been avoided or delayed, as well as the most logical recovery strategies you would recommend to return the athlete to pre-competition or pre-training conditions.

9 a Outline two different reasons why lactate levels are measured during the training of elite sportspeople.
   b As a result of intermediate-interval training, Helena is able to increase her LIP/MLSS. What does this mean in terms of her performance when calling upon the aerobic energy system and anaerobic glycolysis system?

10 Peta is always trying to help out her house at the athletics carnival. She ran in the 1500 metres and came second in a time of 5 minutes 32 seconds. After this

race, her house captain said that another girl had pulled out of the 800-metre race and they didn't have anyone to replace her. True to form, Peta said she would be OK to run. The race was scheduled in 75 minutes' time.

a What recovery strategies would you advise Peta to use to improve her chances of performing well in the 800 metres? Briefly give reasons for your suggestions.

b Explain why the oxygen deficit is greater in the 800 metres compared with the 1500 metres, but the opposite is true for oxygen debt.

11 a Discuss the differences between an active and a passive recovery and explain when each of them would be recommended for each of the following situations:

i Interval training doing 6 × 80-metre sprints

ii Continuous training lasting for 30 minutes

iii Plyometrics training involving bench blasts, clap push-ups, single-leg bounds, etc.

b If an active recovery cannot be undertaken because an athlete is suffering from general rather than local fatigue, what can be done to assist the recovery process?

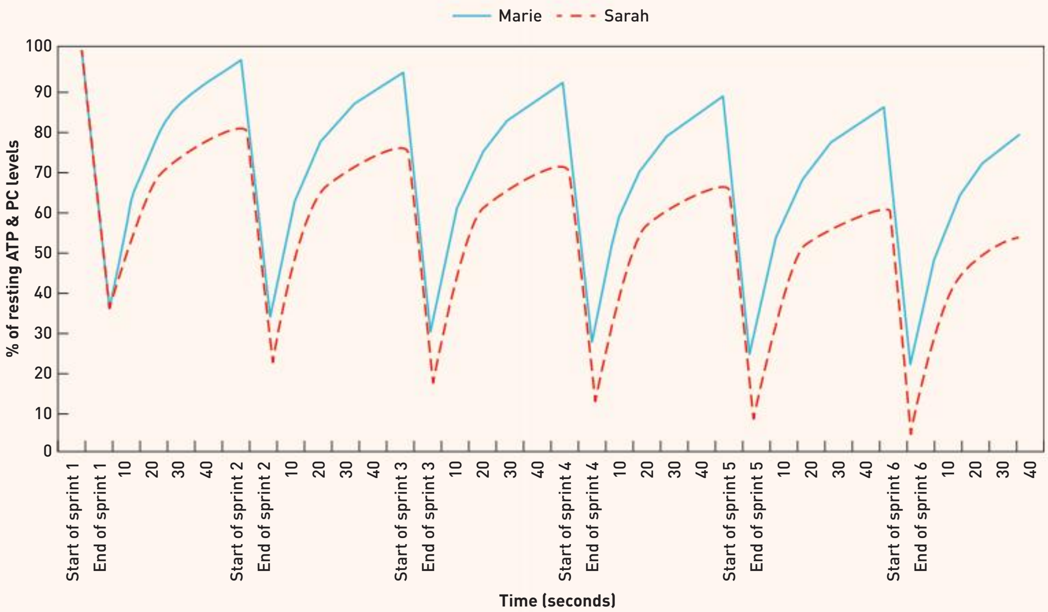
12 The following graph shows the PC depletion and replenishment during 6 × 5-second sprints with 50 seconds rest in between performed by Marie and Sarah (both netball players).

a Provide a reason why you believe Marie is better able to replenish PC than Sarah.

b Is Marie or Sarah more likely to accumulate P_i (inorganic phosphates) during this interval training session?

c Why is it unlikely that a netball goal shooter would fatigue as a result of H^+ accumulation?

d Marie is seen eating a protein bar after the training session. It contains 70 per cent of the recommended daily protein intake and 32 per cent of the recommended daily carbohydrate intake. Discuss the role each of these macronutrients plays in her recovery.



Courtesy of Anthony Dowson, www.shapeperformance.co.uk

UNIT 4

TRAINING TO IMPROVE PERFORMANCE

AREA OF STUDY 1

WHAT ARE THE FOUNDATIONS OF AN EFFECTIVE TRAINING PROGRAM?

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CHAPTER 9

FITNESS COMPONENTS USED IN SPORTS AND ACTIVITIES

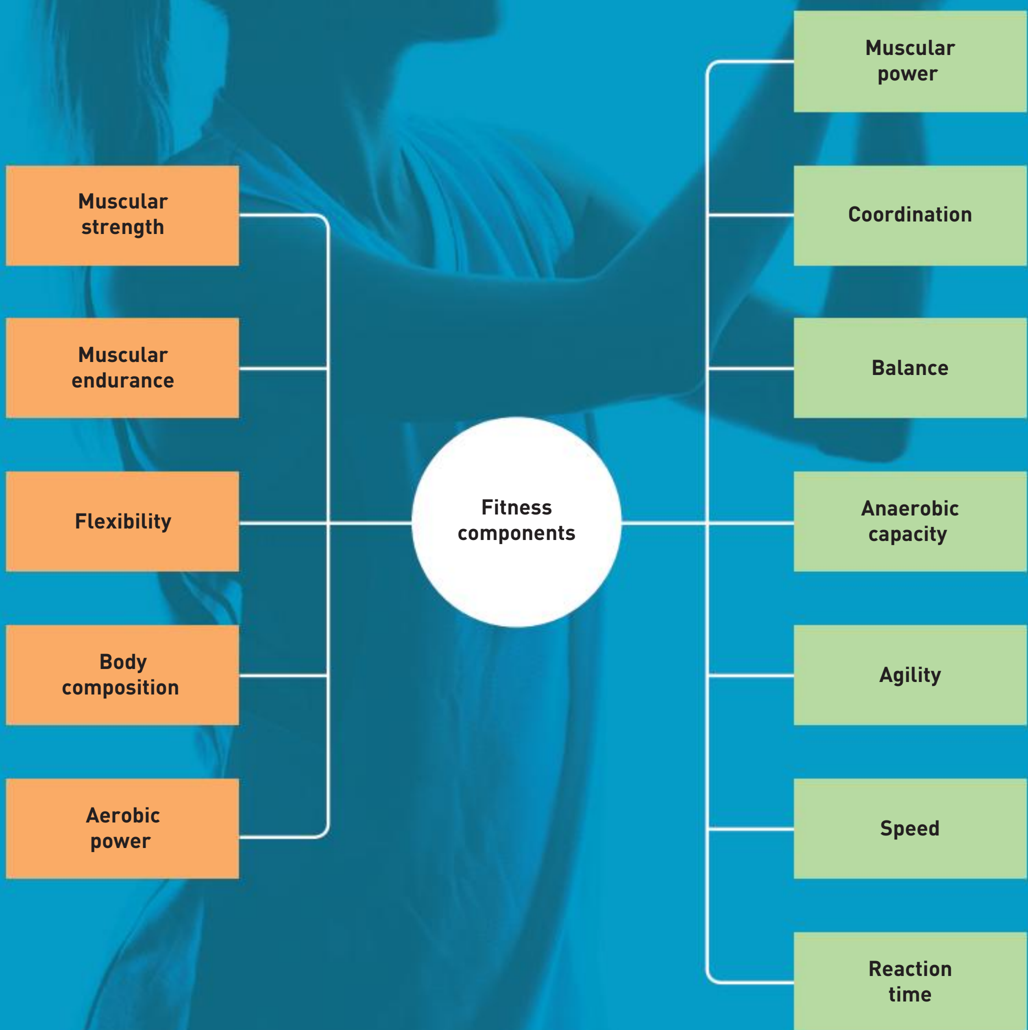
Key knowledge

» fitness components: definitions and factors affecting aerobic power, agility, anaerobic capacity, balance, body composition, coordination, flexibility, muscular endurance, power and strength, reaction time and speed

Key skills

» analyse data to determine the major fitness components and the factors that affect them, and energy systems used in a variety of sporting events and physical activities

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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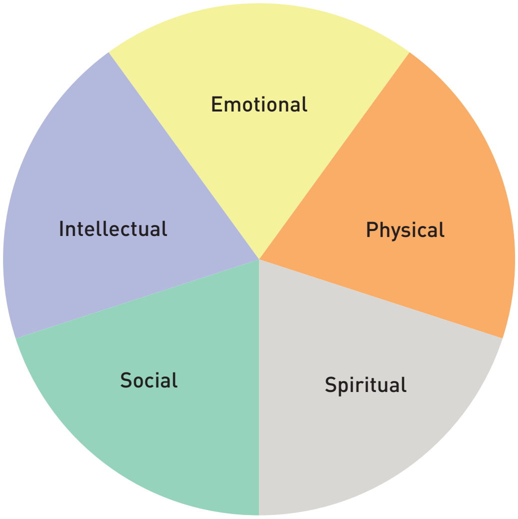
FITNESS, HEALTH AND WELLNESS

In physical education we are interested in being physically fit, but physical fitness is just one aspect of overall health.

Health refers to physical wellness and freedom from illness and disease, and incorporates social, emotional, spiritual, intellectual and physical health. Wellness is a positive component of good health, as opposed to illness, which is a negative component of health. Being physically fit is only one dimension of health and wellness.

If you ask someone how they are, their response may be, 'Well, thanks' or 'Fit and healthy, thank you'. The terms for wellness (or wellbeing), health and fitness are often interchanged, yet they are distinctly different. Wellness is how a person feels about life and how effectively they can function. A person who is 'well' is satisfied at school or work, spiritually fulfilled, enjoys leisure time, is physically fit, is socially involved and has a positive emotional outlook.

Our focus in physical education is physical fitness. It is important to understand what this term means.



The dimensions of health and wellness

PRACTICAL ACTIVITY

TASK:

» Working in small groups (3–4 students), brainstorm words that relate to physical fitness.

» Write these words on poster paper.

» Hang the posters around the room.

Enter all of the words from each group into an online word cloud generator to produce a word cloud of your brainstorm.

1 Which words appear consistently across all the groups?
2 From these words, construct your own definition of physical fitness.
3 Share your definition with the class.
4 Are the definitions created by all the groups the same or different?
5 Are there key words or elements in the definition?
6 Compare your definition to the ones provided below.

There are numerous definitions of physical fitness. In general, it refers to a person's state of health and wellness. Some definitions include the ability to carry out daily tasks and leisure time activities without undue fatigue, and the ability of the cardiorespiratory system to perform at optimal efficiency.

However, there are some questions raised by these definitions, such as how to measure 'undue fatigue' or 'ample energy', or 'optimal efficiency'. How do we compare the fitness level of a triathlete to that of a sprinter? Both are obviously fit, but they have very different capacities.

Fitness is specific to the requirements of the sport and the individual. Even in team sports, the different requirements of different positions mean that players in the same team may have vastly different fitness levels. In soccer, a goalkeeper's fitness requirements are different from a midfielder's; in netball, a goalkeeper's fitness requirements are different from a centre player's.

It is useful to regard fitness as multidimensional, rather than 'one size fits all'. This approach takes into account the similarities and differences we see across sports and across individual athletes. Elite athletes such as Liz Watson (netball), Sally Pearson (athletics) and Steven Smith (cricket) are all very physically fit, which allows them to compete at the highest level for their given sport. Their individual needs in order to excel, however, are quite different.

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Australian hurdler Sally Pearson, netballer Liz Watson and cricketer Steve Smith. How do the fitness requirements for hurdling differ from those for netball and cricket?

PRACTICAL ACTIVITY

COMPARING FITNESS REQUIREMENTS

Using the three photos above, compare and contrast the fitness requirements for each athlete. In your analysis, consider:

1 what each athlete is required to do to participate in their sport
2 how long the activity goes for
3 the activities, movements and skills the athlete needs
4 the intensity of the activities they undertake.

The dynamic nature of fitness

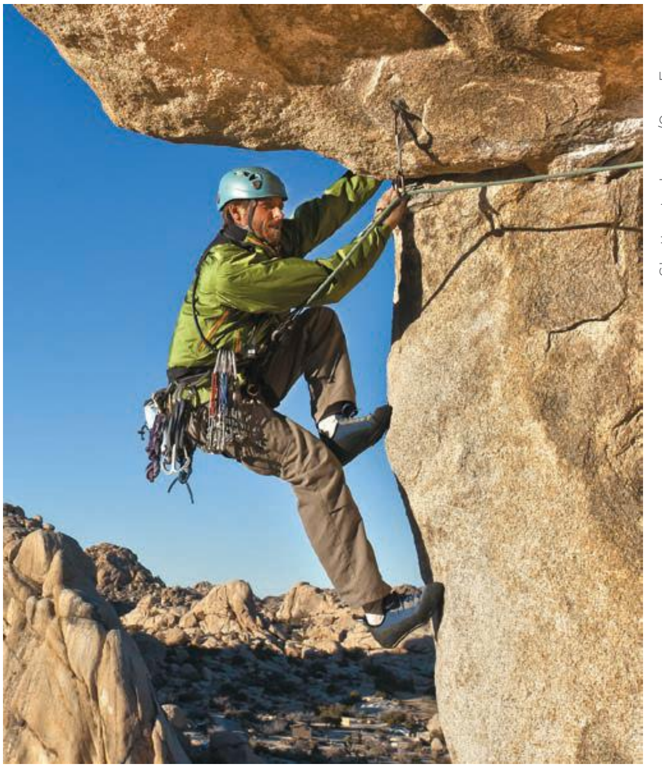
The Olympic motto, 'Citius, Altius, Fortius', is Latin for 'swifter, higher, stronger'. Baron de Coubertin, the founder of the modern Olympics, felt the motto described the goals of great athletes all over the world. As time has shown, athletes continue to improve – they run faster, jump higher and hit harder. These changes are brought about in part by changes to their fitness levels. Coaches, exercise physiologists and athletes focus on improving aspects of fitness that will lead to an improvement in performance. Improving fitness may be important to individuals for different reasons, such as increased mobility and independence in the elderly. Fitness is gained through training and lost through inactivity. As fitness levels change, it can be beneficial to establish a baseline fitness level to determine the amount of change, and relate this change to training and detraining. (See chapter 11 for more on assessing fitness.)

THE COMPONENT MODEL OF FITNESS

Rather than looking at total physical fitness, which is difficult to define, we can use a model based on **health-related components** and **skill-related components**.

Health-related fitness components are more important to overall health and participation in daily activities than to athletic or sporting ability. These are aerobic power, muscular strength, muscular endurance, flexibility and body composition. These components of fitness are directly related to good health and a reduced risk of **hypokinetic disease**. Having a moderate amount of fitness in each of the health-related components is necessary for disease prevention and health promotion, but you do not need exceptionally high levels to achieve health benefits. For example, if we look at strength, a certain degree is required to maintain good posture and prevent back problems. However, a much higher degree of strength is required for activities such as rock climbing.

Skill-related components improve motor skills. They are sometimes referred to as athletic ability or performance components, and include anaerobic capacity, muscular power, speed, agility, coordination, balance and reaction time. A high degree of fitness in these areas is often linked to high levels of athletic performance.



Shutterstock.com/Greg Epperson

What components of fitness might this rock climber call upon while looking around for his next move?

TABLE 9.1 Health- and skill-related components of fitness

Health-related components	Skill-related components
Aerobic power	Agility
Body composition	Anaerobic capacity
Flexibility	Balance
Muscular endurance	Coordination
Muscular strength	Muscular power
	Reaction time
	Speed

The component model of physical fitness allows for measurements to be taken and comparisons to be made. Each individual component can be compared with norms (normative data), and different athletes can be compared in each component. With the component model of fitness, there is no need to determine total physical fitness. An understanding of the fitness levels in each component is enough for coaches, personal trainers, exercise physiologists and athletes to determine athletes' strengths and weaknesses, and to construct training programs to address these areas.

Aerobic power

Aerobic power is the rate of energy release by processes that depend on oxygen (aerobic respiration). Aerobic power depends on the capacity of the cardiovascular and respiratory systems to supply nutrients and oxygen to the muscles and the ability of the muscles to use the oxygen for sustained exercise. Aerobic power is also known as aerobic fitness, aerobic capacity and cardiovascular or cardiorespiratory fitness, endurance or capacity.

Getty Images/Ian Walton

Getty Images/Hagen Hopkins

Getty Images/Richard Heathcote

Why do marathon runners, track cyclists and cross-country skiers need high aerobic power?

Aerobic power is the most important of the health-related fitness components and is related to the ability to perform activities that involve large muscle groups, such as swimming, running and cycling for extended periods of time. High levels of aerobic power also improve recovery after a bout of high-intensity exercise. Individuals with high aerobic power are able to transport and use more oxygen than those with a lower level of aerobic power.

Factors affecting aerobic power

Aerobic power depends on the ability of the body to take in oxygen, transport it and use it. The cardiovascular and respiratory systems are therefore important to aerobic power. Aerobic power is affected by:

- » concentration of oxidative enzymes
- » size and number of mitochondria
- » blood volume
- » cardiac output (stroke volume × heart rate)
- » blood flow to working muscles.

Increased levels of aerobic power are associated with:

- » a stronger and more efficient heart
- » healthy blood vessels (arteries, veins and capillaries) that are elastic and free from obstructions
- » blood that has adequate levels of **haemoglobin** to carry the oxygen
- » a fit respiratory system, including lungs and respiratory muscles
- » muscle tissue that is capable of using the oxygen delivered to it.

See chapter 15 for more about chronic adaptations of the cardiorespiratory system.

Activities that require aerobic power use large muscle groups for an extended period of time. Completing these activities therefore relies on the aerobic energy system to provide sufficient ATP. Some activities that require a high level of aerobic power are marathon running, road cycling, triathlon and 1500-metre swimming. Well-developed aerobic power is also important to the recovery process (chapter 8). The best measure of aerobic power is maximum oxygen consumption (VO_2 max) – testing methods are discussed in chapter 11. Aerobic power is improved through aerobic training such as continuous, fartlek or long-interval training. Training methods are discussed in more detail in chapter 13.

FYI

Some physiologists believed that aerobic power was limited by oxygen supply and others believed the limiting factor was oxygen use. Further research has concluded that it is oxygen transport to the working muscle (supply) that limits VO_2 max (maximal aerobic power), not the available mitochondria and oxidative enzymes (use).

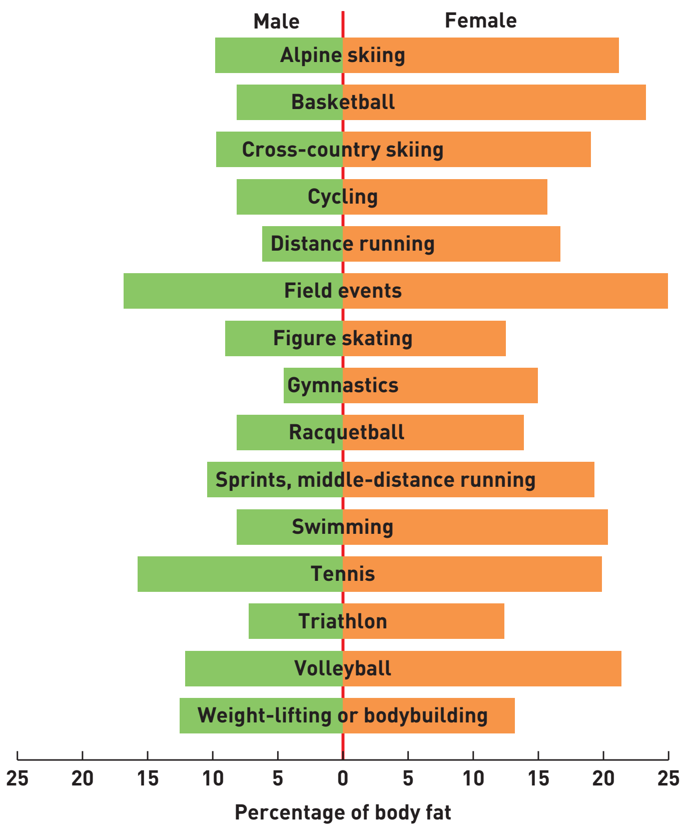
FYI

A normal heart will beat approximately 40 million times a year! A stronger, fitter heart will be able to do the same amount of work with fewer beats.

Body composition

Body composition can be divided into fat-free mass and fat-mass. Fat-free mass includes bones, water, muscle and connective tissue, organs and teeth. Fat-mass includes both essential and non-essential fat stores. Essential fat is required for normal physiological functioning; for body temperature control, shock absorption and the regulation of nutrients. Essential fat is found in the heart, lungs, liver, spleen, kidneys, intestines, muscles, central nervous system and bone marrow. Essential fat in males makes up (on average) 3 per cent of total body mass, and 12 per cent in females. Non-essential fat is found in the **adipose** tissue.

Body composition is important in many sports and activities, as well as for health. In general, healthy body-fat percentages are 16–25 per cent for women and less than 20 per cent for men. Increased levels of non-essential fat are detrimental to health and have been associated with increased risk of disease.



Average body fat of athletes (17–35 years) in selected sports

Adapted from: Wilmore & Costill, 1988

FYI

Females have gender-specific essential fat. It is thought that this extra fat is used for biological functions in child-bearing and other hormone-related functions.

The graph on page 191 shows the percentage of body fat of male and female athletes in different sports. Athletes generally have a body shape and size that suits their specific sport. For example, field athletes (shot-put, hammer throw, discus and javelin) have a high percentage of body fat compared to distance runners. Professional male golfers have a 'normal' BMI when compared to other athletes. Competitive swimmers generally have higher body fat levels than runners, as the requirements of each sport are different. Distance runners would be at a distinct disadvantage if they carried excess body fat.

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How would you classify the body composition of these athletes?

Body composition is important in sports that have weight categories. Often athletes need to lose weight in a short period of time to 'make weight' for their event. This sometimes involves dangerous practices that can compromise the health of the athlete.

There is a lower limit of body mass at which point any further decrease in weight impairs health and alters normal physiological functioning of the body.

Anthropometric measurements cannot provide precise estimates of percentage body fat, but can provide valuable and reliable information on increased health risk.

INVESTIGATION

WEIGHT-CATEGORY SPORTS

Body composition is very important for many sports, particularly those that require athletes to be a certain weight to compete. The following information is taken from the AIS. You can link directly to a fact sheet via http://vcepe34.nelsonnet.com.au.

Weblink

In sports that have a weight category, there are rules and regulations that dictate when and how often an athlete needs to weigh in, as well as the length of time between the weigh-in and the competitive event. Additional characteristics within each sport will further determine the type and extent of any weight-making practices and the potential impact these will have on health and performance. They include:

- the number of weight categories available
- the frequency of competition
- the intensity and duration of the competition
- the environment in which it is held (outside vs indoors, hot/humid vs cold)
- the competition schedule (single vs a series of bouts, heats or finals).

Source: AIS Sports Nutrition © Australian Sports Commission

Use the information provided above to answer the following questions.

1 Brainstorm a list of sports where weight determines the competition in which the athlete competes.

2 List three anthropometric methods that can be used to determine the appropriate weight category an athlete should compete in.

3 Outline three acute weight loss strategies you have found in your research.

Flexibility

Flexibility is the capacity of a joint to move through its full range of motion, and reflects the ability of the muscles and connective tissues to stretch. Flexibility is specific to a joint. Having good flexibility in one joint does not mean you will have good flexibility in all joints of the body.

There are two types of flexibility: static and dynamic. **Static flexibility** refers to a joint's range of motion under stationary conditions. **Dynamic flexibility** refers to the resistance to motion in a joint. Someone with good dynamic flexibility will be able to move the joint through its full range of motion quickly and easily.

Good static flexibility is important for good dynamic flexibility, but having high levels of static flexibility does not automatically mean you will have high levels of dynamic flexibility. Athletes need to train for both, depending on the requirements of their sport. Hurdlers, for example, need good dynamic flexibility to be able to clear the hurdles while moving quickly.

Factors affecting flexibility

Factors that affect an individual's flexibility include joint structure, soft-tissue structures, body and muscle temperature, age and gender.

Joint structure

The flexibility of a joint is determined in part by the type of joint; different joints allow different ranges of movement. Think of the elbow and knee joints; they are both hinge joints that allow

Getty Images/AFP

Dynamic flexibility is important in sports like sepak takraw. How would reduced flexibility affect performance in this sport?

only limited movement: **flexion** and **extension**. Compare the movement at the knee joint and the hip joint. The hip joint is a ball-and-socket joint that allows movement in many directions: flexion, extension, **adduction**, **abduction** and **rotation**. While flexibility can be increased through training, joint structure cannot be altered. Improvements in flexibility come from changes to muscle and connective tissue lengths.

Soft-tissue structures

Soft-tissue structures that surround joints include muscle, connective tissue within the muscle, **tendons**, **ligaments** and skin. Each of these provides resistance to movement and affects flexibility. Connective tissue has a vital role in maintaining joint stability; the restriction of excessive motion is necessary and beneficial to maintaining the function of the joint.

The elastic properties of some of the soft tissue within the joint allow for stretching to occur. Muscle is elastic in nature. Stretching lengthens connective tissues and increases flexibility, but if it is not maintained, these structures will return to their original length, resulting in decreased flexibility. Increasing the length of the muscles and tendons of a joint increases the range of motion and therefore the flexibility of the joint. Skin has little effect on the flexibility of a joint under normal conditions.

Body and muscle temperature

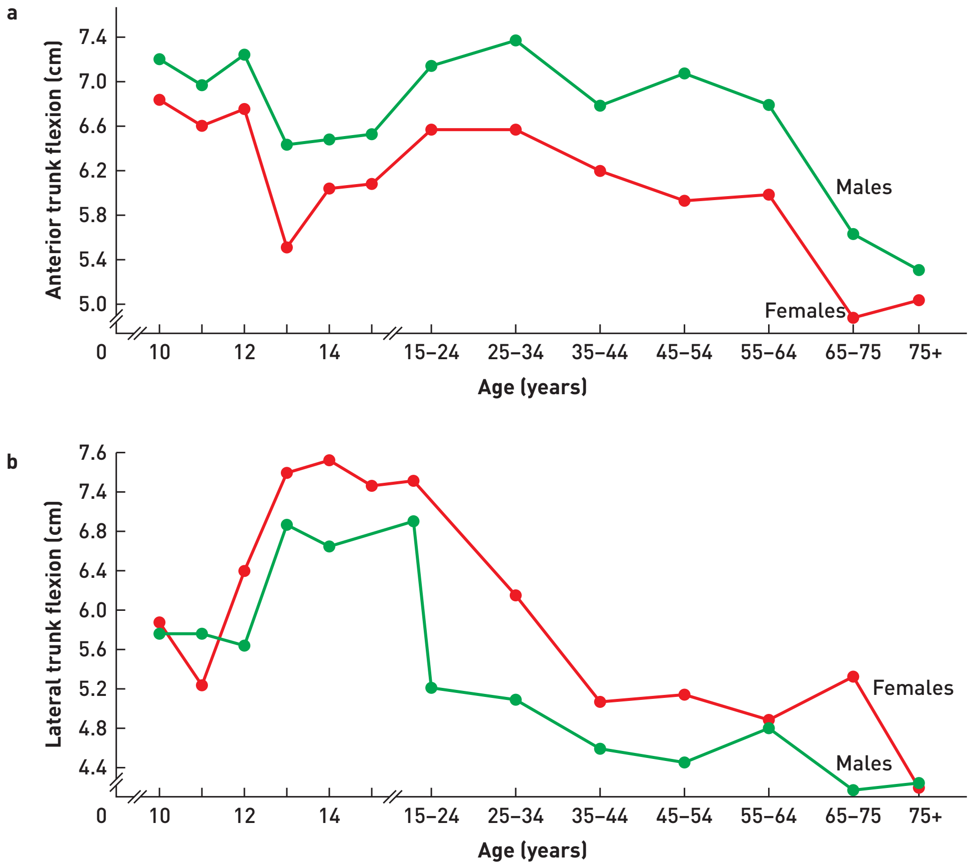
Increasing body and muscle temperature increases the elasticity of the muscle and decreases the stiffness of the muscle and the joint. Increasing muscle temperature through warm-up activities or heat packs improves both the ability to stretch the muscles and the flexibility of the joint.

Age

Children are usually more flexible than adults. Flexibility is initially high in children, but the hormonal changes that occur during puberty often lead to rapid growth, causing the bones to grow at a much faster rate than the muscles and connective tissue. As a result, flexibility declines. The components of the musculoskeletal system catch up to each other in early adulthood, and flexibility peaks in the mid to late twenties. With advancing age, there is a joint-specific decrease in range of motion. This loss of flexibility is thought to be due to the loss of elasticity in the connective tissue, but this decline may be a result of decreasing activity levels, and not purely the result of ageing.

Gender

Females tend to be more flexible than males. This difference is greater during childhood and decreases for adults. The greater flexibility in females is linked to skeletal differences (such as wider hips) and hormonal influences. However, flexibility is joint-specific, and generalisations such as 'females are more flexible than males' may not be accurate. Studies investigating flexibility of the trunk show that males have greater anterior trunk flexion while females have greater lateral trunk flexion (see graphs on next page).



Flexibility in males and females
Adapted from: Plowman & Smith, 2008

The common misconception that females are more flexible than males probably arose because females perform better than males in the sit-and-reach test (see chapter 11, page 270). However, flexibility is joint-specific – a higher level of flexibility in one joint does not necessarily indicate a trend that applies to all joints. Preferred physical activity patterns may also account for some of the differences. Females tend to have higher participation rates in sports and activities that require good flexibility, such as gymnastics, dance and swimming. It can therefore be concluded that, depending on the joint being measured, females may have greater, less or the same flexibility as males.

CHAPTER CHECK-UP

1 Explain the difference between static and dynamic flexibility.
2 Rank the factors that affect flexibility from most limiting to least limiting. Justify the order in which you place them.
3 Provide a rationale for including **flexibility training** as part of an athlete's overall training program.
4 The body composition of elite athletes is often similar across a given sport. Use specific examples to support or refute this statement.

Muscular strength

Muscular strength is the maximal force that can be generated by a muscle or muscle group in one maximal effort. Muscular strength is specific to the muscle group, type of muscle action, speed of contraction and joint angle. The amount of strength that can be generated in an individual muscle or muscle group is dependent on the size, shape and fibre composition of the muscle. Other factors that affect strength are age and gender.

Muscular strength is important in sports where an object needs to be moved forcefully (such as in weightlifting) or when the body needs to hold its position against the opposing force of the opposition (such as in Australian Rules football).

Types of muscle action

When muscles contract, they develop **tension** while shortening, lengthening or staying the same length. The amount of tension depends on the external load placed on the muscles relative to the amount of force developed by the fibres. The load and the force developed by the muscle are opposing forces.

Getty Images/ Phil Walter

Getty Images/Michael Willson/AFL Media

Strength is important when lifting heavy objects and when holding your position to mark the ball in front of your opponent. How is muscular strength different from muscular power?

FYI

Muscle actions have previously been described as 'contractions'. However, to contract means to shorten, and only one of the muscle actions (a concentric action) involves shortening of the muscle!

Table 9.2 shows three types of muscle actions: **isometric**, and **isoinertial actions**: **concentric** and **eccentric**. These can determine the amount of force developed. Isoinertial eccentric muscle actions produce the greatest force; next come isometric (static) muscle actions and then, finally, concentric muscle actions. We will look at each of these in more detail in the following sections.

TABLE 9.2 Types of muscle actions

Load versus force conditions	Type of action
External load equals the force developed in the muscle	Isometric No change in length
External force is less than the force developed in the muscle	Isoinertial concentric Muscle shortens
External force is greater than the force developed in the muscle	Isoinertial eccentric Muscle lengthens

Isometric muscle action

Isometric muscle actions are static, meaning there is no change in muscle length. The elasticity of the fibres ensures that limited shortening occurs with no limb or joint movement. The muscle length remains constant as the force is developed in the muscle. This is because the external resistance is much greater than the internal force that the muscle can generate.

The function of an isometric action is to 'fix' or stabilise the joints and limbs involved in the action (that is, to keep them from moving). An example of an isometric muscle action is holding a crucifix position on the rings in gymnastics (see photo at right). In this case, the external resistance that the muscle is working to overcome is gravity. There are lots of examples of isometric muscle actions in gymnastics, yoga, wrestling and Pilates. Another common use of isometric muscle actions is in gripping sporting apparatus such as bats, clubs and racquets.

Getty Images/PASCAL GUYOT

Holding a crucifix position is an example of isometric muscle action. Why is it difficult to hold isometric muscle actions for a long period of time?

Isoinertial muscle actions

Isoinertial muscular actions are most common. When a whole muscle action produces movement of the skeleton, by shortening or lengthening of the muscle, tension is developed. A more accurate description of this type of action is a dynamic action. There are two types of dynamic actions: concentric and eccentric. A concentric action of the muscle produces tension while shortening. An eccentric action of the muscle produces tension while lengthening.

A simple example of a concentric muscle action is the lifting phase of a biceps curl. The lowering phase of a biceps curl is an example of an eccentric muscle action. Another example is the extension of the elbow in a tennis serve, as the player reaches up to connect with the ball. The triceps muscle contracts and shortens (concentric action) to produce the extension of the elbow.

Shutterstock.com/Di Studio

In this squat identify when the muscles being worked (gluteals) contract concentrically and then eccentrically.

Isokinetic muscle actions

During an **isokinetic muscle action**, the tension developed in the muscle is maximal throughout the whole range of motion, and the velocity of the lengthening or shortening of the muscle is constant. To perform isokinetic muscle actions, specialist equipment such as a Cybex machine is used. The machine controls the speed of the movement; no matter how much tension is developed in the muscle, the speed of movement remains the same. Resistance training machines that use hydraulics are intended to replicate this.

The harder the hydraulic machine is pushed, the greater the resistance it offers. However, depending on the strength of the person using the machine, it is possible to push and pull hydraulic weight machines at different speeds, so the exercises they allow are not purely isokinetic. Hydraulic resistance machines are commonly found in gyms and are often used in circuit training.

The tension generated in the muscle is affected by a number of factors: muscle size, arrangement and type; the length–tension relationship; speed of contraction; and age and gender.

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Hydraulic resistance machines are commonly used in gyms. How can the tension be controlled throughout the whole motion?

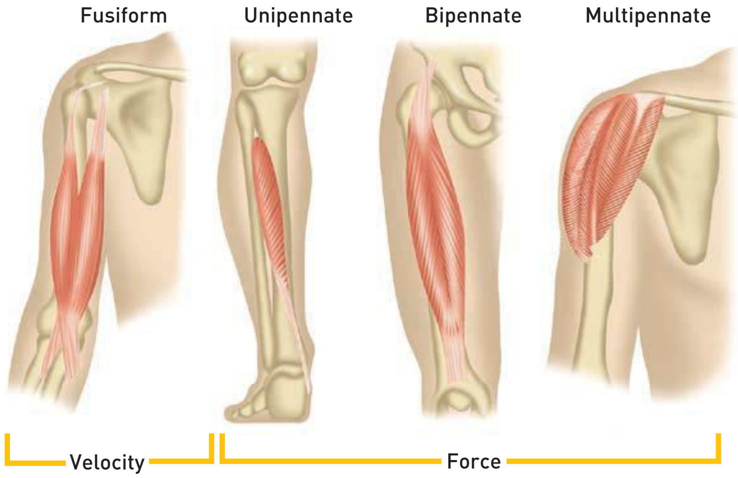
Factors affecting muscle strength

Muscle size, fibre arrangement and type

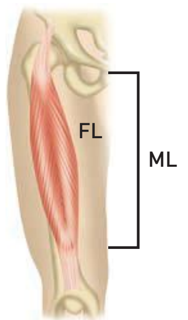
The maximal force that can be generated in a muscle is related to the cross-sectional area of the muscle: the greater the cross-sectional area of the muscle, the greater the strength. Muscles designed for strength have fibre arrangements within them that maximise the cross-sectional area of the muscle. Unipennate, bipennate and multipennate fibre arrangements are all designed for strong, forceful contractions. The fibres in pennate arrangements lie at an angle to the long axis of the muscle. Muscles designed for speed of contraction have fibres arranged in a fusiform pattern, where the fibres run parallel to the long axis of the muscle (see biceps at left, below).

FYI

The origins of words can help us to remember the types of muscle actions:
iso = equal or the same
metric = length
inertial = resistance
kinetic = motion
Therefore, muscle actions that are:
iso-metric = same length (muscle length does not change throughout the movement)
iso-inertial = same resistance (the resistance is constant throughout the movement)
iso-kinetic = same motion (speed of the movement is the same throughout the action).



Muscle fibre arrangements



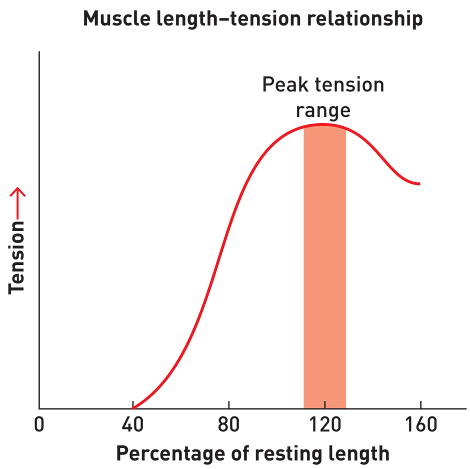
Muscle fibre length compared to muscle length (FL:ML)

The ratio of the length of an individual fibre (FL) to the total length of the muscle (ML) also affects the force that can be generated in the muscle. A low FL:ML ratio produces high force and a high FL:ML produces high contractile velocity.

Length–tension relationship

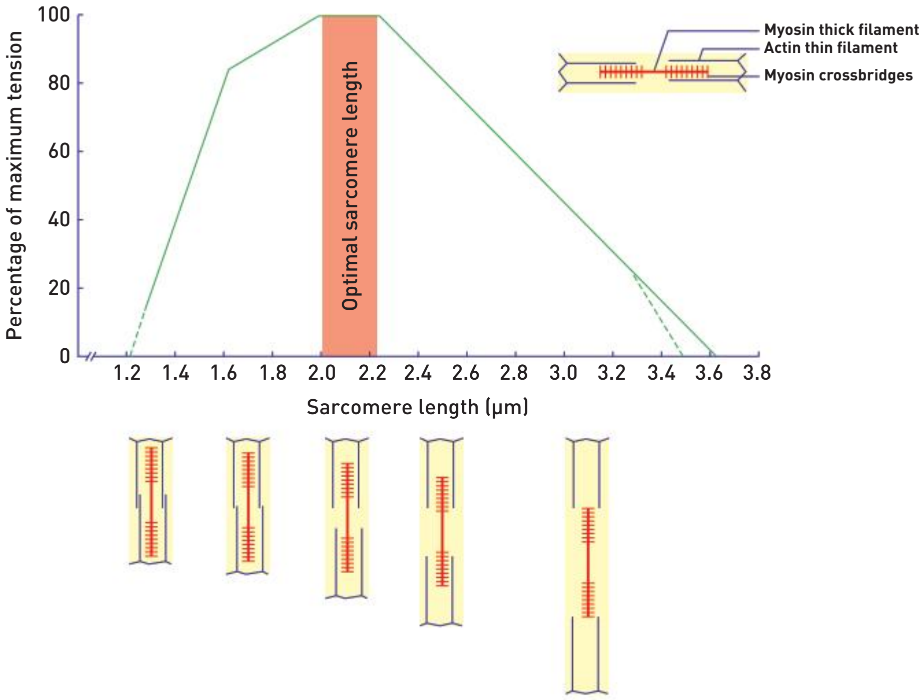
The amount of force developed in a muscle depends on the length of the fibre relative to its optimal length. The optimal length is defined as the **sarcomere** length that allows maximum overlap of the thick (myosin) and thin (actin) filaments. The maximum tension that can be generated in a muscular contraction is shown in the graph at the top of page 199. When there is excessive shortening or lengthening in the sarcomere, less tension is developed. Maximal tension is developed in the muscle when each of the cross-bridges on the myosin filament connect with the actin and the length of the sarcomere is optimal.

Muscles and bones work together; muscles pull on bones to produce movement. The action of the muscle generates the force, and the bones act as the levers to move objects. Peak force is developed in the muscle at lengths just beyond resting length (see graph, left). For actions that move a joint through its full range of motion, the force developed will vary with the change in length of the muscle and the angle of pull of the muscle on the bone (the joint angle). As the joint moves through its full range of motion, different amounts of force are generated at different angles (see graphs at bottom of next page).



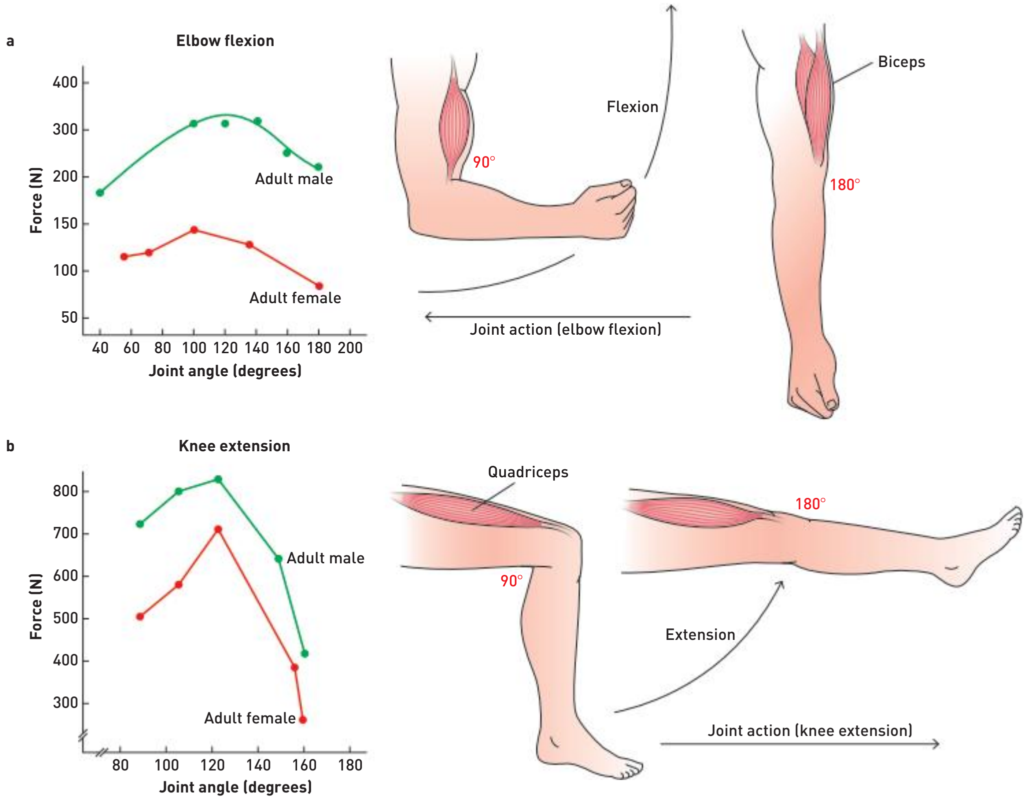
Muscles generate peak tension (force) at slightly greater than 100% of resting length.

Adapted from: Fox, Bowers & Foss, 1993

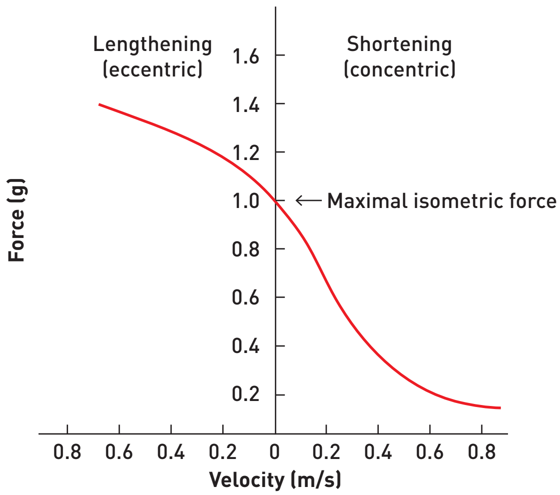


Relationship between tension developed and sarcomere length in skeletal muscle during an isometric muscle contraction. Dotted green line is at the extremes of stretch or contraction.

Adapted from: McArdle, Katch & Katch, 2015



Strength curves showing muscle length–tension relationship for (a) elbow flexion, and (b) knee extension.



A force–velocity curve for muscle action.

Source: Kenny, Wilmore & Costill, 2012

Speed of muscle action

The relationship between force developed in the muscle and the speed of action is very simple: the lighter the load, the faster the action. The greater the amount of force developed in the muscle, the slower the speed of the action. Maximal action velocity occurs when there is no load to move. Zero velocity occurs when the load is too great to be moved; the muscle cannot generate enough force to overcome the resistance of the load. During concentric actions (when the muscle shortens), maximal force is achieved with a slower speed of action, but in eccentric actions (when the muscle lengthens) the opposite is true; fast actions allow for maximal force (see graph, left).

LABORATORY REPORT

MUSCLE SIZE AND STRENGTH

AIM

To devise and test a hypothesis in relation to muscle girth and strength

EQUIPMENT

Students need to be made aware of available equipment and resources to assist in their planning.

METHOD

1 Form a hypothesis about muscle size and strength and discuss its suitability with your teacher.
2 Plan and conduct a laboratory activity to collect data to support your hypothesis.

ANALYSIS

1 Analyse the data you collected, presenting it in tables and/or graphs.
2 Use your data analysis to write a report that addresses the outcome of your experiment and critiques the methodology, measurement and data collection techniques used.
3 Your report must refer back to your aim and provide evidence from the data to support or oppose your original hypothesis. If necessary, it should also suggest improvements to your experimental design.

CONCLUSION

Draw a logical conclusion from your results.

Within a muscle, there are two different types of muscle fibres: Type I fibres (slow-twitch) and Type II fibres (fast-twitch), which can be further classified as fast-twitch A or fast-twitch B. The amount of any one type of fibre is genetically determined; each individual inherits a certain percentage of slow- and fast-twitch. The characteristics of slow- and fast-twitch fibres are shown in Table 9.3.

Certain characteristics of fast-twitch muscle fibres enable them to generate stronger and faster contractions than slow-twitch fibres. Fast-twitch fibres have a greater cross-sectional area, faster twitch (contraction) time and higher force production capabilities than slow-twitch fibres. For this reason, fast-twitch fibres are preferentially recruited for activities that are high in intensity and require more force. Slow-twitch fibres are preferentially recruited for low-intensity, endurance-type activities.

TABLE 9.3 Characteristics of muscle fibres

	Type I	Type II	
	Slow twitch (slow oxidative)	Fast-twitch A (fast oxidative glycolytic)	Fast-twitch B (fast glycolytic)
Structural aspects			
Fibre diameter	Small	Intermediate	Large
Mitochondrial density	High	Intermediate	Low
Capillary density	High	Intermediate	Low
Myoglobin content	High	Intermediate	Low
Functional aspects			
Twitch or contraction time	Slow	Fast	Fast
Relaxation time	Slow	Fast	Fast
Force production	Low	Intermediate	High
Fatigability	Low	Intermediate	High
Metabolic aspects			
PC stores	Low	High	High
Glycogen stores	Low	High	High
Triglyceride stores	High	Intermediate	Low
Myosin–ATPase activity	Low	High	High
Glycolytic enzyme activity	Low	High	High
Oxidative enzyme activity	High	Intermediate	Low

Adapted from: Plowman & Smith, 2008

Age and gender

Strength increases from early childhood, through adolescence and into adulthood. Until puberty, the increase is relatively similar for both boys and girls, but after puberty, boys have higher absolute strength than girls. One of the contributing factors at this time is the effect of testosterone. During puberty, males have increased levels of testosterone, which is involved in the process of muscle growth. This testosterone increase results in greater muscle mass and cross-sectional area, which is reflected in greater overall strength. The trend for males to be stronger than females is continued throughout the life span. However, if strength is compared with cross-sectional area of muscle, no difference is found between males and females.

Muscular strength peaks in adults at about 25–30 years and then plateaus until approximately 45–50 years. After that, strength decreases in both males and females at a rate of roughly 8 per cent per decade. The factors that are thought to lead to this decline in strength include:

» decreased muscle mass
» loss of contractile properties of the muscle
» reduced activation of motor units.

However, the loss of muscle mass is largely due to older adults becoming less active as they age. When a muscle is not used regularly it will **atrophy**, and this decrease in size will result in a corresponding decrease in strength. Older adults can still increase strength and muscle mass – muscles respond to resistance training regardless of age!

Muscular endurance

Muscular endurance is the ability of the muscle or muscle group to perform repeated contractions (concentric, eccentric or isokinetic) for an extended period of time, or to maintain an isometric contraction for an extended period of time.

Muscular endurance is often referred to as local muscular endurance or LME. ('Local' simply refers to the use of a particular muscle group.) Activities such as running and cycling require muscular endurance of the legs, while swimming, rowing and push-ups require muscular endurance of the upper body.

Getty Images/AFP

Why does rowing require local muscular endurance of the upper and lower body?

Factors affecting muscular endurance

Factors that affect muscular endurance are fatigue, fibre type, age and gender.

Fatigue

A muscle that has high levels of endurance must have reduced levels of fatigue; so muscular endurance is also the opposite of fatigue. Fatigue was discussed in detail in chapter 8. To briefly recap, the causes of muscular fatigue include fuel depletion, metabolic by-products and thermoregulation. The ability to sustain a contraction while fatigue increases is an important aspect of local muscular endurance. Slow-twitch fibres are more fatigue resistant than fast-twitch fibres, and are efficient at producing ATP aerobically.

Fibre type

The level of muscular endurance depends on the type of fibre in the muscle. Fast-twitch fibres are suited to high-intensity, anaerobic activities, whereas slow-twitch fibres are highly fatigue resistant and suited for extended periods of exercise or activity (see Table 9.3 on page 201 and chapter 7 page 153–154), such as endurance activities. The greater the percentage of fast-twitch fibres in the muscle, the greater the muscular fatigue. Conversely, the greater the distribution of slow-twitch fibres in the muscle, the lower the levels of muscular fatigue. Slow-twitch fibres will be preferentially recruited for low-intensity endurance activities. If exercise duration is extended, if the intensity is increased or if fatigue occurs, fast-twitch fibres will then be recruited. Muscular endurance activities generate ATP from both the aerobic and anaerobic energy systems.

CHAPTER CHECK-UP

1 Compare and contrast isometric, isoinertial and isokinetic muscular actions.
2 Identify three characteristics of fast-twitch muscle fibres that make them more suitable for activities that require high levels of muscular strength. Justify your selections.
3 Discuss why fast-twitch fibres are not preferentially recruited for endurance activities. Relate your answer to fibre type and function.
4 Consider the information in the table:

Muscle	Fibre arrangement
Hamstrings	Fusiform
Quadriceps	Bipennate
Dorsiflexors	Fusiform
Plantar flexors	Multipennate

Identify which muscles are more suited to developing force, and provide an explanation based on the role these muscles play in movement.

5 'Muscular strength decreases with age.' Discuss the implications of this statement on an ageing population, with regard to maintaining function and independent living.

SKILL-RELATED COMPONENTS

The skill-related fitness components presented in Table 9.1 (page 189) are closely associated with improved performance in sport and physical activity, and less important to improving health and fitness. It is too difficult to measure overall fitness and so (as with the health-related components) we look at the skill-related components individually. Performance in one area does not necessarily transfer to another; you might have a high level of skill in one area but not in another. Increased performance in the skill-related components makes it easier to learn the skills that are needed for sport and physical activity.

High levels of one component may compensate for lack of fitness in another. A person who lacks speed on the tennis court, for example, may compensate for this through excellent coordination. Elite athletes tend to be above average in most (or all) skill-related components of fitness.

Anaerobic capacity

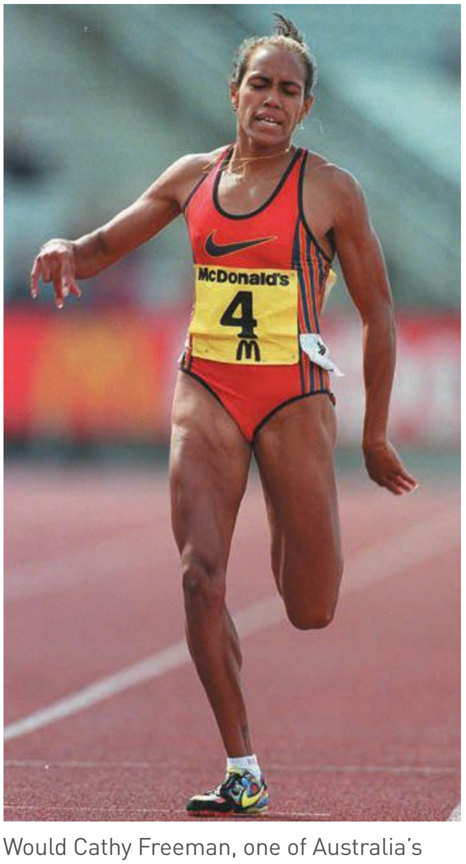
The capacity of the **anaerobic** systems (the ATP–PC and anaerobic glycolytic systems; see chapter 6) to provide energy for muscular contractions is termed **anaerobic capacity** or **anaerobic power**. Although the terms are often used interchangeably, they mean different things. Anaerobic capacity refers to the total amount of work that can be done by the anaerobic systems, while anaerobic power refers to how quickly the work can be done. The 'work' the systems are doing is producing ATP. Unlike the aerobic system, the capacity of the anaerobic systems is limited. Both the ATP–PC and the anaerobic glycolytic system have limited capacity but high power output. Although they can supply energy only for a short period of time, they can provide that energy very quickly. It is easy to see why anaerobic capacity is closely associated with speed. Fast-twitch muscle fibres have a higher anaerobic capacity and power than slow-twitch fibres and are suited to activities that are of high intensity and short duration.

TABLE 9.4 Contribution of the skill-related components of fitness to various sports and activities

Activity	Balance	Coordination	Reaction time	Agility	Power	Speed
Baseball/softball	***	****	****	***	****	***
Basketball	***	****	****	****	****	***
Cycling	****	**	**	*	**	**
Football	***	***	****	****	****	****
Golf	**	****	*	**	***	*
Jogging	**	**	*	*	*	*
Karate	***	****	****	****	****	****
Soccer	**	****	***	****	***	***
Surfing	****	****	***	****	***	*
Swimming (laps)	**	***	*	***	**	*
Tennis	**	****	***	***	***	***
Volleyball	**	****	***	***	**	**
Walking	**	**	*	*	*	*

Note: Components are classified from * (requires minimal skill level) to **** (requires high skill level).

Adapted from: Corbin, et al. 2008, p. 261.



Alamy Stock Photo/PA Images

Would Cathy Freeman, one of Australia's greatest 400-metre runners, have required a high anaerobic capacity to be successful in her event?

In chapter 6 we looked at the power output and capacity of the three energy systems. Table 9.5 shows a comparison of the three energy systems. You can see how much higher the power output is for the anaerobic systems compared with the aerobic system, and how much lower the capacity of the systems is.

TABLE 9.5 Power and capacity of the three energy systems

Energy system		Substrate	Power (mmol/kg/s)*	Capacity (mmol/kg/s)*
Anaerobic systems	ATP–PC	ATP, PC	3–6	20–25
	Anaerobic glycolysis	Glycogen	1.5–3	50
Aerobic system		Glycogen Fatty acids	0.5–0.75 0.24–0.4	Limited only by substrate availability

* Wet muscle

Source: Heck, Schultz & Bartmus, 2003

Look at the graph in chapter 6, page 128. It shows that the anaerobic contribution to the overall energy supply is the same for each of the events (the 200, 400, 800 and 1500 metres). This is because the capacity of the anaerobic systems is finite; there is only a limited amount of energy that can be supplied from these systems. If exercise continues after this point, the energy requirements must be supplied aerobically. As the distance of the race increases, the time taken to complete the race and the contribution from the aerobic system also increase.

Anaerobic capacity is lower in females than in males. This difference is partly because females have lower total muscle mass, strength and neuromuscular factors compared to males. However, even when adjusted to account for these factors, anaerobic capacity is approximately 20 per cent higher in males than in females. This may be explained by the greater relative area and metabolic capacity of the fast-twitch fibres and greater **catecholamine** response to exercise.

Muscular power

Muscular power allows athletes to jump higher, hit a ball harder and ride uphill more easily. Muscular power is the ability to exert a force rapidly, over a short period of time, and is closely related to muscular strength and speed. It is the explosive aspect of strength, and is the product of strength (force) and the speed (velocity) of the movement:

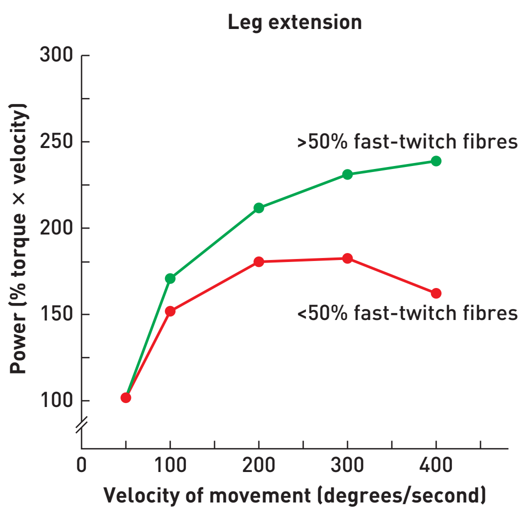
$$\text{power} = \text{force} \times \text{velocity}$$

Activities that require power include jumping events in athletics and throwing events such as javelin, hammer throw, shot-put and discus. Team sports often require power to leap, jump and rebound to intercept a ball from the opposition.

Power activities are high in intensity and short in duration; the energy for muscular contraction is derived from the ATP–PC system. The graph below demonstrates the relationship between power and velocity for both slow- and fast-twitch fibres. Power generated in the muscle increases with increases in velocity. The increase in power is more rapid at lower speeds. At high speeds, power can actually decrease because there isn't enough time to develop maximum force.

Fibre type affects the power that a muscle can generate. Muscles with higher percentages of fast-twitch fibres are able to generate greater force than muscles that have a higher percentage of slow-twitch fibres.

The power that a muscle can generate will depend on the force generated and the velocity at which the muscle lengthens or shortens. Force is determined by the frequency of motor unit stimulation, the number and size of motor units recruited, the number of cross-bridges in action and the length–tension relationship (see pages 198–199). Velocity is affected by the length of muscle fibres in series and the myosin ATPase activity. The largest improvements in power come from improvements in strength as a result of resistance training.



Relationship between power and velocity

Adapted from: Fox, Bowers & Foss, 1993

Getty Images/Cameron Spencer

Power activities require a combination of strength and speed. How would having large fast-twitch muscle fibres be an advantage to power athletes like Australian shotputter Damien Birkinhead?

Speed

Speed is rate of motion, so in physical activity and sport it refers to how fast you can move your body or a body part from one point to another. Speed is obviously important in sprint events. For example, the aim of a 50-metre freestyle event is to get from the start to the finish in the shortest amount of time possible. To do this, the arms and legs move through the freestyle and kicking actions as quickly as possible. In sprint running, the time it takes to run a given distance (such as 100 metres) is dependent on the athlete's ability to accelerate to maximal speed and to maintain that velocity while fatiguing.

Increases in speed rely on a number of factors: the efficiency of the anaerobic system to provide ATP quickly, muscle activation, fibre composition in the muscle, rate of force production, muscle and connective tissue joint stiffness or elasticity, duration of the activity and resistance to fatigue. Some of these factors are closely related.

The ability of the anaerobic pathways to provide energy is linked to the duration of the activity and to fatigue. Metabolic fatigue in a sprint activity is caused by decreases in ATP and PC in the muscles. This reduces the ability of the anaerobic pathways to provide the energy for muscular contraction quickly enough to maintain speed.

Muscle activation is associated with recruitment of motor units. Increasing the activation of motor units (through increased speed of impulses, greater frequency of impulses, and preferentially recruiting fast-twitch fibres for activities that require speed) leads to faster contraction time and an improvement in speed. Increases in motor-neuron excitability are also linked to more powerful contractions (that is, the rate of force production).

Stiffness in the connective tissue in the musculoskeletal system allows for greater energy transfer. In sprint activities, this allows for greater force production, decreased contact time with the ground and a higher peak force being generated.

DATA ANALYSIS

CALCULATING SPEED

In August 2009, Usain Bolt ran a world-record time for the 100 metres at the IAAF World Championships in Berlin. The following table shows his split times. After accelerating in the first 20 metres he ran each split faster than the last until the final 20 metres, where his speed decreased.

QUESTIONS

1 Calculate the speed for each 20-metre split, using the formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

2 Graph your results, using a line graph with time on the horizontal axis and speed on the vertical axis. Discuss the changes in speed throughout the race, referring to the data and graph to support your discussion.

Distance from start (metres)	0	20	40	60	80	100
Time after start (seconds)	0.146	2.89	4.64	6.31	7.92	9.58

Source: www.sportsscientists.com

3 Sprint running is the product of stride length and stride rate (that is, how long each step is and how often you step). Bolt took 41 steps in the race, with an average stride rate of 4.28 steps per seconds and an average stride length of 2.44 metres. How are stride length and rate related to acceleration and speed? Use examples from the data to support your answer.

Alamy Stock Photo/epa european pressphoto agency b.v.

Usain Bolt's world-record time for the 100 metres in Berlin, 2009

4 Usain Bolt's reaction time of 0.146 second was considered quite slow. The fastest reaction time for any runner in the final was 0.119 second. Define reaction time and explain how an improved reaction time could lead to a faster overall time for the 100 metres.

5 Identify and explain the characteristics of fast-twitch fibres that make them more suitable to speed activities than endurance activities.

6 At the Beijing Olympics in 2008, Bolt ran what was then a world-record time of 9.69 seconds. Some commentators suggested that he celebrated too early and did not concentrate over the last 40 metres. Others suggested that he could have run a time under 9.55 seconds if he had maintained his speed over the last 20 metres. Explain the physiological reasons for a speed decline in the last 20 metres of a 100-metre race.

INVESTIGATION

USAIN BOLT'S TIMES

Check out the link to the Science of Sport via http://vcepe34.nelsonnet.com.au for a detailed analysis of Usain Bolt's 100-metre race.

Weblink

Agility

Agility has been defined as the ability to change direction rapidly and accurately. When you think about some types of activities that require agility, however (such as field and court sports), the rapid and accurate change in direction is often in response to a stimulus, such as another player or the ball. So it appears that agility has a cognitive aspect as well as a physical and technical aspect.

Sheppard and Young (2006) have defined agility as 'a rapid, whole-body movement with change in velocity or direction in response to a stimulus'. This definition allows for the necessary cues to be recognised and a decision made, as well as the physical performances involved such as acceleration, deceleration, changes in direction in evading an opponent, sprints with changes of direction to intercept a ball or player, or initiation of a whole-body movement in response to a stimulus.

Getty Images/Atsushi Tomura

Why is agility required in a game of soccer?

TABLE 9.6 Criteria for identifying agility

Agility	Other physical or cognitive skills
» Must involve initiation of body movement, change of direction or rapid acceleration or deceleration » Must involve whole-body movement » Involves considerable uncertainty, in either space or time » Open skills only » Involves a physical and cognitive component, such as recognition of a stimulus, a reaction or a physical response	» Entirely pre-planned skills (such as shot-put) are classified by their skill function rather than included as a type of agility » Running with directional changes is classified as change of direction speed (CODS) rather than agility or quickness » Closed skills that may require a response to a stimulus; e.g. the sprint start in response to the starter's pistol is pre-planned (closed), and therefore is not agility

Adapted from: Sheppard & Young, 2006

Coordination

Many sports and activities require good **coordination**. Coordination may involve the control of body parts to complete a sequence of movements (for example, in a gymnastics routine) or it may involve coordination of an external implement and various body parts (for example, kicking a football). The body uses its senses along with the body parts to perform tasks smoothly and accurately. Coordination of body parts, a racquet or club and a ball is needed for sports such as golf and tennis. Coordination is often referred to as hand–eye, head–eye or foot–eye coordination. This simply refers to the body parts involved in the motor skill.

Performances by elite athletes are often characterised by smooth, well-timed movements. Skilled performers with high levels of coordination are able to execute a skill with less effort. This means it takes them less energy to complete a skill, and the transfer of energy between joints is better (so that a ball, for example, can be thrown, hit or kicked further).

Coordination improves with learning a skill. The first time you do something new, it can feel awkward. For example, imagine a golfer who has been using the same grip for a number of years decides to get some coaching and the coach suggests changing their grip. The first time the golfer swings with the new grip, it feels different and awkward. The golfer may feel as if it takes more effort to swing with this grip, and the movement may be jerky and feel unnatural. With practice, however, learning occurs, and over time the movement will become smooth and coordinated.

Getty Images/Kyodo News

Rafael Nadal has incredible hand–eye coordination, allowing him to connect with the ball smoothly and accurately.

Balance

Balance is important in almost all activities. To maintain equilibrium, external forces acting on the body (gravity, friction and forces applied by moving objects – see chapter 3) must be constantly opposed by internal forces (muscular contractions). Balance is specific to each task being performed. Static equilibrium refers to activities where balance is maintained while the body is stationary (see photo at right). Dynamic equilibrium refers to maintaining balance while moving. Activities such as cycling, gymnastics or surfing require more effort to maintain body balance than walking or sitting in a chair. The body continually adjusts its position in order to maintain balance in all situations.

Rather than just an automatic or reflex response to the environment, balance is thought to be a process through which the body adapts to the external and internal forces acting on it to maintain stability or equilibrium. Balance can be improved by increasing the area of the base of support and/or decreasing the height of the centre of gravity (see chapter 5 pages 92–93). In the photo below right, the surfer's feet are wide apart and his knees are bent to increase his base of support and lower his centre of gravity.

Changes to the equilibrium of a body can occur in three ways:

» by changing the location
» by changing the environment that supports the body
» by changing the position of one or more body parts.

These changes do not depend on each other: for example, a cricketer walking in from the outfield as the bowler starts his run-up only changes location. However, sport or other physical activity often involves two or more of these changes. Riding a skateboard, for example, involves changes in location (as you skate from one place to another), changes in environment (if the surface you are skating on changes) and changes in the position of body parts (as you use your foot to propel the board). Your brain takes in information through the senses to formulate a response that will allow you to keep your balance. This is a continuous process, involving constant evaluation of the surroundings and the body's position to maintain equilibrium.

Shutterstock.com/Jiang Dao Hua

What fitness components are required in holding this position on the beam?

iStock.com/EpicStockMedia

How does bending at the knees help surfers to maintain their balance?

FYI

Studies have shown that reaction time improves with moderate exercise levels. Athletes undertaking moderate exercise were able to respond more quickly and without decreasing accuracy to an external stimulus.

Reaction time

Reaction time is the time it takes the body to react to an external stimulus. Reaction time is very important in sprint events, and in other events where the environment is constantly changing and adjustments to movement need to be made quickly. To make the correct decision, performers need to sort through the information presented to them via stimuli from the environment and select the most appropriate cues for the response that helps them achieve their outcome.

Reaction time is quickest when there is only one possible response. When combined with decision-making, reaction time increases. Distractions can also increase reaction times (e.g. fans waving banners and flags). If you increase both the number of response alternatives and the number of distractions, then reaction time will increase even more. In sprinting, the response to the stimulus is to accelerate out of the blocks as quickly as possible. However, when a player receives the ball in Australian Rules football, there are far more responses to consider. The player needs to consider where their opponents are; who is free to receive the ball; and whether they should run, bounce the football, stop and kick, handball or have a shot at goal. They also have the distraction of environmental factors such as the crowd, noise and their opposition. Sometimes players don't react quickly enough to all of these stimuli and they are caught and tackled, or penalised for holding the ball.

Shutterstock.com/max blain

Why do you think that in Australian Rules football, opposition cheer squads wave their banners and flags behind the goals when the other team are having a set shot at goal?

INVESTIGATION

FASTBALL REACTION TIME

Weblink

Click on the link at http://vcepe34.nelsonnet.com.au to test your reaction time in the Exploratorium.

CHAPTER CHECK-UP

1 List three sports that you believe require agility. For each sport, determine which of the criteria in Table 9.6 (page 208) apply.
2 Select a sport other than those listed in Table 9.4 (page 204), and estimate the relative contribution of each of the skill-related fitness components. Explain your answer.
3 'Health-related components of fitness are more important that skill-related components of fitness.' Discuss.
4 The American College of Sport Medicine states that agility is the ability to change the position of the body in space with 'speed and accuracy'. Compare this to the definition given by Sheppard and Young (page 207) and explain why the term 'accuracy' may have been included.

CHAPTER SUMMARY

- Fitness is difficult to define, as it means different things to different people in different contexts.
- A widely accepted definition of fitness is 'the ability to perform moderate to vigorous levels of physical activity without undue fatigue, and the capability of maintaining such ability throughout life'.
- The component model of fitness allows individual aspects of fitness to be measured and compared to norms.
- Different sports and physical activities have different fitness requirements.
- There are two types of fitness components: health-related fitness components (closely associated with health and fitness) and skill-related fitness components (more important to improved performance in sport and physical activity).
- The health-related components are:
  - aerobic capacity
  - muscular strength
  - muscular endurance
  - flexibility
  - body composition.
- The skill-related components are:
  - anaerobic capacity
  - muscular power
  - speed
  - agility
  - coordination
  - balance
  - reaction time.
- Many factors (including age, gender and the type of training undertaken) affect each of the fitness components.
- Improvement in one component of fitness does not necessarily transfer to the others, and the type of training required to improve each component is different. However, elite athletes often have high levels of all components and exceptionally high levels in the dominant components of their given sport.

CHAPTER REVIEW

Multiple-choice questions

1 Which of the following is the most likely cause of a decline in speed in a 100-metre sprint?
   A decreased motor unit activation
   B decreased energy substrates in the muscle
   C decreased recruitment of fast-twitch muscle fibres
   D decreased reliance on the anaerobic energy system

2 Which of the following statements about anaerobic capacity is false?
   A Anaerobic capacity is the total amount of work that can be done by the anaerobic systems.
   B Anaerobic capacity is limited by the availability of energy substrates in the muscle.
   C Slow-twitch muscle fibres have a higher anaerobic capacity than fast-twitch muscle fibres.
   D Anaerobic capacity is closely linked to speed.

3 Slow-twitch muscle fibres are more suited to aerobic work because they have
   A high glycolytic capacity, fast speed of contraction and a high force capacity.
   B high glycolytic capacity, low oxidative capacity and high resistance to fatigue.
   C high oxidative capacity, high resistance to fatigue and a low glycolytic capacity.
   D high oxidative capacity, slow speed of contraction and low resistance to fatigue.

4 Muscle actions where the overall length of the muscles increases during movement are called
   A concentric muscle actions.
   B eccentric muscle actions.
   C isometric muscle actions.
   D isokinetic muscle actions.

Short-answer questions

5 Select and explain three factors that affect aerobic capacity.

6 Explain the difference between anaerobic capacity and power. Which is more important for a 400-metre sprint and a javelin throw? Justify your answer.

7 Contrast muscular strength, endurance and power. Provide specific sporting examples to support your response.

8 Evaluate the factors that affect balance. Select a sport and explain how balance is maintained.

Extended-response questions

9 Construct an argument exploring the use of talent identification programs that identify muscle fibre types to guide children into sports for which they are genetically suitable. You must discuss both the positive and negative aspects in your response.

10 'It is possible to develop strength without power but not power without strength.' To what extent do you agree or disagree with this statement? Provide evidence from throughout the chapter to support your decision.

CHAPTER

10

ACTIVITY ANALYSIS IN SPORTS

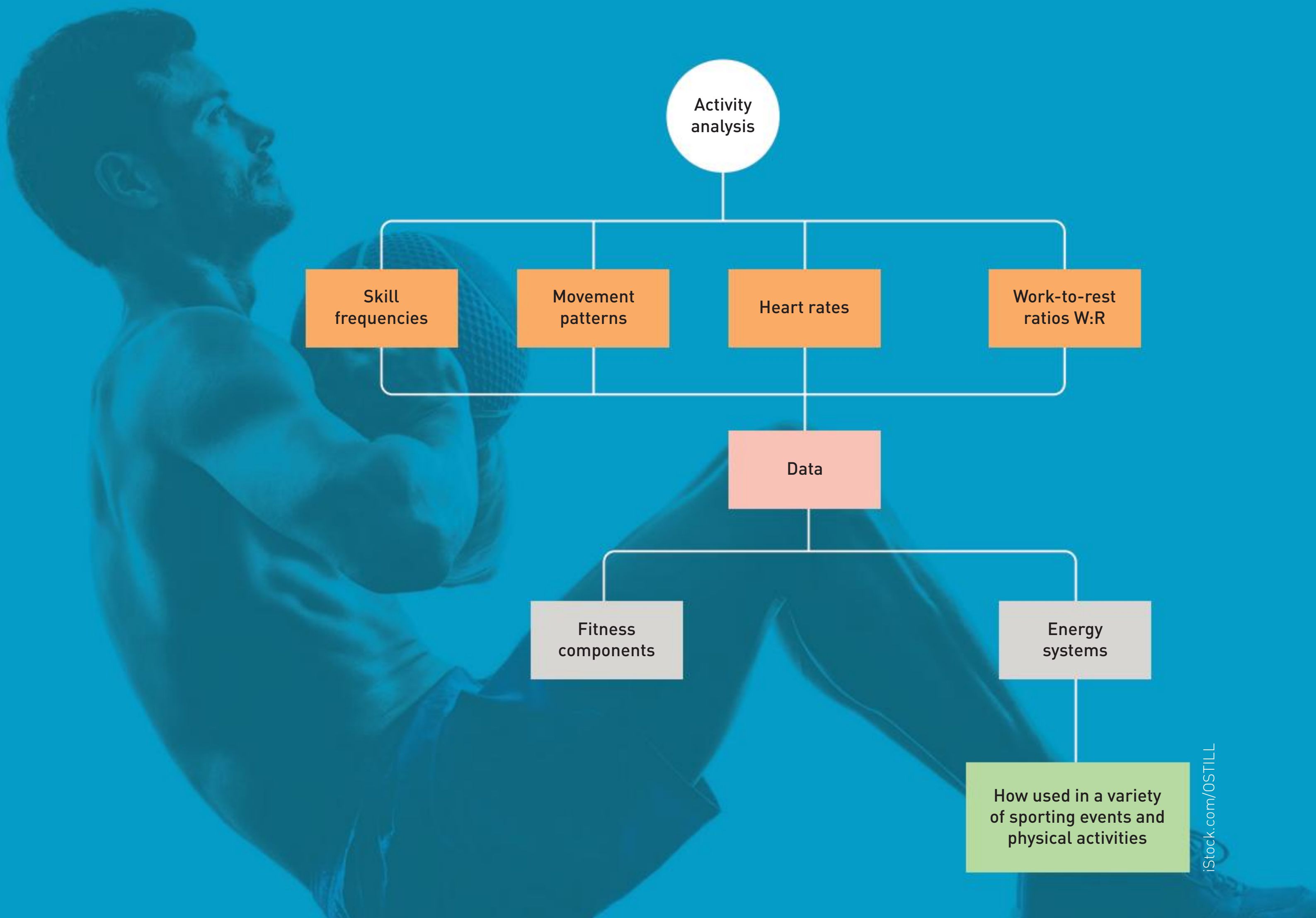
Key knowledge

» activity analysis, including skill frequencies, movement patterns, heart rates and work-to-rest ratios

Key skills

» analyse data to determine the major fitness components, the factors that affect them, and energy systems used in a variety of sporting events and physical activities

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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INTRODUCTION

How often do you hear someone reflecting on a recent sporting performance: 'I just need to work on my fitness level' or 'I just need to work on my skill execution'?

These statements show that the individual is looking to improve their overall performance in a chosen sport or activity. Focusing in more closely, we need to look at how this improvement can be made. The answer, in part, is by conducting an activity analysis. The main purpose of an activity analysis, based on accurate viewing, is to gather specific physiological data and information, either through viewing or recording an individual performance. The analysis of this performance provides information on physiological requirements of the game, which can be used to enhance the specificity of a training program to better prepare an individual for performance in their chosen sport or activity.

FYI

Activity analysis aims to create a reliable record of performance by analysing observations with the aim of making changes specifically to improve performance.

THE ROLE OF ACTIVITY ANALYSIS

Two types of data can be gained by conducting an activity analysis. The first type looks at the tactical and technical aspects of a performance, and the second focuses on the physiological requirements of the performance.

Tactical (patterns of play) and technical (technique/performance) data can be viewed, recorded and acted upon while the performance is happening, with the viewer (most likely the coach) receiving and recording information and providing immediate feedback to the performer/s. This area of activity analysis tends to be more tactics-focused in a sports game scenario, concentrating on the individual game being played, the patterns of play that are occurring and the technical demands of the sport or activity. Theoretically, performance will be improved straight away due to the coach's immediate intervention.

In senior physical education, it is important to focus on the physiological data that we gain through an activity analysis. This data allows us to determine the relevant fitness components, energy systems, movement patterns, heart rates, work-to-rest ratios and skill frequencies, so that appropriate fitness tests can be selected to test these aspects. The components of fitness have been covered in chapter 9. Recording a performance establishes a permanent record of the data, which can then be stored and reviewed at any time. The data can be used as a baseline for future comparisons, and can be compared to similar data from other players, including those at higher performance levels. The physiological data can be analysed over a period of time. Armed with valid and reliable performance data, performers can be monitored and evaluated in an unbiased and objective manner; allowing for a more specific training program design.

An activity analysis is the first step in effectively developing and implementing a strategic training program. The advantage of recording the performance, as opposed to simply viewing it, is that doing so eliminates the limitation of recall (memory).

Recording the performance allows the viewer to focus on isolated aspects of the performance, concentrating on key areas and identifying areas for improvement, which can then be worked on over a longer time period.

Once recorded, the performance can be analysed repeatedly, isolating different physiological requirements each time. Specific information that can be drawn out of the activity analysis includes:

» identifying energy system contribution, requirements and interplay during different parts of the performance
» identifying the major fitness components that were used and how they were used

FYI

Two key studies have highlighted memory retention problems, with coaches able to recall only 30–50% of key performance factors they have witnessed, even with special training in observation.

Source: Bishop, 2008

» the movement patterns that occurred in the performance
» performance intensities
» likely factors associated with fatigue
» skill frequencies and related muscle groups requiring conditioning
» the major muscle groups used in the performance
» the work-to-rest ratio
» heart-rate data.

Interpreting this information can help us optimise our body's capacity to deal with fatiguing mechanisms, thereby improving overall performance. Understanding the causes of fatigue will also help define specific recovery strategies and techniques to minimise residual fatigue.

Once a performance has been recorded, viewed and analysed, the person viewing the performance can implement change objectively, either by providing feedback directly to the player, or by designing a specific training program aimed at improving performance in the particular sport or activity.

Data analysis is increasingly used to identify psychological and tactical performance limitations and to focus on ways to improve in these areas.

FYI

Analysis based on accurate observation and recall is a key tool for improving future performance.

Source: Bishop, 2008 p. 39

The four key aspects related to activity analysis are:
» physical (physiological requirements of performance and recovery)
» mental (psychological skills training and performance under pressure)
» technical (successful performance of skills under pressure)
» tactical (coaching for decision-making and game sense).

DATA COLLECTION METHODS

Direct viewing analysis

Direct viewing analysis is the most common form of activity analysis used in schools and universities. It is also used at the elite level in sports such as Australian Rules football, soccer, netball, basketball and hockey, where coaches position themselves in designated coaching boxes or move up and down the side of the playing area to directly communicate with their playing group. The game is viewed and subjective information is gathered, which allows immediate changes to be made if required. Typical information gathered includes:
» skill frequencies
» players' movement patterns (the type of movements being made)
» use of the playing area and location of the 'hot spots' or most-utilised parts of the field
» playing intensities and ability to sustain high-intensity efforts
» key actions and associated muscles and fitness components called upon
» repeated actions and set team plays, for both the team and the opposing team.

At the elite level, coaching/viewing observations and decisions are based on years of experience, but at lower levels they may be compromised by lack of experience or game knowledge, observer bias towards certain players or playing styles, an inability to keep up with the pace of the game or with multiple players, and a loss of concentration.

The viewing team

Some of the problems associated with direct viewing analysis can be alleviated by setting up a viewing team. This is typically what students do when asked to conduct an activity analysis of their classmates during a practical activity. A team of three or four students is assigned to each key player, with each student responsible for noting specific aspects of play such as the skills conducted, the movement patterns, playing intensities and the major muscles and fitness components called upon. However, this still leaves the challenge of being able to discuss the performance in a more meaningful way with players after the match, and being able to compare changes in performance over time.

Direct viewing analysis and statistical recording

Statistical recording accompanying a viewed performance as well as a viewing team greatly increases the ability to store and compare data, and can result in more specific and effective feedback. Statistical recording can be accomplished by manually completing paper-based data collection sheets while viewing the play, so quantitative data can be analysed post-performance. This method is often used in a school setting. One problem with this data collection method is that it can be difficult to both watch and manually record information at the same time.

The next step is the viewer recording data with the help of a computer program. This method has vastly improved the accuracy of the data collected as recorders have become more highly trained, and can enter data via a keypad without taking their eyes off the players.

Digital recording

Digital recording includes the use of digital video cameras, tablets, mobile apps, heart-rate monitoring, global positioning systems (GPS) and recording and/or aerial sports analysis technology, the last three with a linked computer interface or download of data that can be filtered and set to summarise a multitude of variables.

In a school setting, a game can be recorded using a digital video camera, a smart phone or a tablet. These are all practical and accessible means by which performance data can be recorded, viewed and played back as often as needed. The recording device must remain on the performer at all times to accurately capture their performance. This allows for a truly accurate analysis, which leads to specific fitness testing followed by accurate program design, tailored to the needs of the individual.

Mobile apps in activity analysis

The advantages of mobile apps include their convenience and portability, as well as their accessibility and affordability. For students, apps such as Time Motion and Easy Tag represent a contemporary means of achieving activity analysis.

NIKE, Inc.

Image courtesy of GrantAbt, www.grantabt.com

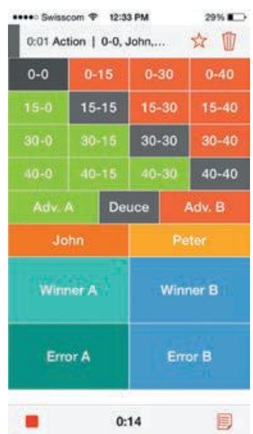
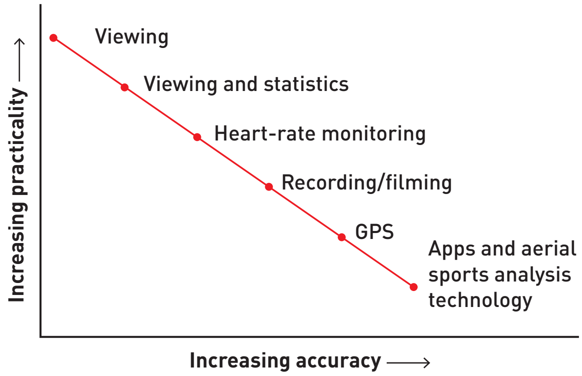


Image courtesy of Dartfish, www.dartfish.com. Used with permission.

Mobile apps provide an easy and accessible way to record and analyse movement statistics.



Practicality versus accuracy trade-off for activity analysis methods

Practicality versus accuracy

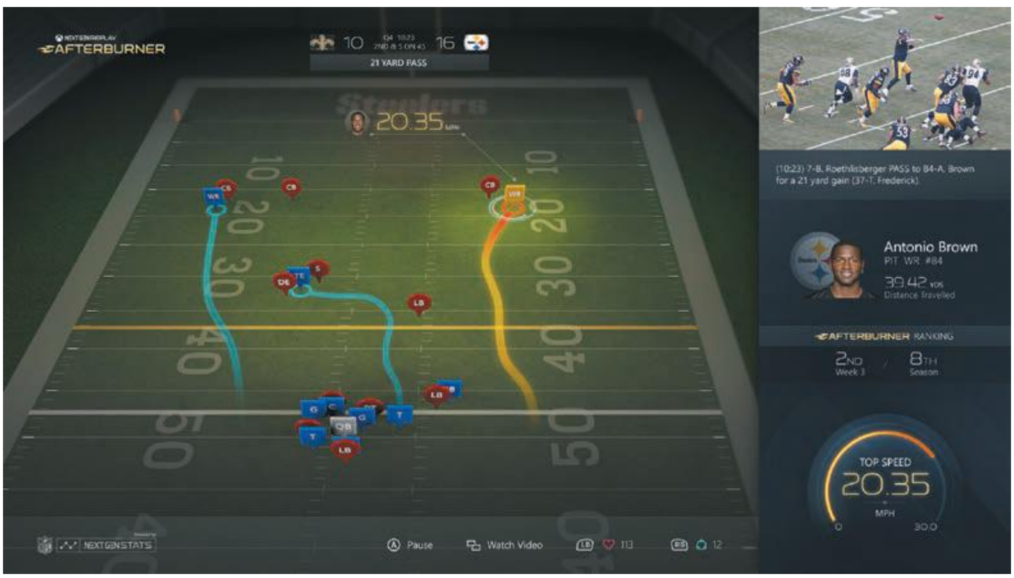
When considering various activity analysis methods, it is important to consider how practical the measure is against the accuracy of the information it can provide. Highly practical data collection methods tend to have lower accuracy levels, whereas those that are less practical are often more accurate.

Sporting technology

Technology shapes the way we develop and monitor an individual's physiological, mental, technical and tactical capabilities. Innovative technologies need to capture data, then present it instantaneously in an understandable format.

Technology is changing the way we perform in and monitor sport and physical activity, from the recreational to the elite level. Technologies previously seen as cutting edge, such as heart-rate monitors and smart phones, are being replaced by innovations that are empowering a wider cross-section of the community to access information. Wearable technology, such as fitness trackers, smart watches, GPS tracking devices and mobile apps are dominating the market. In an activity analysis context, wearable technology allows coaches to track performance and download and utilise data to analyse, manage and improve individual and team performance.

Examples of wearable technology



© Microsoft

Wearable data in sports coverage. The 2015 NFL season kicked off with all 1696 players fitted with a set of RFID (radio-frequency identification) chips capable of sending back stats on position, pace, distance travelled and acceleration in real time.

Image courtesy of Xmetrics: www.xmetrics.it

This is a wearable device used in swimming. It sits on the back of your head, to minimise drag, and measures a broad range of biomechanics as well as kick turn times, breath counts and stroke efficiency.

© Fitbit, Inc.

Activity trackers feature advanced sensors to pick up stress and blood pressure to get further insights for more specific coaching advice.

FYI

In 2015, NBA champions the Golden State Warriors began using wearable sensors in their clothes. The sensors, made by an Australian company called Catapult Sports, recorded heart rate, breathing and muscle use.

BIOMETRICS IN SPORT

REAL WORLD APPLICATION

NFL 'Next'

Weblink

Watch the short NFL video via http://vcepe34.nelsonnet.com.au and then answer the questions below.

1 How is biometrics defined?
2 What is scientific performance management?
3 How has Catapult technology specifically helped the Jacksonville Jaguars?
4 What is a biostamp patch?
5 What is the Athletes Service Model at the IMG Academy?
6 According to Dr James Carter, Director of the Gatorade Sports Science Institute, what is the specific focus of the test (in the field) to capture the athlete's physiological and metabolic response to that particular session?
7 Why will players buy into wearable tech?

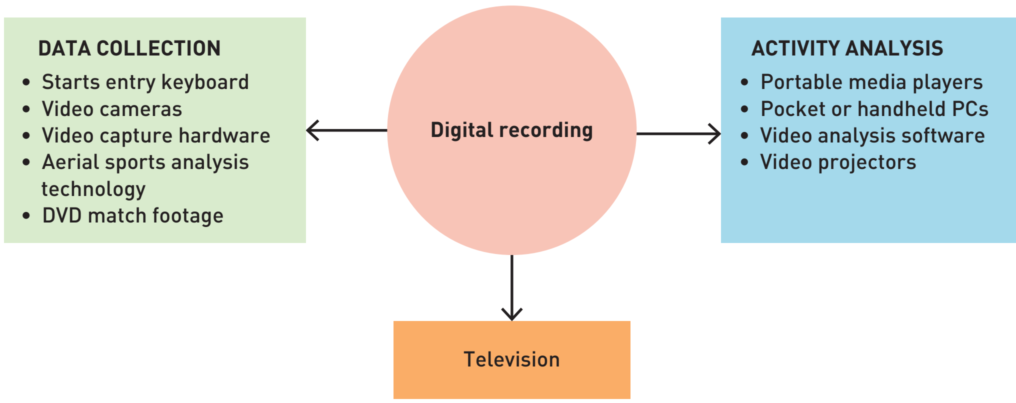
Aerial sports analysis technology

Sports analysis can now be conducted through the use of aerial technology. The elevated vantage point offers an unparalleled view of individual and team performance.

You may have watched sports coverage where vision was supplied by motion control software such as Skycam or Spidercam. These systems all operate on a similar principle. Cameras are suspended from cables anchored to the roof of indoor stadiums or, for outdoor venues, from high poles. Radio-controlled by a team of operators, the cameras are able to view each performer from many different angles. This allows picture-in-picture analysis of players even while they are off the ball. (Data about what performers are doing for the duration of the game is vital – not just when they are involved in the play!) This analysis can be used to improve individuals' skill execution by allowing them to focus on specific body segments and limb movements, or to compare their own movements with those of others. This is especially useful when the goal is to improve performance skills, rather than bring about physiological improvements. A recent development is the use of unmanned aerial vehicles (drones) in various aspects of sports media.

FYI

Skycam was first publicly used in 1984 at a pre-season National Football League match in San Diego, USA. Spidercam was first employed on a television production in Austria in 2004, before going on to be used at major sporting events.



Alamy Stock Photo/Cal Sport Media

Digital recording is used by most sporting teams and elite performers.

CHAPTER CHECK-UP

1. Why is it important to focus on the physiological data that we gain through conducting an activity analysis?
2. List two advantages and two disadvantages associated with direct viewing analysis as a means of analysing player performance.
3. How can clubs use video analysis or other data analysis to improve the tactical aspects of their game?
4. What simple aspect could be added to viewing the performance to make it a much more powerful means of collecting and using games data?
5. By using two activity analysis methods and referring to the graph on page 218, clearly demonstrate that you understand the trade-off between the two methods.
6. Aerial sports analysis technology is an example of analysis of the 'big picture'. Discuss why it is important to focus on passages of play and movements both on and off the ball, rather than simply focusing on what is happening with individual players.
7. Discuss how games analysis can be used to improve player performance and to make recovery sessions more specific. In your discussion, choose a sport and playing position, and discuss how this would differ for any other player on the team.

Activity analysis – making the connection

No matter how performance data is collected (viewing, statistical support, digital recording or all three), being aware of the advantages and disadvantages of each will help you to make informed choices. Table 10.1 summarises these advantages and disadvantages.

TABLE 10.1 Advantages and disadvantages of methods of activity analysis

Activity analysis method	Advantages	Disadvantages
Direct viewing	» Immediate changes can be made to the playing set-up or style of play in response to how the game is progressing. » Player fatigue is easily viewed and counteracted by using the bench for recovery. » Players are able to stay on the field, with positions rotated to increase player efficiency.	» Decisions are subjective or opinion-based. (This disadvantage can be reduced with training and increased viewing experience.) » There is no way of showing players how they performed. » It does not provide reference for comparing future performances. » Viewers need to rely on memory, which may be limited. » The pace of the game can be too fast to take everything in. » It can be difficult to view multiple players at the same time. » Large playing fields increase the distance over which observations need to be made.

TABLE 10.1 (*Continued*)

Direct viewing and statistical recording	» Viewers are able to discuss performance with players more objectively. » Data can be archived or stored and referred to in future. » Player or performance profiles are easier to establish.	» Training for viewers is required before accurate recording. » It is difficult for one person to both view and record what is happening. » It can be extremely labour-intensive, requiring a lot of effort to arrive at game summaries. » Guessing may be needed if vision is obstructed or players are too far away.
Digital recording	» Data is readily downloadable and processing by computers allows many player summaries to be created. » Data can be archived and easily accessed and saved data replayed at any time. » Data can be manipulated and transmitted easily.	» Can be expensive. » Technical expertise is often needed to operate the equipment.
Heart-rate monitoring	» Monitoring is relatively cheap. » Monitoring is generally unobtrusive and doesn't interfere with performance. » It creates an accurate collection of playing intensities.	» Waterproof monitor models are expensive. » There may be interference from nearby digital transmitters. » There may be delays in 'real-time' signals. » Data may need to be downloaded after an event is finished, if the receiver is not close.
Global positioning system (GPS)	» GPS combines movement patterns with intensities. » It easily identifies the players who are 'fatiguing' and the players whose efforts are dropping in intensity (useful for player rotation on and off the bench). » Can be used in the field – doesn't require a laboratory.	» The number of monitors may be limited, so it may not be possible for every player to be monitored. For example, six of an AFL team's players might be monitored in any one game. » With no reference to other players, limited contextual information can result. » Some models can be uncomfortable to wear.
Filming, aerial sports analysis, etc.	» Every player is visible for the whole game. » Picture-in-picture allows players to be monitored when 'off the ball' and enables tactical decision-making to be observed. » Movements can be further analysed by biomechanists and/or computer programs to make comparisons with the most efficient or effective techniques and skill execution. » Increases spectators' understanding and following of the game. » Allows field referees to call for third-umpire decisions.	» This is expensive to set up and requires many operators to use the many cameras or recorders (though remotely operated recording is increasingly being used).

To thoroughly understand the game requirements, data should be collected that will enable analysis of movement patterns, fitness components, energy systems, skill frequencies, playing intensities (including work-to-rest periods and heart rates) and the use of key muscles in bringing about successful skills or performances. When viewing digital recordings or footage with statistical support it is vital that the performer is in view at all times. This is why it is impossible to complete an activity analysis by simply viewing the TV footage of an event.

Table 10.2 lists the skills you are likely to observe when viewing a game of basketball, netball, hockey, volleyball, tennis or badminton. Before the game, set up a recording sheet with the relevant skills in one column and a blank column in which to record the frequency of each skill.

TABLE 10.2 Skills most likely to be viewed in six common sports

Basketball	Netball	Hockey	Volleyball	Tennis/ Badminton
Chest pass	Chest pass	Push	Serve: overarm	Serve
Overhead pass: two hands	Overhead pass	Hit	Serve: underarm	Forehand
Overhead pass: one hand (shoulder pass)	Catch	Flick	Dig	Backhand
Rebound	Rebound	Dribble up to 5 m	Set	Volley
Jump	Jump	Dribble more than 5 m	Spike	Forehand winner
Guard	Guard	Intercept	Leap forwards	Backhand winner
Defend	Defend	Tackle on opposition	Leap sideways	Smash
Leap forwards	Leap forwards	Disposal	Dive	Lob
Leap sideways	Leap sideways	Corner	Jump	Change of direction
Change of direction	Change of direction	Change of direction	Change of direction	
Lay-up	Toss-up	Lunge	Tip-off	
Posting or screening	Centre pass	Trap	Lunge	

ANALYSIS OF MOVEMENT PATTERNS

Player movements link directly to both fitness components and energy systems, as well as providing information about fatigue-related factors. It is very difficult to plot or draw movement patterns directly onto a scale diagram of the playing field while the action is occurring, because it's nearly impossible to have your eyes on the recording sheet and the players at the same time. For this reason, it is easiest to use a digital recording method to capture movements and later analyse these.

While this is useful for determining 'hot spots' on the field and repeated movement patterns or set plays, it is easier when determining specific fitness tests and training activities to simply break movements down into movement intensities and then work with these. When this information is combined with skill frequencies, a more meaningful set of data can be achieved.

Table 10.3 provides a sample analysis of a player's movement during two quarters of an AFL game. Each zone equates to a range of movement speeds. For example, zone 1 (0–6 kilometres per hour) would include walks and low-intensity jogs, while at the other end of the scale, zone 6 (22–40 kilometres per hour) would be high-intensity sprints.

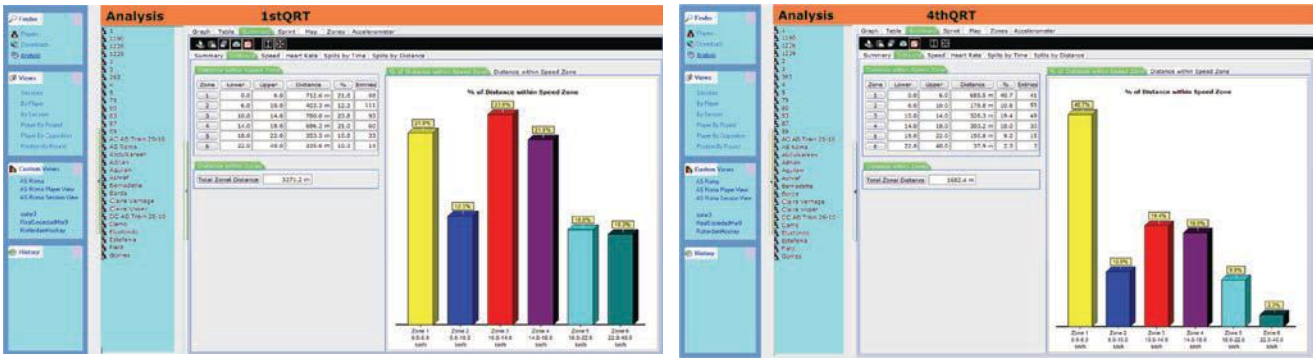
The data reveals obvious fatigue when comparing last-quarter efforts to those of the first quarter. For example, in the last quarter:

» there were only three zone-6 entries, compared with 14 in the first quarter
» 51.3 per cent of time was spent in zones 1 and 2, compared with 34.1 per cent in the first quarter
» the average sprint distance was 12.6 metres (37.9 metres ÷ 3 efforts). This had dropped from 24 metres (335.6 metres ÷ 14 efforts) in the first quarter.

TABLE 10.3 First-and last-quarter movement patterns for an AFL player

Zone	Speed range (km/h)	Distance (m)	% of quarter	Entries
1st quarter				
1	0–6	712.6	21.8	68
2	6–10	403.3	12.3	111
3	10–14	780.0	23.8	93
4	14–18	686.2	21.0	60
5	18–22	353.5	10.8	33
6	22–40	335.6	10.3	14
Total zonal distance (m)		3271.2		
4th quarter				
1	0–6	685.5	40.7	41
2	6–10	178.8	10.6	55
3	10–14	326.3	19.4	49
4	14–18	303.2	18.0	33
5	18–22	150.8	9.0	15
6	22–40	37.9	2.3	3
Total zonal distance (m)		1682.5		

Adapted from GPSports



The summaries in Table 10.3 use the activity analysis data shown in these screenshots.

Source: GPSports software

Analysis of movement patterns allows a specific sprint distance to be selected for fitness testing. There is little point in assessing a player's speed over 100 metres if this rarely or never occurs during a match. A more specific speed test could be the 30-metre sprint test, or, depending on the size of the playing field, a 20-metre sprint. For some sports, a repeat effort sprint recovery test may be the most relevant test. Players need to be constantly replenishing their phosphocreatine (PC) stores following repeated high-intensity efforts. The ability of the body to replenish phosphates is assessed via the phosphate recovery test (see chapter 11). If 24 metres is the average sprint distance observed during the game, the short course (25 metres) would prove to be much more specific to game demands than the long course (40 metres).

As soon as players start showing a decrease in the number of high-intensity efforts, coaches consider giving them a short break. This gives the players an opportunity to refuel, recover and then rejoin the game and have a greater input. It also allows them to communicate directly with the coach, giving them an opportunity to discuss tactics they need to put in place when they return to the field. In the long term, this data can be used to make training more specific, building the capacity of the player to bring about improved performance.

The table below can be used as the basis of a statistical recording sheet to be used when viewing games or competitions. Use a separate sheet for each time period; this could range from 10 minutes to a quarter or half of the game, depending on the sport or activity. It is very important to record the stage of the game, as this allows for consideration of fatigue and recovery mechanisms. You can fill in an online template via http://www.nelsonnet.com.au, using your login.

Table 10.4 gives sample data from one row of a locomotor recording sheet. The corresponding calculation of distance in the zone is shown in Table 10.5.

Scaffold

LOCOMOTOR RECORDING SHEET									
Obervation time (stage of the game) ________________ (minutes)									
Locomotion (zone)	**Intensity**	**Distance moved (m)**				**Number of entries**	**Distance in the zone (m)**	**% of total distance**	**Average distance (m)**
		0–5	**6–10**	**11–15**	**16+**				
Walk	Low								
Jog	Low–medium								
Shuffle	High								
Sprint	Very high								
Totals								**100%**	

TABLE 10.4 Sample data from one zone of a locomotor recording sheet

0–5	6–10	11–15	16+	Number of entries	Distance in the zone (m)	Average distance (m)
IIII	𝍸𝍸	𝍸	II	21	193	193 ÷ 21 = 9.2

TABLE 10.5 Sample calculation of distance in the zone

Distance (m)	Midpoint (m)	Tally	Midpoint × tally
0–5	2.5	4	10
6–10	8	10	80
11–15	13	5	65
16+	19	2	38
Totals		21	193

ANALYSIS OF SKILL FREQUENCIES

Coaches can use data about the frequency and effectiveness of skills to improve technical and tactical performances, as well as improve the contribution of the most important fitness components. For example, Table 10.6 shows frequencies for skills that a tennis player used during the first set of a match. The data shows that the player was 92 per cent effective for forehand ground strokes but only 65 per cent effective for backhand. This information helps the coach identify a skill that can be improved. The analysis also provides important information about physiological parameters. For example, knowing that the player executed five smashes in the first set would indicate that arm power is important.

TABLE 10.6 Sample skill frequencies for a tennis player

Skill	Forehand	Backhand	Serve	Smash	Volley	Lob	Directional change
Frequency	68	52	64	5	29	4	198
Effectiveness (%)	92	65	81	80	90	50	n/a

n/a =not applicable

The number of serves also indicates that arm power is an important component, and data about the number of forehand and backhand winners might also support this. The large number of directional changes is a clear indication that **agility** is very important, and because players can't be agile unless they are fast and flexible, speed and flexibility would also be important components.

Table 10.7 shows frequencies for skills that an Australian Rules footballer used during one quarter of a match. Knowing that the player had 15 kicks measuring longer than 45 metres would indicate the reliance on leg power and flexibility, but a right-foot disposal efficiency of 85 per cent compared with 55 per cent for the left foot would indicate that left-foot skills need attention.

TABLE 10.7 Sample skill frequencies for an Australian Rules footballer

Skill	Tackle	Overhead (aerial) mark	Kick <45 m	Kick >45 m	Handball	Directional change
Frequency	8	7	L: 2, R: 3	L: 4, R: 11	L: 1, R: 13	255
Effectiveness (%)	100	100	L: 60, R: 95	L: 50, R: 80	L: 100, R: 95	n/a

L = left, R = right, n/a = not applicable

Table 10.7 reveals a large number of directional changes, indicating a reliance on high levels of agility and muscular power. The use of muscular power is also evident from the number of kicks over 45 metres in length. Strength is quite often observed in team sports where contact is a feature of the game, such as Australian Rules football, rugby and some martial arts, such as judo. The eight tackles recorded probably involve maximal contraction speed being applied over a longer period of time than for muscular power, and would therefore call upon muscular strength.

Analysis of muscle groups

While effectiveness of skills is crucial information for elite coaches and performers, senior physical education students need to focus on the physiological aspects of activity analysis and performance, rather than tactical or technical aspects. In other words, analysing the effectiveness of skills is not as important as documenting all the skills that are performed.

TABLE 10.8 Sample skill frequencies for basketball

Skill	Frequency	Skill	Frequency
Chest pass	38	Guard	12
Overhead pass: 2 hands	8	Defend	35
Overhead pass: 1 hand (shoulder pass)	15	Leap forwards	16
		Leap sideways	12
Rebound	7	Directional change	95
Jump	52	Posting or screening	9

Adapted from: GPSports

The skills must be broken down into the major associated muscles, and specific fitness tests must be chosen to match (as closely as possible) the way muscles are used during the game. This is taken a step further when the muscles are trained specifically, utilising similar actions, as part of a training program. (See table 10.9 for examples.)

Posting or screening requires high levels of core stability and strength in the abdominal and lower back muscles to hold off (or hold out against) opponents. Even though basketball is a non-contact sport, strength is required in these instances.

Activity analysis should reveal the major muscles used during the activity. This is very important when considering the major fitness components and energy systems used, and will influence the fitness tests chosen and specific training activities undertaken. Table 10.9 provides you with some examples.

TABLE 10.9 Training activities targeting specific skills and muscles

Skill	Major muscles	Similar or specific fitness test	Specific training activity
Chest pass	Pectorals, deltoid, trapezius	Seated basketball throw	1 Clap push-ups 2 Pec deck resistance machine (weights)
Shoulder pass	Biceps, triceps, pectorals, trapezius	Baseball throw	1 Overhead elastic pulls 2 Dips 3 Lat pull-downs (weights)
Leap	Quadriceps, hamstrings, gastrocnemius, tibialis anterior	Vertical jump	1 Wall slaps 2 Stair running 3 Depth jumps (plyometrics)
Directional changes	Quadriceps, hamstrings, abdominals, lower back	SEMO agility	1 Agility sprints over 5–10 metres 2 Interval sprints 3 PNF stretching (lower back)

CHAPTER CHECK-UP

1. Whenever activity analysis reveals directional changes or other movements requiring agility, what other related components must be considered?
2. Table 10.3 (page 224) compared first- and last-quarter locomotor patterns for an AFL player. What is the average distance sprinted (zone 6) for each of these quarters?
3. Discuss any likely causes of fatigue evident from the data in Table 10.3 and discuss three different fatigue mechanisms responsible for this. Use the data to support your answer.
4. Table 10.3 also provides evidence of changing energy system interplay when comparing the quarters. Discuss the likely energy system interplay for each quarter, using the data provided.
5. Table 10.2 (page 223) shows skills that might be evident in games analysed by students. Choose three skills observed in volleyball and identify the major muscles used to perform these skills. (Remember that each action will involve an agonist and an antagonist muscle action.)

ANALYSIS OF WORK-TO-REST RATIOS AND PLAYING INTENSITY

Meaningful data on playing intensity can be collected by observation, supplemented with statistical recording. It is also possible to combine work-to-rest ratio information. The main problems with trying to capture playing intensities are that it cannot be done live and that it must be done at regular intervals. Whatever occurs in between these viewing and recording intervals cannot be captured. Therefore, as well as being regularly spaced during the activity analysis, the viewing periods must also be as frequent as possible.

Analysis of intensity

The example below shows one way of recording playing intensity. The columns have been colour-coded to give an overall picture of changes in intensity and to help compare results from different 2-minute intervals. Alternatively, multiple copies of single-minute recording sheets (see below) could be used throughout the game.

PLAYING INTENSITY RECORDING SHEET

Player: Jake **Date:** 1 June **Time:** 5 p.m.

Time (seconds)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
Intensity	M	H	L	M	L	H	H	V	H	L	M	L	H	L	L	L	M	H	L	M	H	M

L = Low, M = Medium, H = High, V = Very high

SINGLE-MINUTE RECORDING SHEET

Player: ______________________ **Date:** ______________ **Time:** ____________

1st minute of play												
Time (seconds)	5	10	15	20	25	30	35	40	45	50	55	60
Intensity												
2nd minute of play												
Time (seconds)	5	10	15	20	25	30	35	40	45	50	55	60
Intensity												

Analysis of work-to-rest data

The sample record on page 230, which shows playing intensities and work-to-rest data, provides much more accurate and usable information than the simple intensity tables shown above.

This form tracks a player throughout the game. The first column of entries (5, M, 15) represents 5 seconds of medium-intensity followed by 15 seconds of rest. The next column (3, H, 2) shows 3 seconds of high-intensity activity followed by only 2 seconds of rest.

This method requires an observer calling out the intensities to a recorder and the use of two stopwatches: one to record work and another to record rest. Alternatively, a team of four could conduct this analysis. One person observes work and calls out to a recorder, while a third person times work and a fourth times rest.

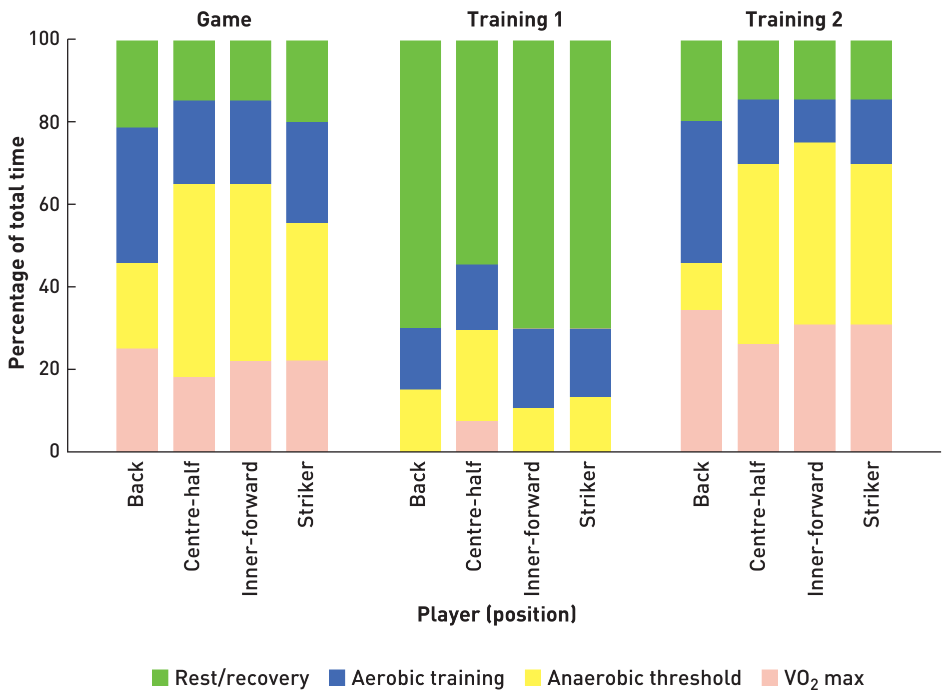
The yellow highlighted area on the record sheet shows consecutive areas of very high or high intensity actions with limited rest, and thus limited ability to restore fuels. The more often this occurs during a game, the more this intensity needs to be prepared for during training.

FYI

A work-to-rest ratio of 1:1 highlights high reliance on the aerobic energy system, while 1:4 highlights a major contribution from the lactic acid energy system and 1:6+ highlights reliance on the ATP–PC energy system.

PLAYING INTENSITY RECORDING SHEET																						
Player: Sasha					Date: 3 July					Time: 10:06												
Time (seconds)	5	3	3	15	14		7	4		5	4	8	4	7	10	10	5	8	4	5	2	15
Intensity	M	H	H	M	L	V	H	V	H	L	M	H	H	H	L	L	M	H	L	M	H	M
Rest (seconds)	15	2	15	10	5	5	5	6	2	25	10	16	12	20	14	14	15	12	10	25	3	20

L = Low, M = Medium, H = High, V = Very high



Intensities observed during a game of hockey and two training sessions

It is absolutely critical that the game intensities identified in the activity analysis are replicated during training sessions (with similar work periods followed by similar rest periods) to best develop the associated energy systems and fitness components, according to the principle of specificity.

In the graph below, Training 1 spends too much time at low intensities, which is not replicating what occurs during the game. This means Training 1 lacks specificity and real purpose.

Training 2 better simulates what happens during the game and so is a much more specific form of training.

Alamy Stock Photo/Ian G Dagnall

This GPS app allows the recording and analysis of many parameters, including speed, total distance covered, accelerations, decelerations and body load information.

Global Positioning System (GPS)

GPS is one of the best ways to assess playing intensities. GPS not only provides an idea of how fast a player is moving (and hence their intensity), but also gives an idea of where on the field or court they are moving. Live GPS data allows coaching staff or an individual to act immediately on the information being provided. Typical GPS data can provide speed, distance, heart rate, body load information and intensity graphs, as well as generally tracking workloads. This player tracking option provides insights into performance and game demands, which better informs decision-making, as the GPS user can objectively manipulate volume and intensity of training loads for optimum game day performance.

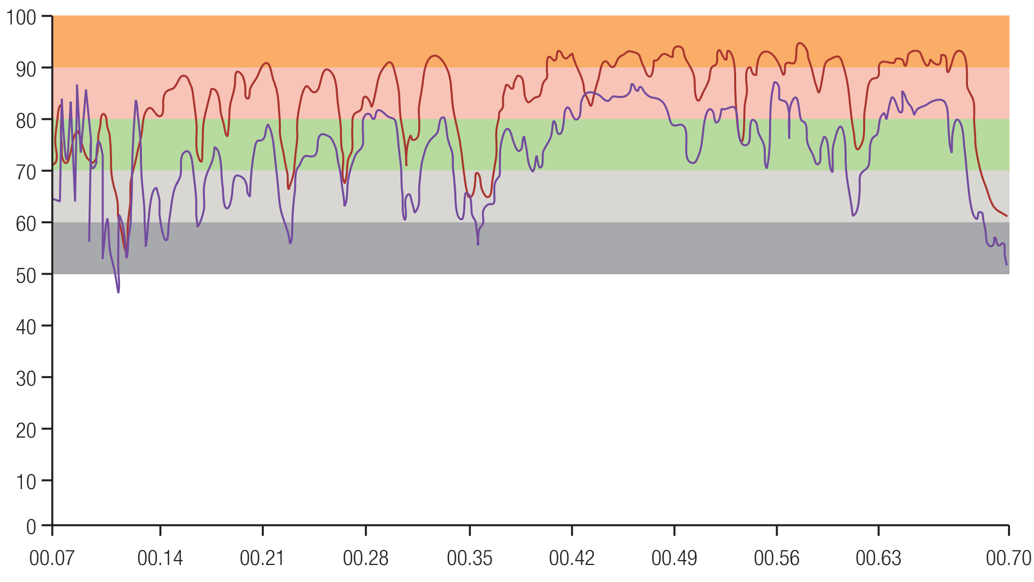
ANALYSIS OF HEART RATE

Heart rate can be collected in a variety of ways. An individual can take their own pulse (the number of heart beats per minute) quickly and efficiently, by locating a radial or carotid pulse measurement at the wrist or neck. Heart rate (HR) is the number of times the heart contracts per minute, and is measured in beats per minute. It increases linearly with intensity until it reaches maximum. External heart-rate monitors and the many heart-rate monitoring apps available provide another mode of recording heart-rate data (allowing for technological error).

Heart rate can be monitored during a game situation or during physical activity to inform us of the intensity at which we are working at any particular moment. Intensity can refer to the level of exertion or how hard the body is working at any point, measured by heart rate. The data collected by heart-rate monitoring can inform us of the training zones that we should be working within during training sessions, which in turn ensures that the relevant energy systems and fitness components are being developed during training. This is a direct application of the 'specificity' training principle.

For example, you may have completed an activity analysis of a centre player in netball. This player may frequently move at high intensity over short distances during their game, and heart-rate data would reveal an elevation of heart rate during these efforts. In situations where efforts are exceptionally short, the time for heart rate to increase significantly may not allow this to be recorded. In this case, a GPS monitor would accurately record speed (this can be expressed as a percentage of maximum). To replicate these specific actions (a sprint) during a strategically planned training session, an individual would need to move at the intensity recorded during the game. What does this look like? In practical terms this may be achieved by undertaking a short-interval training session. Conversely, the heart rate of a soccer goalkeeper may reflect low-intensity exercise during specific stages of the game, such as when the play is at the other end of the ground and they are not directly involved in the play. This heart-rate data would indicate that the goalkeeper would be working at a low intensity or submaximally at that exact point of the game – evidence of the aerobic energy system being utilised at that time. It is critical to train at the correct intensity to improve and maximise chronic adaptations.

The graph below provides evidence of heart rates during a training session for two soccer players. The analysis of heart-rate data provides specific data to an individual;



Heart-rate responses between a fit (purple line) and an unfit (red line) soccer player for the same training session. The average heart rate for the fit player was 73% (training load of 127), compared with the unfit player's 84% average heart rate (training load of 173).

this can shape training zone intensities for future training sessions to prepare the player for similar game situations, ensuring specificity. The analysis provides important information about physiological parameters, such as required fitness levels. Analysing this data further, a fitness coach in collaboration with the head coach could then optimise training by designing specific training sessions for the individual.

Getty Images/Erik van Hannen

Information can be downloaded from a heart rate monitor to a computer.

Heart-rate monitors

Heart-rate monitors allow the user to instantly track and monitor key aspects of performance. Heart-rate monitors are becoming cheaper, smaller and connectable to a computer interface. This allows information to be stored during the game or performance and then downloaded for analysis.

Analysis of time spent in specific intensity zones

The energy demands specific to netball player position (wing attack, goal attack, centre and wing defence) were highlighted by Woolford and Angrove (1991). Their study aimed to determine whether intensities experienced during training matched game intensities. Incremental treadmill tests were used to determine each player's maximum heart rate (max HR). From these results, four intensity zones were calculated for each player, as shown in Table 10.10.

TABLE 10.10 Analysis of playing time spent in each intensity zone by netball players in four key positions

Zone	Intensity (% max HR)		Percentage of playing time spent in zone			
			WA	GA	C	WD
1	95	Improving aerobic power	0	54	25	10
2	85–95	Anaerobic endurance	45	39	44	63
3	75–85	Aerobic endurance	32	6	9	22
4	<75	Recovery and regeneration	43	0	22	5

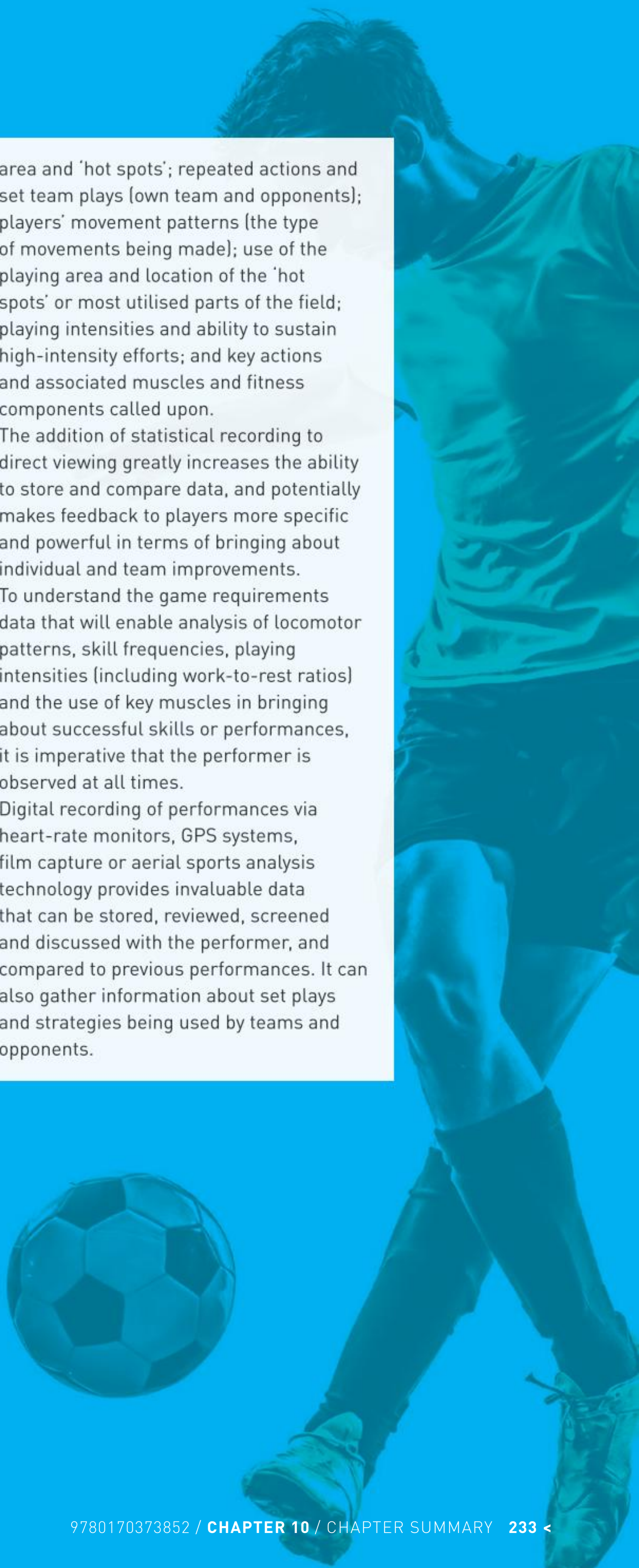
The study found that players spent a lot more time in zones 3 and 4 during training than in games. The implication for coaches is that training programs must incorporate drills designed around the specific demands of the position, using appropriate intensities depending on the stage of training. Appropriate pre-season fitness testing could provide base values for regular monitoring of exercise intensity throughout training and games. Pre-season fitness testing is a key element in the planning, design and implementation of any training program. This planning is known as **periodisation**, whereby the year is organised into conditioning cycles or phases of training. This systematic planning strategically directs the training focus in terms of intensities, frequency, duration and load/volume over the year.

CHAPTER CHECK-UP

1. How could analysis of intensity versus game time be used to improve training?
2. Why is work-to-rest ratio so important in planning training sessions?
3. How can GPS technology improve an individual's performance?

CHAPTER SUMMARY

- The main purpose of activity analysis is to determine how the performance might be improved by a coach's immediate intervention, or (once the game or performance data has been analysed) how the performance can be improved by the application of specific training drills and programs.
- More time is being devoted to activity analysis data to better understand specific physiological requirements, such as the energy system contribution and interplay during different parts of the game; major skills performed and related muscle groups requiring conditioning; and likely causes of fatigue and recovery strategies. Data analysis is increasingly being used to identify psychological and tactical performance limitations and to address these during training.
- Direct viewing analysis is the most common form used in schools and universities. This is where the coach and other interested parties observe the game from a viewing point close to the performance area. It is also used at the elite level in sports such as Australian Rules football, soccer, netball, basketball and hockey, where coaches position themselves in designated coaching boxes or move up and down the side of playing areas to directly communicate with their playing group.
- Typical observations include locomotor (movement) patterns; use of the playing area and 'hot spots'; repeated actions and set team plays (own team and opponents); players' movement patterns (the type of movements being made); use of the playing area and location of the 'hot spots' or most utilised parts of the field; playing intensities and ability to sustain high-intensity efforts; and key actions and associated muscles and fitness components called upon.
- The addition of statistical recording to direct viewing greatly increases the ability to store and compare data, and potentially makes feedback to players more specific and powerful in terms of bringing about individual and team improvements.
- To understand the game requirements data that will enable analysis of locomotor patterns, skill frequencies, playing intensities (including work-to-rest ratios) and the use of key muscles in bringing about successful skills or performances, it is imperative that the performer is observed at all times.
- Digital recording of performances via heart-rate monitors, GPS systems, film capture or aerial sports analysis technology provides invaluable data that can be stored, reviewed, screened and discussed with the performer, and compared to previous performances. It can also gather information about set plays and strategies being used by teams and opponents.



CHAPTER REVIEW

Multiple-choice questions

1 What is the main advantage of direct viewing as a data collection method?
   A Immediate changes can be made to a player's practices or performances.
   B Viewers are not distracted by having to record statistical data as well.
   C Viewers can watch many players at the same time.
   D The tasks can be divided up among a team of viewers.

2 The main purpose of conducting an activity analysis is to determine
   A the work-to-rest ratio, attitudinal rating and fatigue index of performers.
   B the effectiveness of training methods and programs.
   C the main fitness components, energy systems and movements required to bring about successful performance.
   D the most appropriate time to introduce variety to training programs.

3 Data that can be archived is useful to coaches because it is easy to
   A compress into smaller manageable segments.
   B contrast the playing strengths and weaknesses of opposition teams.
   C compare any performance changes after interventions such as coaching advice, training or tactical plays.
   D contradict the information obtained using less effective, subjective data collection methods.

Short-answer questions

4 Suggest three reasons why people performing an activity analysis task should undertake training and practice before they conduct their first 'real' analysis.

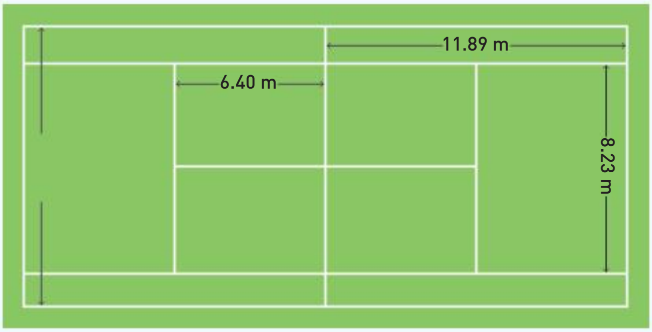
5 Prepare a written critique that explains why heart-rate data would not be as useful to a netball coach as GPS data.

6 a Draw the following movement pattern on a tennis-court template like the one at the bottom of this page. There is a downloadable template on the NelsonNet website. Log in and go to this page of the chapter.
   The player serves to the forehand side and sprints to the net, changes direction and moves to other side of the court to play a volley, moves backwards to position for a ball that has been lobbed, and hits a backhand winner across court.

Scaffold

   b On three separate tennis-court templates, draw movements (of your own choice) for the next three points in the match. Make sure you include a variety of locomotor patterns and skills.
   c Summarise the data you have presented, or challenge one of your classmates to 'read' the three movement diagrams you have created.
   d Identify the most common sprinted distance and the main fitness component and energy system utilised in the points . You can fill in the online template, and copy it, via http://www.nelsonnet.com.au, using your login.

Scaffold



7 Create a table similar to Table 10.9 (page 228) for soccer, volleyball or badminton. Identify four typical skills (see Table 10.2 on page 223), the top three associated muscles, one fitness test that best replicates the actions of those muscles, and three training activities that would best highlight the principle of specificity. There is a template on your NelsonNet website. Log in and go to this page of the chapter.

Scaffold

CHAPTER 11

ASSESSMENT OF FITNESS

Key knowledge

» assessment of fitness including:
  - the purpose of fitness testing including physiological, psychological and sociocultural perspectives
  - pre-participation health screening (PAR-Q)
  - informed consent
  - test aims and protocols
  - test reliability and validity

» methods of at least two standardised, recognised tests for aerobic power, agility, anaerobic capacity, body composition, flexibility, muscular endurance, power, strength and speed

Key skills

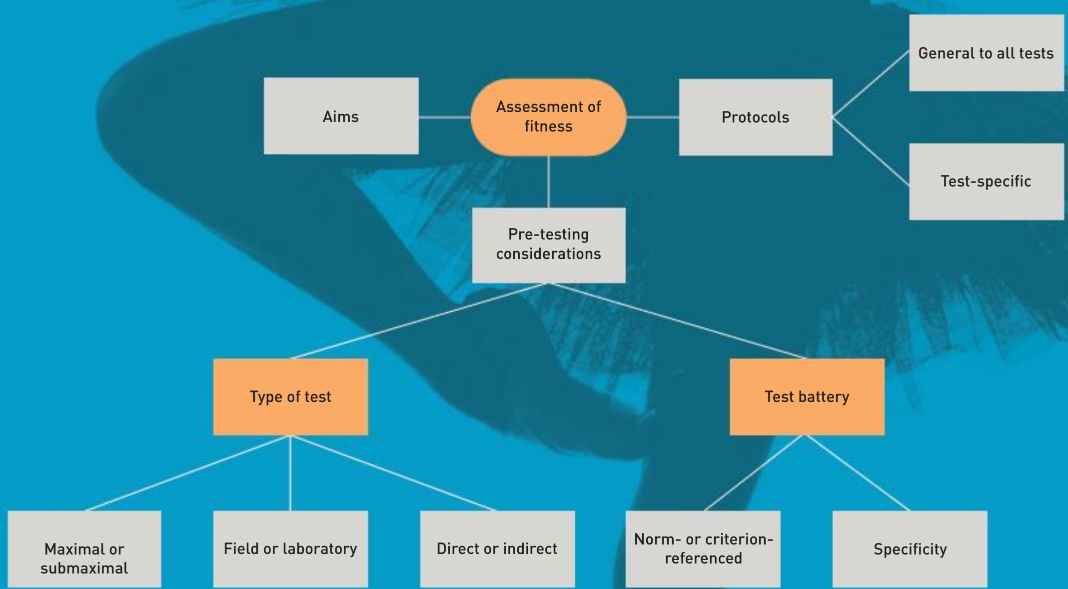
» determine an appropriate fitness testing regime based on the physiological, psychological and sociocultural needs of the individual and the requirements of the activity

» conduct a valid and reliable assessment of fitness using ethical protocols

» perform, observe, analyse and report on practical laboratory exercises designed to assess fitness prior to designing a training program

» justify the selection of fitness tests in relation to the physiological, psychological and sociocultural requirements of the test subject

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



iStock.com/OSTILL

A variety of fitness components were introduced in chapter 9. Given the range of components that exist, it would be impossible to simply select one test to evaluate a performer's overall fitness. A variety of fitness tests are required to evaluate a performer's fitness levels for the various fitness components.

PRE-FITNESS ASSESSMENT CONSIDERATIONS

Fitness testing provides opportunities for people to increase their understanding and appreciation of supportive environments and diversity in training. It should include activities that encourage participants to:

- accept that levels of performance will be unique to individuals
- understand that commitment to developing health-related fitness is affected by motivation, sociocultural factors and environment
- recognise the barriers and enablers experienced by individuals or groups who wish to participate in health-related fitness programs
- recognise that participants with disabilities or learning difficulties may require some tests and training activities to be modified to optimise both their participation and their ability to reach goals. Parents/carers and specialist support staff should be consulted to determine whether modification is necessary

Before any fitness assessment is considered, the intended outcome should be clear to both the person undertaking the assessment and the person conducting it. This may help to alleviate some of the anxiety that is often associated with testing.

The most common settings for fitness testing include:

- schools
- sporting clubs
- elite sportspeople/teams.

The purpose of fitness assessment for elite sportspeople is usually very clear to both the participant and test administrators and may include any of a number of reasons (see page 239) such as benchmarking, evaluation of a training program and determining strengths and weaknesses. As with any testing, cultural sensitivities need to be taken into consideration.

For both school and community settings, participant sensitivity is of the utmost importance. The way the testing and result dissemination are conducted could have serious long-term consequences for an individual, particularly if the participant's experiences are negative, and may discourage them from future participation in physical activity. Important questions include:

- Is it culturally acceptable to be conducting this testing?
- Has consideration been given to participants involved in mixed-gender group fitness assessment?
- Has consideration been given to sensitivity of the participants, particularly when group testing is undertaken? What impact may this have on a person's self-efficacy? Is it appropriate to conduct body composition measurements in a group setting? Is this appropriate culturally?
- Are norm- or criterion-referenced result comparisons being used? Remember, norm-referenced results will particularly highlight participants who are below average for their population group.
- How will poor results impact on an individual, such as a low 20-metre shuttle run test (SRT) in a group setting or a high body mass index (BMI) or waist circumference measurement?
- Confidentiality is also important. For example, in a group setting, are all participants comfortable with their results being compared, or even completing a test in a group setting?

» Should parents be aware of any intended fitness assessment?
» Is participation voluntary or mandated?
» Does the participant have the option to discuss their involvement in the assessment regime before the actual testing commences? Has allowance been made for this discussion to take place in a confidential environment?
» Does the feedback enable participant respect for self and others?

Getty Images/Adam Pretty

Is the 20-metre SRT a maximal test? At what age is this test appropriate?

It is also important to consider the following factors before commencing fitness testing:

» safety of all those involved in fitness assessment. This may include completing pre-participation health screening such as a PAR-Q or the more contemporary adult pre-exercise screening system (see pages 242–245) before any fitness assessment is undertaken.
» financial costs involved in the test; is it affordable for the intended person/group? As an example, a VO_2 maximum test may cost $250 or more. A suitable alternative may be the 20-metre multi-stage shuttle run, which can be conducted at a fraction of the cost.
» Whether the testing be should be maximal or submaximal. Is there a health concern with the person performing a maximal test such as a VO_2 max or a 20-metre shuttle run test? Would a submaximal test such as the PWC170 provide the required information without placing the participant under undue physiological stress?
» access to equipment and facilities
» whether the fitness testing is necessary. How will the testing be used to help the individual/group involved in the testing? Could the same outcome be achieved without conducting a fitness assessment?
» planning and scheduling. Fitness testing can often be time-consuming, particularly when testing multiple fitness components. This is important when periodising the fitness program for an individual or team.

PURPOSE OF FITNESS ASSESSMENT

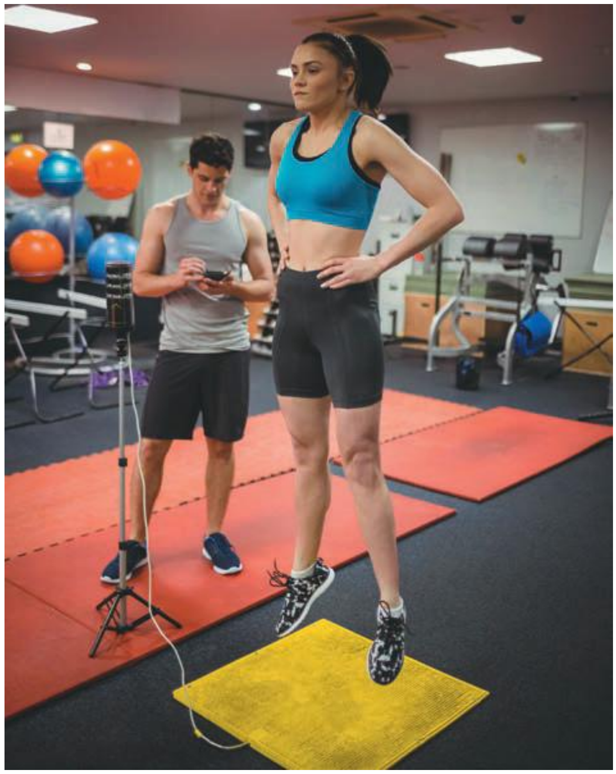
Fitness assessment usually evokes a range of psychological responses, and even anxiety, from those about to be tested. A more favourable response can be achieved if there is a clear purpose for performing the fitness test, and this purpose is communicated to the performer undertaking the test. Purposes of fitness assessment include physiological, psychological and sociocultural perspectives.

Determining fitness component strengths and weaknesses

To determine fitness component strengths and weaknesses, results are usually compared to a set of normative or criterion-referenced results. A profile of the performer is developed and a more specific training program can then be designed based on these results and the information obtained from an activity analysis. (See diagram below.)

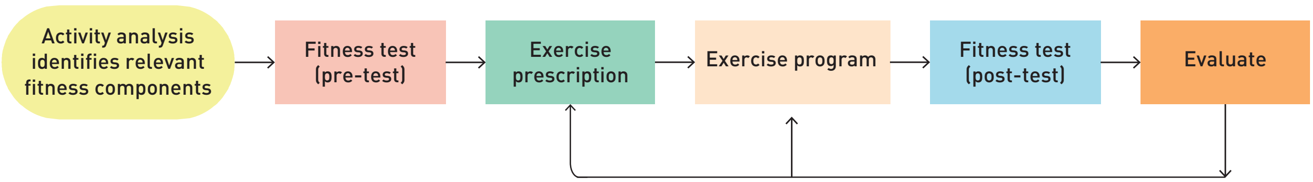
Establishing a baseline

We first need to establish a baseline or benchmark with which to compare future test results. These stages are often referred to as pre- and post-testing. Post-testing means the success of the training program can be evaluated before continuing or modifying the program.



Alamy Stock Photo/Wavebreak Media Ltd

Apart from determining strengths and weaknesses, what other roles does fitness testing play in bringing about improved performances?



The steps involved in fitness assessment

Mental toughness

Maximal tests such as a VO_2 max test or the phosphate recovery test require a participant to mentally push through the desire to slow down or stop. This is designed to assess the participant's psychological strength when physical pressure is exerted.

Motivation

A performer may be more conscientious in completing a training program if they realise re-testing will take place. Goal setting could also be established, with a performer aiming to achieve a certain result in the next test. Goal setting is a particularly powerful motivator that is discussed in more detail in chapter 16. Setting and achieving goals will also help increase a participant's self-efficiency. Increased motivation may also be achieved through enlisting social support for both the testing and any subsequent training program.

Determining team positions

More suitable team positions could be determined based on a performer's fitness test results. For example, if a goalkeeper achieves an outstanding result in the 20-metre shuttle run test, the coach may consider moving this player into a more aerobic-dominated position.

Predict potential

Fitness assessment can help predict the potential of future performers. Several nations have wide-ranging testing programs as part of a talent identification program.

Assess cardiovascular risk

Fitness assessment can assess potential cardiovascular risk factors through body composition testing.

Selection criteria

Fitness testing can form part of selection criteria for employment (see Table 11.1 for Victoria Police fitness testing).

TABLE 11.1 Minimum scores required for successful completion of the Victoria Police fitness tests

20-metre shuttle run test (level and shuttle)	Illinois agility run	Grip strength	Plank/prone bridge	Push-ups
Minimum of stage 5, level 1	within 20 seconds	30 kg grip strength in each hand	Held for 60 seconds	5 from toes

Note: There is also the requirement to be able to climb over a 1.3 m obstacle and swim 100 m in 4 minutes.

Source: Victoria Police

Newspix/Tony Gough

Do you think the requirement for entry into the police force is too high, too low, or appropriate? Do you think you would be able to reach this level of fitness?

CHAPTER CHECK-UP

1 Outline three important considerations before fitness testing.
2 Why is it important to establish the intended outcome of fitness testing?
3 Explain why an activity analysis should be completed before fitness testing.
4 Would a hand-held timing device be more reliable for a 10-metre or 50-metre sprint test? Justify your response.
5 Discuss one potential negative consequence of fitness testing.
6 Explain two purposes of fitness testing.

HEALTH SCREENING FOR FITNESS

Becoming more physically active is an important consideration for improving quality of life and helping to prevent many lifestyle illnesses. Both federal and state governments are significantly increasing funding to create more opportunities for Australians to increase their physical activity. However, it is important to consider your current health status before undertaking fitness testing or commencing an exercise regime. For some people, particularly those with a history of poor health, it may also be prudent to check with a medical practitioner first.

Pre-exercise screening questionnaires are available to help determine your readiness for fitness testing or an exercise program, and are particularly important for older adults and those with known health risks. The most well-known of these is the Physical Activity Readiness Questionnaire (PAR-Q). The PAR-Q was created by the British Columbia Ministry of Health and the Multidisciplinary Board on Exercise in Canada.

Australia has established a more contemporary screening system. A technical committee, chaired by Professor Kevin Norton and comprising members from Sports Medicine Australia (SMA), Exercise and Sports Science Australia (ESSA) and Fitness Australia has developed an adult pre-exercise screening system (APSS). The APSS, which appears on the next four pages, is now accepted as the industry standard pre-exercise screening system.

Adult Pre-Exercise Screening System © Exercise and Sports Science Australia, Sports Medicine Australia and Fitness Australia. Image courtesy of ESSA www.essa.org.au

ADULT PRE-EXERCISE SCREENING TOOL

This screening tool does not provide advice on a particular matter, nor does it substitute for advice from an appropriately qualified medical professional. No warranty of safety should result from its use. The screening system in no way guarantees against injury or death. No responsibility or liability whatsoever can be accepted by Exercise and Sports Science Australia, Fitness Australia or Sports Medicine Australia for any loss, damage or injury that may arise from any person acting on any statement or information contained in this tool.

Name: ______________________________

Date of Birth: ______________ Male ☐ Female ☐ Date: ______________

STAGE 1 (COMPULSORY)

AIM: to identify those individuals with a known disease, or signs or symptoms of disease, who may be at a higher risk of an adverse event during physical activity/exercise. This stage is self administered and self evaluated.

Please circle response

1.	Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke?	Yes	No
2.	Do you ever experience unexplained pains in your chest at rest or during physical activity/exercise?	Yes	No
3.	Do you ever feel faint or have spells of dizziness during physical activity/exercise that causes you to lose balance?	Yes	No
4.	Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months?	Yes	No
5.	If you have diabetes (type I or type II) have you had trouble controlling your blood glucose in the last 3 months?	Yes	No
6.	Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise?	Yes	No
7.	Do you have any other medical condition(s) that may make it dangerous for you to participate in physical activity/exercise?	Yes	No

IF YOU ANSWERED 'YES' to any of the 7 questions, please seek guidance from your GP or appropriate allied health professional prior to undertaking physical activity/exercise

IF YOU ANSWERED 'NO' to all of the 7 questions, and you have no other concerns about your health, you may proceed to undertake light-moderate intensity physical activity/exercise

I believe that to the best of my knowledge, all of the information I have supplied within this tool is correct.

Signature ______________________ Date ______________

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EXERCISE INTENSITY GUIDELINES

INTENSITY CATEGORY	HEART RATE MEASURES	PERCEIVED EXERTION MEASURES	DESCRIPTIVE MEASURES
SEDENTARY	< 40% HRmax	Very, very light RPE# < 1	• Activities that usually involve sitting or lying and that have little additional movement and a low energy requirement
LIGHT	40 to <55% HRmax	Very light to light RPE# 1-2	• An aerobic activity that does not cause a noticeable change in breathing rate • An intensity that can be sustained for at least 60 minutes
MODERATE	55 to <70% HRmax	Moderate to somewhat hard RPE# 3-4	• An aerobic activity that is able to be conducted whilst maintaining a conversation uninterrupted • An intensity that may last between 30 and 60 minutes
VIGOROUS	70 to <90% HRmax	Hard RPE# 5-6	• An aerobic activity in which a conversation generally cannot be maintained uninterrupted • An intensity that may last up to about 30 minutes
HIGH	≥ 90% HRmax	Very hard RPE# ≥ 7	• An intensity that generally cannot be sustained for longer than about 10 minutes

= Borg's Rating of Perceived Exertion (RPE) scale, category scale 0-10

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ADULT PRE-EXERCISE SCREENING TOOL

STAGE 2 (OPTIONAL)

Name: ______________________________

Date of Birth: ____________________ Date: ____________________

AIM: To identify those individuals with risk factors or other conditions to assist with appropriate exercise prescription. This stage is to be administered by a qualified exercise professional.

		RISK FACTORS
1. Age ______ Gender ______	≥ 45yrs Males or ≥ 55yrs Females +1 risk factor	
2. Family history of heart disease (eg: stroke, heart attack) Relative / Age / Relative / Age ☐ Father ____ ☐ Mother ____ ☐ Brother ____ ☐ Sister ____ ☐ Son ____ ☐ Daughter ____	If male < 55yrs = +1 risk factor If female < 65yrs = +1 risk factor Maximum of 1 risk factor for this question	
3. Do you smoke cigarettes on a daily or weekly basis or have you quit smoking in the last 6 months? Yes No If currently smoking, how many per day or week? ______	If yes, (smoke regularly or given up within the past 6 months) = +1 risk factor	
4. Describe your current physical activity/exercise levels: Sedentary ☐ Light ☐ Moderate ☐ Vigorous ☐ Frequency (sessions per week) ____ ____ ____ Duration (minutes per week) ____ ____ ____	If physical activity level < 150 min/ week = +1 risk factor If physical activity level ≥ 150 min/ week = -1 risk factor (vigorous physical activity/ exercise weighted x 2)	
5. Please state your height (cm) ______ weight (kg) ______	BMI = ______________ BMI ≥ 30 kg/m^2 = +1 risk factor	
6. Have you been told that you have high blood pressure? Yes No	If yes, = +1 risk factor	
7. Have you been told that you have high cholesterol? Yes No	If yes, = +1 risk factor	
8. Have you been told that you have high blood sugar? Yes No	If yes, = +1 risk factor	

Note: Refer over page for risk stratification.

STAGE 2 Total Risk Factors = ______

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9. Have you spent time in hospital (including day admission) for any medical condition/illness/injury during the last 12 months? Yes No	If yes, provide details
10. Are you currently taking a prescribed medication(s) for any medical conditions(s)? Yes No	If yes, what is the medical condition(s)?
11. Are you pregnant or have you given birth within the last 12 months? Yes No	If yes, provide details. I am ______ months pregnant or postnatal (circle).
12. Do you have any muscle, bone or joint pain or soreness that is made worse by particular types of activity? Yes No	If yes, provide details

STAGE 3 (OPTIONAL)

AIM: To obtain pre-exercise baseline measurements of other recognised cardiovascular and metabolic risk factors. This stage is to be administered by a qualified exercise professional. (Measures 1, 2 & 3 – minimum qualification, Certificate III in Fitness; Measures 4 and 5 minimum level, Exercise Physiologist*).

	RESULTS		RISK FACTORS
1. BMI (kg/m²)		BMI ≥ 30 kg/m² = +1 risk factor	
2. Waist girth (cm)		Waist > 94 cm for men and > 80 cm for women = +1 risk factor	
3. Resting BP (mmHg)		SBP ≥140 mmHg or DBP ≥90 mmHg = +1 risk factor	
4. Fasting lipid profile*		Total cholesterol ≥ 5.20 mmol/L = +1 risk factor	
Total cholesterol		HDL cholesterol >1.55 mmol/L = -1 risk factor	
HDL		HDL cholesterol < 1.00 mmol/L = +1 risk factor	
Triglycerides		Triglycerides ≥ 1.70 mmol/L = +1 risk factor	
LDL		LDL cholesterol ≥ 3.40 mmol/L = +1 risk factor	
5. Fasting blood glucose*		Fasting glucose ≥ 5.50 mmol = +1 risk factor	

STAGE 3 Total Risk Factors =

RISK STRATIFICATION

Total stage 2
or
Total stage 3
Plus stage 2 (Q1 - Q4)

≥ 2 RISK FACTORS – MODERATE RISK CLIENTS
Individuals at moderate risk may participate in aerobic physical activity/exercise at a light or moderate intensity (Refer to the exercise intensity table on page 2)

< 2 RISK FACTORS – LOW RISK CLIENTS
Individuals at low risk may participate in aerobic physical activity/exercise up to a vigorous or high intensity (Refer to the exercise intensity table on page 2)

Note: If stage 3 is completed, identified risk factors from stage 2 (Q1-4) and stage 3 should be combined to indicate risk. If there are extreme or multiple risk factors, the exercise professional should use professional judgement to decide whether further medical advice is required.

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Adult Pre-Exercise Screening System ©Exercise and Sports Science Australia, Sports Medicine Australia and Fitness Australia. Image courtesy of ESSA www.essa.org.au

INFORMED CONSENT

Informed consent is a process designed to minimise the risk of harm to both the performer and the test administrator. It can be represented by the flow chart at the bottom of the page. An example of an informed consent form from the Australian Sports Commission can be found below.

Often information about the test will be sent to the participant in advance. This should explain the nature and purpose of the test, and any risks involved. Before commencing the test, the participant must be given the opportunity to ask questions and should also be aware that they can withdraw their consent at any time before or during the test.

FORM 2.4 Informed Consent

I (print name), ______________________________, consent to participate in the physiological assessment on the following terms:

1. I have read the Explanation of Physiological Assessment Procedures attached and understand what I will be required to do. I have had the opportunity to ask questions and have received satisfactory explanations about the tests being conducted.
2. I understand that I will be undertaking physical exercise at or near the extent of my capacity and there is possible risk in the physical exercise at this level, such as episodes of transient light-headedness, fainting, abnormal blood pressure, chest discomfort, and nausea.
3. I understand that this may occur although the staff in the laboratory will take all and proper care in the conduct of the assessment, and I fully assume the risk.
4. I understand that I can withdraw my consent, freely and without prejudice, at any time before, during, or after testing.
5. I have told the person conducting the assessment of any illness or physical defect I have that may contribute to the level of that risk.
6. I understand that the information obtained from the test will be treated confidentially with my right to privacy assured. However, the information may be used for statistical or science reasons with privacy retained. (Note: Members of sports teams should have made special arrangements about treatment of individual data with team coach or manager.)
7. I release this laboratory and its employees from any liability for any injury or illness that I may experience during this assessment as well as any subsequent injury or illness that is connected to or to any extent influenced by the assessment.
8. I will indemnify this laboratory in respect to any liability it may incur in relation to any other person in connection with the assessment.
9. I hereby agree that I will present myself for testing in a suitable condition having abided by the requirements for diet and activity prescribed to me by laboratory staff.

Participant signature: ______________________________ Date ____________________

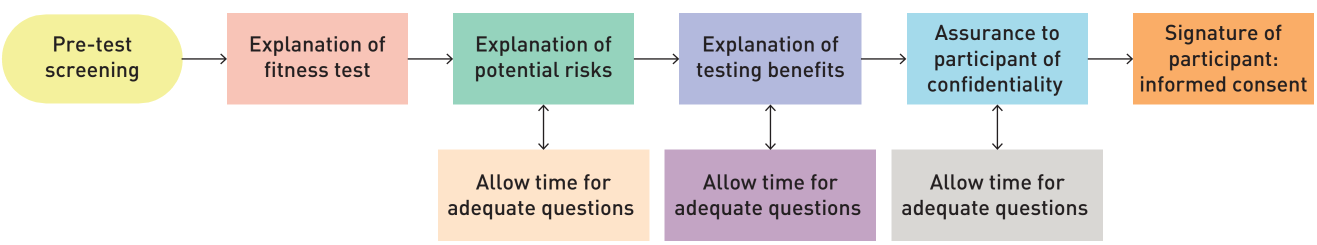
Parent/guardian name (required if age less than 16)

Signature ______________________________ Date ____________________

Witness name:

Signature ______________________________ Date ____________________

Source: Australian Institute of Sport, 2013



Informed consent process

CHAPTER CHECK-UP

1 According to the Australian Sports Commission (see page 246), what are some of the potential risks associated with fitness testing?
2 Why would a performer continue with testing when they have been made aware of some of these potential risks?
3 In the flow chart on the previous page, three opportunities for the performer to ask questions are emphasised. Why is this so important?
4 If sporting clubs do not follow the informed consent flow chart, discuss two possible consequences.

FITNESS ASSESSMENT PROTOCOLS

Protocols are the rules or procedures associated with fitness testing. Specific testing protocols, which state how each test should be conducted, will be discussed later in the chapter. There are also some very important generic testing protocols that apply to all testing. These include:

» validity
» reliability
» accuracy
» informed consent.

Validity

Is the test measuring what it claims? There is an array of both laboratory and field tests to measure aerobic power, including VO_2 max tests and the 20-metre shuttle run. A 50-metre sprint test would not be a valid test of aerobic power!

Several fitness components have what is known as **gold standard tests**. Generally, these are laboratory based, such as a VO_2 max test. Field tests are often validated, or compared, against these gold standard tests to ensure their stated objective is measuring what it claims. The 20-metre shuttle run test **correlates** successfully as an aerobic power test.

Reliability

Will the chosen test produce consistent results? That is, if the test is performed multiple times in succession (assuming appropriate recovery, etc.) will the same result be obtained? External factors such as time of day, nutritional status and facility can all impact on the reliability of the testing protocol. To increase **reliability**, the following points should be considered:

» Tests should be conducted at the same time of day.
» The same warm-up should be conducted before each specific test.

- The same order of testing should be completed; this should include prioritising ATP–PC dominated tests, such as the vertical jump test, to minimise the effects of fatigue.
- There should be similar environmental conditions whenever possible, such as temperature, humidity, indoors or outdoors, etc.
- There should be similar nutrition and hydration levels; these should be part of a performer's daily routine.
- The performer is well rested prior to testing.
- The same equipment, clothing and footwear are used.
- The same test is used for the specific fitness component.
- The performer's health status is unchanged.
- The performer's activity levels prior to testing are similar, if not the same.

For elite athletes, a pre-testing routine involving many of the points above is often prescribed to ensure reliability of testing results.

Accuracy

To increase reliability, testing also needs to be accurate. Elite testing is generally performed in sports science laboratories. The cost of the equipment is beyond the scope of most sporting organisations, and trained professionals are required to carry out testing. To guarantee accuracy, the testing equipment needs to be regularly calibrated and maintained. The Australian Sports Commission provides a quality assurance scheme for interested sports science laboratories to standardise testing protocols, ensuring that testing integrity is maintained.

Field testing can be inaccurate if specific testing protocols are not followed. An example involves the 20-metre shuttle run test. If the performer does not make the line twice in a row, they should be removed from the test. If this is not followed stringently then different results could be obtained, diminishing the accuracy of the testing.

Timing gates, used for speed testing, are too expensive for most sporting organisations. Hand-held timers are the usual substitute. In this instance, accuracy would be improved by the same person performing the timing for both pre- and post-tests, using the same procedure. Timing variations in a 10-metre sprint test can make a huge difference to the result.

CHAPTER CHECK-UP

1. Distinguish between validity and reliability.
2. Rank in order of priority four considerations to increase reliability.
3. Justify your highest ranked consideration to increase reliability.
4. The Harvard step test is being used less frequently as a field test to assess aerobic power. It has a correlation of between 0.6 and 0.8 as a measure of aerobic power – in other words, it is only 60–80 per cent 'accurate'. Discuss two likely reasons for its demise as a field test.

TYPES OF FITNESS ASSESSMENT

Laboratory and field testing

Sports science laboratory testing is usually reserved for elite performers, where accuracy in fitness testing is paramount. 'Gold standard' tests, performed by sports scientists, are readily available in this setting. The cost of facilities, equipment and maintenance is very high, which generally makes it prohibitive to test anyone other than elite performers.

Field testing can still be very functional and accurate, provided the protocols discussed earlier are followed. The advantage of field testing is that several people can be tested at once. For example, the 20-metre shuttle run test is only limited by the number of people who can fit into the available space! Most people would be familiar with field testing from their school or local sporting club environment.

Maximal and submaximal testing

A maximal test is one that is performed as close as possible to exhaustion. **Maximal testing** is often associated with laboratory testing, such as a VO_2 max test or Wingate anaerobic test. Field tests can also be maximal, as athletes who have undertaken the 20-metre shuttle run test will confirm! The 20-metre shuttle run is not a maximal test if athletes drop out a couple of shuttles before pushing themselves and reaching their maximum result.

Submaximal tests are those that are not performed to exhaustion. An example of a submaximal aerobic test is the PWC_{170}, performed on a bicycle ergometer. In this test the intensity on the bike ergometer is increased until the performer reaches a heart rate of 170 bpm. The performer's VO_2 max can then be predicted. This is based on the fact that heart rate and oxygen consumption increase linearly as intensity increases. The performer's VO_2 max is extrapolated from this relationship.

FYI

PWC is an abbreviation for Physical Work Capacity. Two variations of this test include the PWC_{75}, where exercise is terminated at 75% of predicted maximum heart rate, and the PWC_{130}, which is appropriate for the elderly.

Direct and indirect testing

Direct testing, as the name implies, directly measures the function of a fitness component. An obvious example is a VO_2 max test that directly measures a person's aerobic power. Conversely, the Cooper's 12-minute run, while also a maximal test if done to exhaustion, indirectly predicts a person's VO_2 max and their aerobic power.

Indirect fitness assessment is based on the use of predictive measures and equations linked to norms to estimate fitness levels.

Selecting fitness tests

It is possible to individually assess one fitness component. This may be appropriate in a very specific sporting scenario (i.e. VO_2 max testing for an endurance athlete to establish aerobic power) or for rehabilitation purposes (i.e. flexibility testing after reconstructive surgery).

In most team sport scenarios and in many individual sporting pursuits, a coach and/or performer will build a fitness profile. Several different fitness tests will be used to assess the various fitness components for the required profile. This group of tests is usually referred to as a **fitness test battery**.

In selecting the tests to be used in the fitness test battery, the following points need to be considered

- specificity
- result comparison.

Specificity

When assessing the various fitness components for a chosen sport, it is important to keep the testing as specific as possible to the requirements established in a games or activity analysis (see chapter 10). For example, a 50-metre sprint test for speed is not very specific to the explosive distances sprinted by a netballer; a 10- or 15-metre sprint test would be more specific to their requirements. If assessing aerobic power for a Tour de France cyclist such as Richie Porte, then a VO_2 max test on a bicycle would be more specific than a similar test on a treadmill.

Specificity should also take into consideration both the age and ability of the participant. There may be little value in assigning a specific fitness test to a participant who will not be able to achieve some level of success, e.g. a VO_2 max test on a bicycle ergometer for a participant about to start training for the 210-kilometre section of the 'Around the Bay' cycling event. Is their fitness level suitable to undertake this test, or would a PWC_{170} submaximal test on a bicycle be more suitable? Another consideration would be whether either test is affordable.

Result comparison

There are two ways that results can be compared: normative tests, and criterion-based tests.

Normative tests

Normative data, or 'norms', represent the distribution of results of a particular reference group. These results are typically based on **percentiles**, where a performer's result is compared to the group. A subject who scores at the 80th percentile has achieved a result better than 80 per cent of the reference group; 20 per cent of the group achieved a higher result. When comparing to norms, it is important to compare to similar reference groups. General population norms, such as those in this book, are appropriate for the majority of participants. However, elite talent, such as those testing for the AFL draft, will use norms based on previous combined draft results. General population norms would be irrelevant for these participants.

When considering the use of norms, particularly in adolescent participants, results generally favour those who are already advanced, fitness-wise, in the particular test. Conversely, those participants who are less advanced may become discouraged by their performance.

Criterion-based tests

Some tests use a criterion-referenced approach to standards, such as body mass index (BMI), waist circumference or blood-pressure readings, rather than a rating. The goal of the criterion-referenced approach is to identify a level of fitness appropriate for health promotion. With sufficient levels of physical activity, all students should be able to achieve an acceptable level. Using this method of testing, comparison with others is irrelevant. Results are based on meeting acceptable parameters for improved health, and do not depend on the performance of a population group.

Referencing to existing data may not always be possible, such as with the various Yo-Yo tests, which lack normative data at present. A coach, personal trainer, or even an individual may be using a specifically designed or customised test, or the normative reference group may not be appropriate, or may be out of date in terms of when the norms were established. Provided that the test is both valid and reliable, these results will still be valuable in a pre- and post-test scenario to assess the success of the training regime.

In selecting a fitness testing battery it is important to consider sequencing of tests. Where possible, avoid two maximal tests in a row, as the fatigue from one test may have a carryover effect on the next test, diminishing the subsequent test's reliability. For example, performing a 20-metre shuttle run test and phosphate recovery test on the same day will not allow the best possible outcome for both tests.

Finally, resourcing will also affect the choice of tests available for a testing battery. Resources include facilities, access to testing equipment, and the appropriate staff to execute the testing.

CHAPTER CHECK-UP

1 For each of the following aerobic power tests, classify them as laboratory or field, maximal or submaximal, direct or indirect: VO_2 rowing ergometer test, 20-metre shuttle run test, Cooper's 12-minute run, 1.6-kilometre run, PWC_{130} and Yo-Yo Intermittent Recovery test.
2 Other than for the elderly, when may it be more appropriate to use the PWC_{130} test?
3 Distinguish between norm-referenced and criterion-referenced results.
4 What care needs to be taken when using norm-referenced data?

FITNESS TESTS FOR THE COMPONENTS OF FITNESS

The fitness tests listed in Table 11.2 are available for assessing performance in each of the components of fitness. The testing protocols for those tests marked with a page reference are outlined in this chapter.

These tests have been chosen for the following reasons:

» They are easy to administer.
» They require minimal equipment.
» Norms are generally available for rating performance.

TABLE 11.2 Fitness component tests

Component of fitness	Fitness test	Page reference
Aerobic power	VO_2 max	
	20-metre shuttle run test	254
	Cooper's 12-minute run	256
	1.6-kilometre run	257
	Yo-Yo Intermittent Recovery test	258
	Harvard step test	
	PWC_{170}	
Anaerobic capacity	Phosphate recovery test	260
	300-metre shuttle run test	267
	Running-based anaerobic sprint test (RAST)	262
	30-second Wingate test	263
Muscular strength	Handgrip dynamometer strength test	263
	1RM bench press test	264
	1RM leg press test	264
	7-stage abdominal strength test	265

TABLE 11.2 (*continued*)

Component of fitness	Fitness test	Page reference
Muscular endurance	Partial curl-ups	265
	Timed sit-ups	266
	Timed push-ups	266
	Pull-up tests	267
	Flexed-arm hang test	267–268
	30-second endurance jump	268
	Multistage hurdle jump test	269
Flexibility	Modified sit-and-reach test	269
	Shoulder and wrist elevation test	271
	Trunk and neck extension test	271
	Ankle extension test	271
	Shoulder rotation test	271–272
	Ankle (dorsi) flexion test	272
	Groin flexibility test	272
Body composition	BMI	273
	Waist circumference	274
	Sum of skin folds	274
	Percentage body fat	
Muscular power	Vertical jump test	275
	Standing long jump test	276
	Seated basketball throw	277
	Kneeling power ball chest launch	278
Speed	35-metre sprint test	279
	50-metre sprint test	279
Agility	Illinois agility test	279
	SEMO agility test	280
Coordination	Alternate hand wall toss test	
	Soft-drink can test	
Balance	Stork stand balance test	
	Standing balance test	
Reaction time	Ruler drop reaction test	

Aerobic power tests

There are a multitude of tests available to measure, or predict, aerobic power. The 'gold standard' for directly assessing aerobic power is through a VO_2 maximum laboratory test where gas analysis is used to determine oxygen utilisation.

VO_2 max tests can be performed on a treadmill, bicycle ergometer, rowing ergometer or swimming plume. In these types of tests the performer exercises to exhaustion, with a gas analysis machine determining the precise amount of oxygen being used; that is, the maximum volume of oxygen that a performer can intake, transport and utilise – known as the VO_2 maximum. This is measured in millilitres of oxygen consumed per minute per kilogram of body weight (mL/min/kg). Heart rate data, which directly increases with exercise intensity, is also recorded during this test.

Advantages and disadvantages of VO_2 tests

Advantages of a VO_2 maximum test include:

» It permits precise measurement of VO_2 maximum.

» Maximum heart rate can be accurately established simultaneously. (This is important, as the use of maximum heart rate predictions such as 220 – age have an error of ± 12 beats per minute.)

» The performer's lactate inflection point (LIP) as a given percentage of their VO_2 max, as well as for a corresponding heart rate, can be predicted.

» Training programs utilising heart-rate training zones can now be accurately tailored for a performer.

Disadvantages of VO_2 maximal testing include:

» Trained professionals in a laboratory setting are required to perform the test.

» Testing is time- and labour-intensive; only one person can be tested at a time.

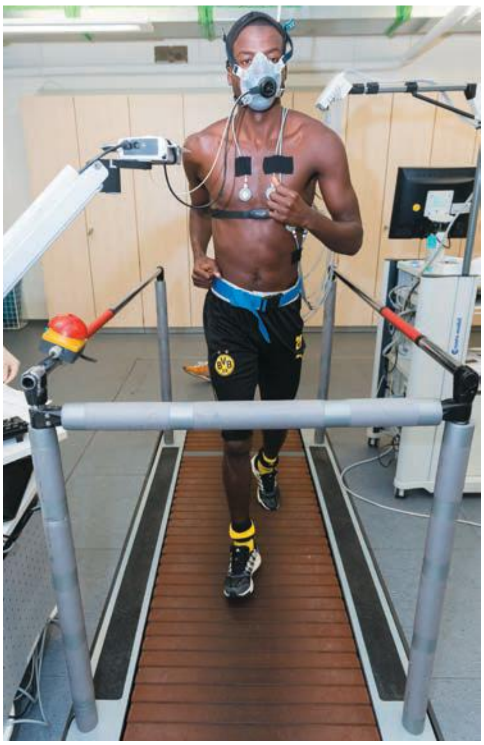
» There is limited availability of testing venues.

VO_2 max tests are generally only performed by elite performers who require precise information, as there are several less expensive and stressful tests available that will accurately predict a person's VO_2 maximum.

FYI

Absolute VO_2 is the maximum amount of oxygen (in litres) that a person can consume in one minute, and is represented as L/min. VO_2 maximums are always represented as relative measures such as mL/min/kg, taking into consideration the participant's weight. This allows equitable comparison between two individuals of different, or similar weight, and therefore relative effective oxygen intake, transport and utilisation per kilogram of body weight.

Getty Images/Alexandre Simoes



Science Photo Library/ARNO MASSEE

How is the principle of specificity being applied in these VO_2 max tests?

QUICKVID

Weblink

You can watch a quick video on what to expect in a VO_2 max test via http://vcepe34.nelsonnet.com.au.

20-metre shuttle run test

The 20-metre shuttle run test, or **beep test**, as it is commonly known, is the dominant field test in Australia for predicting aerobic power.

It has several advantages as a field test, including:

» Correlation with VO_2 max tests is very high.

» The test increases work rate every minute by decreasing the time between beeps, compelling the participant to keep up with the increase in speed, and thereby intensity. This eliminates the need for pacing, such as in the Cooper's 12-minute run (page 256).

» As the test increases in intensity it will allow someone who is less aerobically fit to discontinue the test earlier, giving them longer to recover if further activities have been planned.

» Whole teams can perform the test at the one time; space is the only limiting factor.

» As for all aerobic power field tests, it is cost-effective compared to completing a VO_2 max test in a laboratory.

Disadvantages: while extremely accurate, it is still only a prediction, as are all aerobic field tests. Some sports teams, particularly overseas soccer clubs, prefer to use the Yo-Yo Intermittent Test (page 258) as it more closely resembles the demands of intermittent sport.

LABORATORY

20-METRE SHUTTLE RUN TEST ('BEEP' TEST)

AIM

To follow the progressively increasing pace over a 20-metre course for as long as possible

EQUIPMENT

A CD or media player, a CD with the appropriate signals recorded, a tape measure and a suitable area for testing

BEFORE THE TEST

- Do not eat for two hours before the test.
- Do not drink for 15 minutes before the test.
- Wear suitable clothing and footwear.
- Avoid heavy exercise the day before.
- If you have any doubt about your health, ensure that you consult your doctor before taking the test.

METHOD

Draw two lines on the course, 20 metres apart. The subject runs backwards and forwards between the lines. At each signal, the subject must have reached one of the 20-metre lines. Upon hearing the signal, they reverse direction by pivoting on the line and running to the other line in time for the next signal. If the subject is not within two strides of the line when the signal sounds, and this happens twice in a row, they must remember the last number announced. This is the subject's stage level and equates to their score (see Table 11.3 on page 255).

DURING THE TEST

- Do the best you can. Remember, this is a maximal-effort field test.
- STOP THE TEST if you feel dizziness, pain or nausea.
- Remember the last stage announced on the tape when you stop – this is your result.

RESULTS

Refer to Table 11.4 and convert your stage level and shuttle number to your VO_2 max. For example, if the last number you heard was level seven shuttle number six, then your predicted VO_2 max is 38.5 mL/min/kg.

NORMS

Use Table 11.5 (males) or Table 11.6 (females) to find your fitness category. Being at the 80th percentile means that 80 per cent of the population achieved below you and 20 per cent above. The 50th percentile score and the mean average are very similar.

>

TABLE 11.3 Shuttles per level, speed per level and time per shuttle for the 20-metre shuttle run test

Level	Shuttles	Speed (km/h)	Shuttle time (s)	Level	Shuttles	Speed (km/h)	Shuttle time (s)
1	7	8.0	9.0	12	12	14.0	5.14
2	8	9.0	8.0	13	13	14.5	4.97
3	8	9.5	7.58	14	13	15.0	4.80
4	9	10.0	7.20	15	13	15.5	4.65
5	9	10.5	6.86	16	14	16.0	4.50
6	10	11.0	6.55	17	14	16.5	4.36
7	10	11.5	6.26	18	15	17.0	4.24
8	11	12.0	6.00	19	15	17.5	4.11
9	11	12.5	5.76	20	15	18.0	4.00
10	11	13.0	5.54	21	16	18.5	3.89
11	12	13.5	5.33				

Source: Courtesy of Topend Sports, www.topendsports.com

TABLE 11.4 Predicted maximum oxygen uptake (VO_2 max) in mL/min/kg for the 20-metre shuttle run test

Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max
4	2	26.8	9	2	43.9	14	2	61.1	18	2	74.8
4	4	27.6	9	4	44.5	14	4	61.7	18	4	75.3
4	6	28.3	9	6	45.2	14	6	62.6	18	6	75.8
4	9	29.5	9	11	46.8	14	8	62.7	18	8	76.2
						14	10	63.2	18	10	76.7
5	2	30.2	10	2	47.4	14	13	64.0	18	12	77.2
5	4	31.0	10	4	48.0				18	15	77.9
5	6	31.8	10	6	48.7	15	2	64.6			
5	9	32.9	10	8	49.3	15	4	65.1	19	2	78.3
			10	11	50.2	15	6	65.6	19	4	78.8
6	2	33.6				15	8	66.2	19	6	79.2
6	4	34.3	11	2	50.8	15	10	66.7	19	8	79.7
6	6	35.0	11	4	51.4	15	13	67.5	19	10	80.2
6	8	35.7	11	6	51.9				19	12	80.6
6	10	36.4	11	8	52.5	16	2	68.0	19	15	81.3
			11	10	53.1	16	4	68.5			
7	2	37.1	11	12	53.7	16	6	69.0	20	2	81.8
7	4	37.8				16	8	69.5	20	4	82.2
7	6	38.5	12	2	54.3	16	10	69.9	20	6	82.6
7	8	39.2	12	4	54.8	16	12	70.5	20	8	83.0
7	10	39.9	12	6	55.4	16	14	70.9	20	10	83.5
			12	8	56.0				20	12	83.9
8	2	405	12	10	56.5	17	2	71.4	20	14	84.3

TABLE 11.4 *(continued)*

Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max	Level	Shuttle	Predicted VO_2 max
8	4	41.1	12	12	57.1	17	4	71.9	20	16	84.8
8	6	41.8				17	6	72.4			
8	8	42.4	13	2	57.6	17	8	72.9	21	2	85.2
8	11	43.3	13	4	58.2	17	10	73.4	21	4	85.6
			13	6	58.7	17	12	73.9	21	6	86.1
			13	8	59.3				21	8	86.5
			13	10	59.8				21	10	86.9
			13	13	60.6				21	12	87.4
									21	14	87.8
									21	16	88.2

Source: *British Journal of Sports Medicine* by British Association of Sport and Medicine, reproduced with permission of BMJ Publishing Group via Copyright Clearance Center.

TABLE 11.5 Male fitness ratings for the 20-metre shuttle run test

Age	Very poor	Poor	Fair	Average	Good	Very good	Excellent
12–13	< 3/3	3/4–5/1	5/2–6/4	6/5–7/5	7/6–8/8	8/9–10/9	> 10/9
14–15	< 4/7	4/7–6/1	6/2–7/4	7/5–8/9	8/10–9/8	9/9–12/2	> 12/2
16–17	< 5/1	5/1–6/8	6/9–8/2	8/3–9/9	9/10–11/3	11/4–13/7	> 13/7
18–25	< 5/2	5/2–7/1	7/2–8/5	8/6–10/1	10/2–11/5	11/6–13/10	> 13/10

Source: Courtesy of Topend Sports, www.topendsports.com

TABLE 11.6 Female fitness ratings for the 20-metre shuttle run test

Age	Very poor	Poor	Fair	Average	Good	Very good	Excellent
12–13	< 2/6	2/6–3/5	3/6–5/1	5/2–6/1	6/2–7/4	7/5–9/3	> 9/3
14–15	< 3/3	3/3–5/2	5/3–6/4	6/5–7/5	7/6–8/7	8/8–10/7	> 10/7
16–17	< 4/2	4/2–5/6	5/7–7/1	7/2–8/4	8/5–9/7	9/8–11/10	> 11/11
18–25	< 4/5	4/5–5/7	5/8–7/2	7/3–8/6	8/7–10/1	10/2–12/7	> 12/7

Source: Courtesy of Topend Sports, www.topendsports.com

Cooper's 12-minute run

Before the 20-metre shuttle run test became popular, the Cooper's 12-minute run was an extremely popular test to measure aerobic power. Like all aerobic power field tests, it is cost-effective.

This test involves running as far as possible in 12 minutes. The further you can run, the higher your level of aerobic power. You should do this test on a 400-metre track that has been measured out in 20-metre intervals.

The major disadvantage of this test is that a performer must hold their highest intensity for the full 12 minutes to ensure the reliability of the test. However, the ability to run for the full 12 minutes seems to be difficult for many performers. To get ratings for the 12-minute run for males and females, follow the link at http://vcepe34.nelsonnet.com.au.

Weblink

1.6-kilometre run test

The 1.6-kilometre run test employs a similar testing protocol to the Cooper's 12-minute run, except participants cover a set distance using a 400-metre track. The test is usually completed in a shorter time than the 12-minute run.

The advantage of this test over the 12-minute run is that it may be easier for performers to pace themselves over four laps. The disadvantage is that the fitter aerobic power performers will finish first. This may reduce the recovery time of the less-fit performers if there are other activities to follow. Tables 11.7 and 11.8 present norms for the 1.6-kilometre run test.

FYI

VO_2 maximum can also be predicted from the Cooper's 12-minute run by applying the following formula: VO_2 max = (22.351 × kilometres) – 11.288

TABLE 11.7 1.6-kilometre run: male norms

Percentile	12	13	14	15	16	17+
100	6:03	5:40	4:30	4:42	4:49	4:46
95	6:43	6:25	6:01	5:50	5:40	5:35
90	6:57	6:39	6:13	6:07	5:56	5:57
85	7:11	6:50	6:26	6:20	6:08	6:06
80	7:25	7:00	6:33	6:29	6:18	6:14
75	7:41	7:11	6:45	6:38	6:25	6:23
70	7:56	7:20	6:59	6:48	6:33	6:32
65	8:05	7:29	7:09	6:57	6:44	6:40
60	8:14	7:41	7:19	7:06	6:50	6:50
55	8:25	7:55	7:29	7:16	6:58	6:57
50	8:40	8:06	7:44	7:30	7:10	7:04
45	8:58	8:17	7:59	7:39	7:20	7:14
40	9:11	8:35	8:13	7:52	7:35	7:24
35	9:40	8:54	8:30	8:08	7:53	7:35
30	10:00	9:10	8:48	8:29	8:09	7:52
25	10:22	9:23	9:10	8:49	8:37	8:06
20	10:52	10:02	9:35	9:05	8:56	8:25
15	11:30	10:39	10:18	9:34	9:22	8:56
10	12:11	11:43	11:22	10:10	10:17	9:23
5	13:14	12:47	12:11	11:25	11:49	10:15
0	23:05	24;12	18:10	21:44	20:15	16:49

Source: Courtesy of The President's Challenge Physical Activity & Fitness Awards Program, U.S. Department of Health and Human Services, www.presidentschallenge.org

TABLE 11.8 1.6-kilometre run: female norms

Percentile	12	13	14	15	16	17+
100	6:22	5:42	5:00	5:51	5:58	6:20
95	7:35	7:21	7:20	7:25	7:26	7:22
90	8:00	7:49	7:43	7:52	7:55	7:58

TABLE 11.8 (*continued*)

Percentile	12	13	14	15	16	17+
85	8:23	8:13	7:59	8:08	8:23	8:15
80	8:52	8:29	8:20	8:24	8:39	8:34
75	9:15	8:49	8:36	8:40	8:50	8:52
70	9:36	9:09	8:50	8:55	9:11	9:15
65	10:05	9:30	9:09	9:09	9:25	9:33
60	10:26	9:50	9:27	9:23	9:48	9:51
55	10:44	10:07	9:51	9:37	10:09	10:08
50	11:05	10:23	10:06	9:58	10:31	10:22
45	11:23	10:57	10:25	10:18	10:58	10:48
40	11:47	11:20	10:51	10:40	11:15	11:05
35	12:01	11:40	11:10	11:00	11:44	11:20
30	12:24	12:00	11:36	11:20	12:08	12:00
25	12:46	12:29	11:52	11:48	12:42	12:11
20	13:35	13:01	12:18	12:19	13:23	12:40
15	14:12	14:10	12:56	13:33	14:16	13:03
10	14:39	14:49	14:10	14:13	16:03	14:01
5	16:00	16:10	15:44	15:17	18:00	15:14
0	24:54	20:45	20:04	24:07	21:00	28:50

Source: Courtesy of The President's Challenge Physical Activity & Fitness Awards Program, U.S. Department of Health and Human Services, www.presidentschallenge.org

Yo-Yo Intermittent Recovery test levels 1 & 2

The Yo-Yo Intermittent Recovery test is a very popular test of aerobic power in the UK and Europe. The test was developed by Danish soccer physiologist Jens Bangsho and his colleagues. The goal was to establish a field test that more closely resembled the intermittent demands of soccer; that is, the ability to perform repeated high-intensity activity relying on a combination of both aerobic and anaerobic energy supply.

There are two variations to the Yo-Yo test; the Yo-Yo Intermittent Recovery test, with an active recovery of 10 seconds to walk/jog 5 metres, and the Yo-Yo Intermittent Endurance test, with an active recovery of 5 seconds to walk/jog 2.5 metres. Each test has two levels. The level 1 test is aimed at recreational performers starting at 10 kilometres per hour, while the level 2 test is directed towards more elite performers commencing at 13 kilometres per hour.

While norms are limited, the web offers comparisons to many of the world's leading soccer players and intermittent team sports.

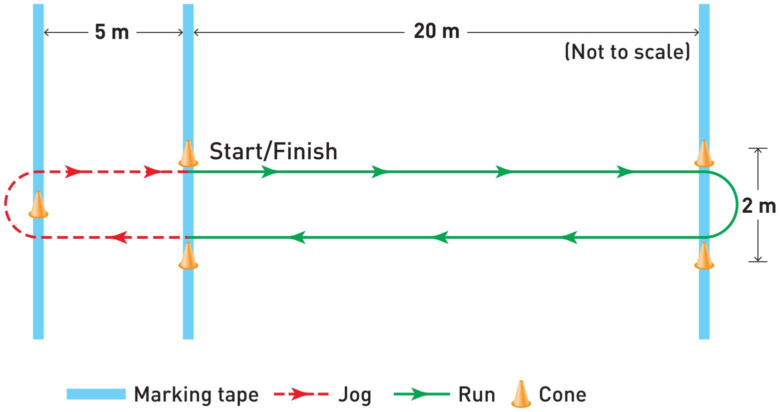
The following testing protocol has been supplied courtesy of the National Sport Science Quality Assurance (NSSQA) Program at the Australian Institute of Sport.

Equipment

- measuring tape
- marking tape and cones
- CD player
- test CD
- recording sheets

Test set-up

1 Using a measuring tape and marking tape, measure out a 20-metre test course. Mark a line at 0 metres and a line at 20 metres.
2 At each end of the course, place two markers spaced 2 metres apart horizontally.
3 In addition to the 20-metre line, measure out a 5-metre distance behind the 0-metre line.
4 Place a marker on the 5-metre line, in the middle of the two 0-metre line markers, as shown below. The markers should be parallel to each other along the marked lines. Ensure that there is one course set up per athlete.



Set-up for Yo-Yo Intermittent Recovery test

Source: Kate Fuller, National Sport Science Quality Assurance (NSSQA) Program, Australian Institute of Sport

Procedure

1 Instruct athletes to line up on the 0-metre line.
2 Start playing the Yo-Yo test CD.

Note: There are two levels for this test: level 1 and level 2. Currently, the standard testing criteria are level 1. If an athlete is able to run faster than the speed-level 23, they should perform the level 2 test on the next occasion.

3 At the first signal, athletes run towards the 20-metre line. At the sound of the second signal, athletes should arrive at the 20-metre line and then turn and run back to the 0-metre line, arriving on the next beep. When the start marker is passed (0 metres), the athletes continue forward at a reduced pace (jogging) towards the 5-metre mark, where they then make a turn around the cone and return to the start line. At this point the athletes stop and wait for the next signal to sound.

Note: Athletes are required to place one foot either on or behind the 0-metre, 5-metre and 20-metre lines at the start and end of each test interval.

4 Athletes should continue running for as long as possible, until they are unable to maintain the speed indicated by the CD.
5 The end of the test is indicated by the inability of an athlete to maintain the required pace for two successive trials. The first time the start marker is not reached, a warning is given. The second time, the athlete must withdraw.
6 When the athlete withdraws, the last speed and the number of 2 × 20-metre intervals performed at this speed are recorded. (N.B. The last 2 × 20-metre interval is included, even if the athlete has not made the complete distance.)
7 Upon completion of the test, all athletes should warm down.

8 The final Yo-Yo Intermittent Recovery speed and interval score obtained by each athlete is used to calculate the total distance covered by the athlete during the test (refer to the Yo-Yo Calculator to calculate the corresponding total distance attained for Level 1 and Level 2).

Note: The Yo-Yo Intermittent Recovery test is effort dependent, so for valid results athletes must attempt to reach the highest level possible before stopping. Verbal encouragement should be given to the athletes throughout the test.

(While comparative data is not available at present, the test could still be used to assess the effectiveness of a training program through pre- and post-testing.)

FYI

There is an abundance of results for the Yo-Yo test available online for sports such as soccer.

Anaerobic capacity tests

Anaerobic capacity tests can be used for two purposes.

1 Where there is a recovery period involved between repetitions, such as in the phosphate recovery, the test measures the PC system's ability to replenish its high-energy phosphate bonds in order to dominate the next repetition.

2 If there is no recovery period, such as in the 300-metre shuttle run, the test measures the ability of the two anaerobic systems to supply high-intensity energy over a relatively short time.

Phosphate recovery test

Aim

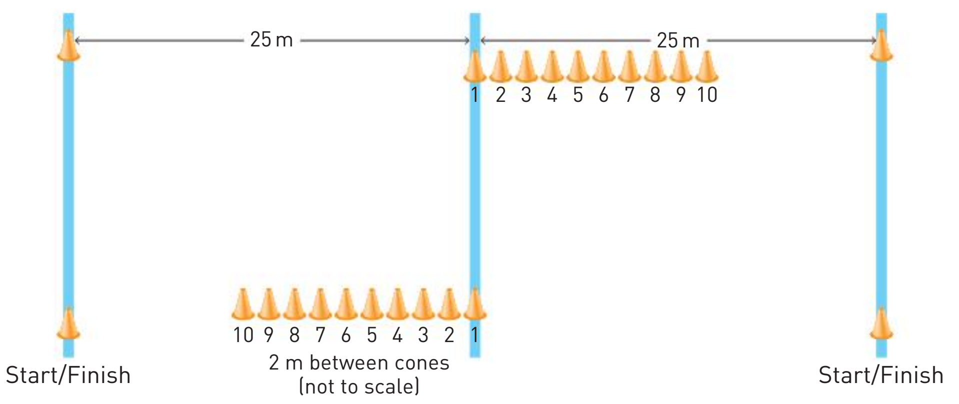
To challenge the ability of the body to replenish high-energy phosphates in between each repetition of the test. This style of effort is required in sports such as Australian Rules football, rugby, netball, hockey, basketball, squash and tennis. Table 11.9 demonstrates three versions of the test. Instructions are given for the short course.

TABLE 11.9 Options for the phosphate recovery test

Course	Number and duration of sprints	Starting every:	Work-to-rest ratio
Short course (25 m)	8 × 7 seconds	30 seconds	1:3.3
Long course (40 m)	8 × 7 seconds	40 seconds	1:4.7
Long course (40 m)	8 × 5 seconds	30 seconds	1:5

Equipment

You will need two sets of 10 cones (numbered 1 to 10), additional cones to mark start and finish lines, stopwatches, whistles and scorecards (see example on the next page). Set up the short course as shown in the diagram below. (For the long course, 25 metres becomes 40 metres.) The numbers on the cones must face towards the scorer.



Short course phosphate recovery test

PHOSPHATE RECOVERY TEST: SHORT COURSE

8 × 7-second sprints (every 30 seconds)

Name: ________________________________

Sprint number	1	2	3	4	5	6	7	8	Total
Score									

(Circle your best score and calculate your total score.)

Best possible score = best score × 8 = _______ × 8 = _______

Total decrement = best possible score – total score = _______ – _______ = _______

Percentage total decrement = $\frac{\text{total decrement}}{\text{best possible score}} \times 100$ = _______%

Norms for the test

(Circle your rating)

Good	Average	Below average	Poor
12–20%	20–30%	30–40%	>40%

Sample scorecard for the short-course phosphate recovery test and ratings

Adapted from Davis et al., 1991

Procedure

1 Choose a partner to work with (one person performs the test, the other records the results) and a timekeeper. Each participant should be thoroughly familiar with the procedure.
2 The performers line up at the left. After giving a 5-second warning, the timekeeper blows a whistle and starts two stopwatches. The performer sprints to the right, at maximal effort. Each performer's score is the number of the cone in the top right-hand section of the course reached at the 7-second mark.
3 The performers jog to the start/finish line at the right and line up ready to sprint to the left when the second stopwatch reaches 30 seconds. For this sprint, the cones in the bottom left-hand part of the course are used for scoring.
4 The process is repeated until the performers have sprinted eight times.

Calculations and norms

Complete the calculations on the scorecard to find the percentage decrement. The lower the decrement, the better the result. Norms for the test are shown on the scorecard above.

LABORATORY

PHOSPHATE RECOVERY TEST

The following table shows results for three athletes performing 8 × 7-second sprints over the short course (25 metres). The data has been analysed for Athlete 1.

METHOD

1 Complete the analysis for Athletes 2 and 3. You can use an online table via http://nelsonnet.com.au. You will need your login code).
2 What is the rating for each athlete? (See norms on the scorecard at the top of this page.)
3 Briefly discuss the fitness of each athlete, using evidence from the analysis.

RESULTS

Athlete	Phosphate recovery test scores	Best possible score	Total score	Total decrement	Percentage decrement
1	7 5 4 3 3 2 2 2	7 × 8 = 56	28	56 – 28 = 28	$\frac{28}{56} \times 100 = 50\%$
2	7 6 5 5 5 4 4 4				
3	6 5 5 5 5 4 4 4				

Scaffold

300-metre shuttle run test

The 300-metre shuttle run test was designed by A. Moore et. al., from the University of Technology in Sydney. The purpose was to design an easily administered test for field sports that rely heavily on a large anaerobic contribution.

Equipment

To undertake this test you will require:

» a flat, non-slippery surface at least 20 metres long
» 20-metre tape measure
» marking cones
» recording sheets.

Method

1 The performer runs between two lines 20 metres apart for 15 repetitions, covering a total of 300 metres.
2 The performer completes the 15 shuttles in the fastest possible time, which is then recorded.

The test appears to be a valid predictor of anaerobic capacity when compared to Maximally Accumulated Oxygen Deficit (MAOD). Comparative data is not available, but the test can be used to assess the effectiveness of a training program through pre- and post-testing.

Running-based anaerobic sprint test (RAST)

The RAST is similar to the Wingate 3-second cycle test (see below), and is much simpler than the phosphate recovery test. The test provides athletes and coaches with measurements of power and a fatigue index.

Equipment

A 400-metre track with a 35-metre marked section on the straight, two stopwatches, two assistants and a set of scales

Procedure

1 The athlete is weighed immediately before the test.
2 Perform a 10-minute warm-up, followed by a five-minute recovery.
3 Complete six × 35-metre sprints (maximum pace) with a 10-second turn-around between sprints.
4 Assistants record times to the nearest hundredth of a second.

Calculations

For each of the six sprints, calculate the power of each run and then determine the average power and fatigue index. Power is calculated by multiplying a performer's weight by the square of the distance travelled, and dividing by the cube of the time taken, as shown in the following formula. (Distance is measured in metres and time in seconds.)

$$\text{power (watts)} = \text{weight (kg)} \times \text{distance}^2/\text{time}^3$$

or

$$\text{power (watts)} = \text{weight (kg)} \times (\text{distance} \times \text{distance})/(\text{time} \times \text{time} \times \text{time})$$

The formula for power comes from combining the following physics formulas:

» velocity (m/s) = distance (m)/time (s)
» acceleration (m/s^2) = velocity (m)/time (s^2)
» force = weight (kg) × acceleration (m/s^2)
» power (watts) = force × velocity

The sample form on the next page shows calculations of results for an athlete who weighs 65 kilograms and runs 35 metres. Two methods of calculating power are shown. You could use each method to check one of the power values and see which you prefer.

Analysis

Scores can be compared with previous test scores. Note that:

» The maximum power is an indication of sprint speed and strength.

» Average power gives an indication of ability to maintain power over time.

» The fatigue index indicates the rate of power decline over time. A score greater than 10 indicates you may need to improve lactate tolerance.

Go to http://vcepe34.nelsonnet.com.au to download a RAST calculator.

Weblink

30-second Wingate test (Wingate anaerobic test)

The 30-second Wingate test is a laboratory-based maximal test requiring the participant to pedal a mechanically braked bicycle ergometer maximally for 30 seconds. Both anaerobic power and anaerobic fatigue results can be obtained.

RUNNING-BASED ANAEROBIC SPRINT TEST (RAST)
Sprint distance: 35 metres

Performer's weight: 65 kg

Sprint number	Time (seconds)	Calculation	Power (watts)
1	4.39	65 × (35 × 35) ÷ (4.39 × 4.39)	941
2	4.62		807
3	4.79		725
4	5.08	65 × 35² ÷ 5.08³	607
5	5.19		570
6	5.49		481
Totals	29.56		4131

Maximum power = 941 watts

Minimum power = 481 watts

Average power = total power ÷ 6 = 4131 ÷ 6 = 689 watts

Fatigue index = (maximum power − minimum power) ÷ total time

= (941 − 481) ÷ 29.56

= 460 ÷ 29.56 = 15.6 watts/second)

Sample RAST results


Getty Images/Jen Fuller

Wingate bike test; an arm-ergometer could also be used

Muscular strength tests

Handgrip dynamometer strength test

Equipment

A **handgrip dynamometer**

Procedure

Adjust the handgrip size to a position that is comfortable for the individual. The subject should stand upright, with their arms at their sides. They hold the dynamometer parallel to their side, with the dial facing away from their body. The subject squeezes the dynamometer as hard as possible without moving their arm (see photo at right). There are usually three trials for each hand, with a one-minute rest between trials. Norms are provided in Tables 11.10 and 11.11.

Camry Scale Store, www.camryscalestore.com

This dynamometer measures grip strength. What other kinds of dynamometers test the strength of other body parts?

TABLE 11.10 Norms for static strength (kg) using a grip dynamometer for males

Grip strength ratings for males (kg)			
Age	Weak	Normal	Strong
10–11	<12.6	12.6–22.4	>22.4
12–13	<19.4	19.4–31.2	>31.2
14–15	<28.5	28.5–44.3	>44.3
16–17	<32.6	32.6–52.4	>52.4
18–19	<35.7	35.7–55.5	>55.5

TABLE 11.11 Norms for static strength (kg) using a grip dynamometer for females

Grip strength ratings for females (kg)			
Age	Weak	Normal	Strong
10–11	<11.8	11.8–21.6	>21.6
12–13	<14.6	14.6–24.4	>24.4
14–15	<15.5	15.5–24.4	>27.3
16–17	<17.2	17.2–29.0	>29.0
18–19	<19.2	19.2–31.0	>31.0

Source: Courtesy of Topend Sports, www.topendsports.com

1-repetition maximum (1RM) bench press and leg press tests

The aim of these two tests is to assess maximal strength of the upper body and leg musculature. It is crucial for injury management to use correct, controlled technique at all times. Practice sessions to ensure performers are familiar with the correct technique are highly recommended.

The following testing guidelines are recommended to determine the **1-repetition maximum (1RM)**:

1. The subject should warm up by completing several repetitions at a lower weight.
2. Begin the test with a weight/resistance of about 50–70 per cent of the subject's capacity.
3. Progressively increase the weight/resistance by increments of between 2.5 and 20 kilograms until the subject cannot complete the selected repetition. All repetitions should be performed at the same speed of movement and range of motion to ensure consistency between trials.
4. Complete four trials, with rest periods of 3–5 minutes between trials.
5. The final weight lifted successfully is recorded as the absolute 1RM.

   Results are based on dividing the weight lifted by actual body weight for both the bench press and leg press.

$$\text{Bench press ratio} = \frac{\text{weight lifted}}{\text{body weight}}$$

$$\text{Leg press ratio} = \frac{\text{weight lifted}}{\text{body weight}}$$

TABLE 11.12 Ratings for 1RM bench press and leg press

Rating	Bench and leg press	
	Boys < 20 years	Girls < 20 years
Excellent	1.34+	0.77
Good	1.19–1.29	0.65–0.76
Fair	1.06–1.16	0.58–0.64
Poor	0.76–1.01	0.41–0.57
Very poor	<0.76	<0.41

Adapted from ACSM, 2014

7-stage abdominal strength test

Aim

To assess abdominal strength

Equipment needed

2.5-kilogram and 5-kilogram weights

Method

The subject lies on their back with their knees at right angles and feet flat on the ground. They attempt to complete one sit-up from each of the levels described in Table 11.13. Each level is completed satisfactorily if one full sit-up can be performed without the performer's feet leaving the floor.

Performers with heavy upper bodies may find this test difficult because it is harder to keep their feet on the ground.

TABLE 11.13 Ratings for 7-stage abdominal strength test

Level	Rating	Description
0	Very poor	Cannot curl up at all
1	Poor	with arms extended, the athlete curls up so that the wrists reach the knees
2	Fair	with arms extended, the athlete curls up so that the elbows reach the knees
3	Average	with the arms held together across abdominals, the athlete curls up so that the chest touches the thighs
4	Good	with the arms held across the chest, holding the opposite shoulders, the athlete curls up so that the forearms touch the thighs
5	Very good	with the hands held behind the head, the athlete curls up so that the chest touches the thighs
6	Excellent	as for level 5, with a 2.5 kg weight held behind the head, chest touching the thighs
7	Elite	as for level 5, with a 5 kg weight held behind the head, chest touching the thighs

Source: Courtesy of Topend Sports, www.topendsports.com

Local muscular endurance

Partial curl-up

Equipment

Masking tape and a metronome

Procedure

1 The performer lies on a mat with their knees at 90 degrees. Their arms are by their sides, palms facing down with the middle finger touching a piece of masking tape.
2 A metronome is set to 50 beats per minute and the person does slow, controlled curl-ups, lifting their shoulder blades off the mat (their trunk should form a 30-degree angle with the mat) in time with the metronome, at a rate of 25 per minute. The test is done for 1 minute. The lower back should be straightened out before commencing each curl-up.
3 The individual performs as many curl-ups as possible without pausing, to a maximum of 25.

TABLE 11.14 Ratings for partial curl-ups performed in one minute

Rating	Partial curl-up	
	Boys < 20 years	Girls < 20 years
Excellent	25	25
Very good	21–24	18–24
Good	16–20	14–17
Fair	11–15	5–13
Needs improvement	10	4

Adapted from ACSM, 2014

Timed sit-ups

Equipment

A stopwatch

Procedure

The performer takes up the starting position, lying on a mat with their knees bent at a 90-degree angle, arms straight and fingers flat. A partner provides assistance, placing their forearm across the subject's knees, and counting the number of sit-ups performed. A sit-up is completed each time the subject slides their hands along the top of their thighs, touches their partner's forearm and returns the back of their head to the mat. Sit-ups must be completed at a rate of 20 per minute, to a maximum of 60. If students are unable to perform two consecutive sit-ups with the correct procedure, at the required rate, they withdraw from the test and record the number of correctly completed sit-ups.

The following are national norms for 16- to 19-year-olds.

TABLE 11.15 Norms for timed sit-ups

Gender	Excellent	Above average	Average	Below average	Poor
Male	>30	26–30	20–25	17–19	<17
Female	>25	21–25	15–20	9–14	<9

Source: Fitness2u, 2013

Maximal push-ups in 60 seconds

The push-up test will assess upper-body muscular strength and endurance for each push-up. Table 11.16 provides the norms.

Procedure

1 The person being tested assumes the standard push-up position: legs together and hands pointing forward, shoulder width apart, positioned directly under the shoulders (see photos, page 267).
2 A partner places a fist on the floor directly under the person's chest.
3 The performer lowers themselves until their chest touches the fist, keeping their body straight and rigid, and then pushes themselves back up to the starting position. This counts as one repetition. The toes are the pivotal point. Rest is allowed in the up position only.
4 The score is the total number of push-ups completed in 60 seconds.

Shutterstock.com/Mihai Blanaru

Correct push-up technique

TABLE 11.16 Norms for maximal push-ups in 60 seconds for youths aged 15–19

	Males	Females
Excellent	39+	33+
Very good	29–38	25–32
Good	23–28	18–24
Fair	18–22	12–17
Needs improvement	17 or less	11 or less

Source: Canadian Society for Exercise Physiology

Pull-ups

Equipment

A pull-up bar

Procedure

Take up your starting position with feet together and your hands holding the bar above you, palms facing outwards.

Pull up until your chin clears the bar and then lower your body back into the starting position. Repeat this activity until you are unable to continue. Record complete pull-ups only. Norms are provided in Table 11.17.

Alamy Stock Photo/Ron Sumners

Correct pull-up procedure

TABLE 11.17 Norms for pull-ups for 17-year-olds

Results	Boys	Girls
Excellent	15+	2
Good	12–14	1
Average	8–11	1
Fair	5–7	0
Poor	0–4	0

Source: Hoffman, 2006

Flexed-arm hang test

An alternative to the pull-up test is the flexed-arm hang test.

Equipment

A pull-up bar

Procedure

1 Set the bar slightly higher than the performer's standing height.
2 The performer should grip the bar using an overhand grip, with their thumbs wrapped around it.
3 Spotters lift the performer so that their chin is above the bar but not touching it. The performer's arms should be flexed, and their chest close to the bar.
4 Once the performer is in position, the spotter lets go. The time is recorded from the moment the spotters let go to the moment that the individual's chin touches the bar or falls below it.

TABLE 11.18 Flexed-arm hang norms for youths aged 15–17+

Percentile	Boys			Girls		
	15	16	17+	15	16	17+
90	62	61	56	34	30	29
80	49	46	45	23	21	20
70	40	39	39	15	16	15
60	35	33	35	10	10	11
50	30	28	30	7	7	7
40	25	22	26	5	5	5
30	20	18	20	4	3	4
20	14	12	15	2	2	2
10	8	7	8	1	0	1

30-second endurance jump test

The 30-second endurance jump test measures lower-body muscular endurance. While no norms exist, this test is suitable for a pre- and post-comparison.

Equipment

A stopwatch and a 30-centimetre high barrier or hurdle to repeatedly jump over. Folded cardboard could easily serve this purpose.

Procedure

1 Stand with both feet on one side of the 'barrier'.
2 Timing commences from the first movement.
3 Jump off both feet, landing on the other side of the barrier on both feet.
4 Continue as many times as possible.

Scoring

Total number of completed jumps in 30 seconds

Multistage hurdle jump test

The multistage hurdle jump test measures lower-body muscular endurance, particularly targeting repeated efforts. While no norms exist, it would be suitable for a pre- and post-comparison.

Equipment

A stopwatch and a 30-centimetre barrier or hurdle to repeatedly jump over. Folded cardboard could easily serve this purpose.

Procedure

1 Stand with both feet on one side of the 'barrier'.
2 Timing commences from the first movement.
3 Set 1: Jump off both feet, landing on the other side of the barrier on both feet, as many times as possible in 20 seconds.
4 Rest for 20 seconds
5 Set 2: Jump off both feet, landing on the other side of the barrier on both feet, as many times as possible in 20 seconds.

Scoring

Total number of completed jumps over both sets (40 seconds in total). A fatigue index can also be calculated with the following formula:

$$\frac{\text{Set 2 total jumps}}{\text{Set 1 total jumps}} \times 100$$

QUICKVID

Watch a demonstration of multistage hurdle jumping by clicking on the link via http://vcepe34.nelsonnet.com.au.

Weblink

Static flexibility tests

Modified sit-and-reach test

The modified sit-and-reach test measures hip and trunk flexibility.

Equipment

A ruler and a sit-and-reach box

Procedure

Sit with your legs fully extended and the bottom of your feet against the sit-and-reach box. Place your hands one on top of the other and gradually reach forward, sliding your fingers along the ruler. Hold the final position for two seconds (see photo, right).

Correct sit-and-reach procedure

TABLE 11.19 Norms (cm) for flexibility tests

Test item	Men	Performance rating	Women
Modified sit-and-reach test			
	>9	Excellent	>16
	6–9	Good	13–16
	2–5	Average	10–12
	–5–1	Fair	6–9
	<–5	Poor	<5
Shoulder and wrist elevation test			
Difference between arm length and best score	<15.0	Excellent	14.0 or fewer
	15.0–21.0	Good	14.0–19.0
	21.1–29.0	Average	19.1–27.3
	29.1–32.0	Fair	27.4–30.0
	>32.0	Poor	>30.0
Trunk and neck extension test			
Difference between trunk and neck length and best score	<8.0	Excellent	<6.0
	8.0–15.0	Good	6.0–14.6
	15.1–20.0	Average	14.7–19.7
	20.1–25.0	Fair	19.8–25.0
	>25.0	Poor	>25.0
Ankle extension test			
Difference between scores 1 and 2	<2.0	Excellent	<1.3
	2.0–3.8	Good	1.3–3.2
	3.9–5.0	Average	3.3–4.5
	5.1–7.6	Fair	4.6–5.7
	>7.6	Poor	>5.7
Shoulder rotation test			
Difference between best score and shoulder width	<17.8	Excellent	<12.7
	17.8–29.2	Good	12.7–25.0
	29.3–36.8	Average	25.1–33.0
	36.9–50.2	Fair	33.1–45.1
	>50.2	Poor	>45.1
Ankle dorsiflexion test			
Distance between toe line and wall	>89.0	Excellent	>81 0
	82.6–89.0	Good	77.6–81.0
	75.1–82.5	Average	67.1–77.5
	67.0–75.0	Fair	61.5–67.0
	<67.0.0	Poor	<61.5

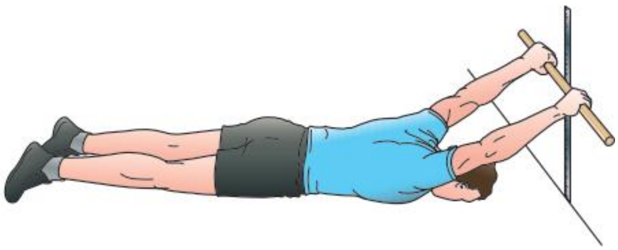
Adapted from Johnson & Nelson, 1986

Shoulder and wrist elevation test

Equipment

A wooden rod and a vertical scale (a metre ruler taped to the wall, with the zero end at floor level)

Procedure



Correct shoulder and wrist elevation procedure

Lying prone on the floor with arms fully extended overhead, grasp the wooden rod with your hands shoulder-width apart. Raise the rod as high as possible while keeping your chin on the floor. Your partner should read the score from underside of the wooden rod (against the metre ruler taped to the wall). Measure your arm length from **acromial process** to fingertips and subtract your best trial score from your arm length.

Trunk and neck extension test

Equipment

A metre ruler, taped to the wall, with the zero end at floor level

Procedure

Correct trunk and neck extension procedure

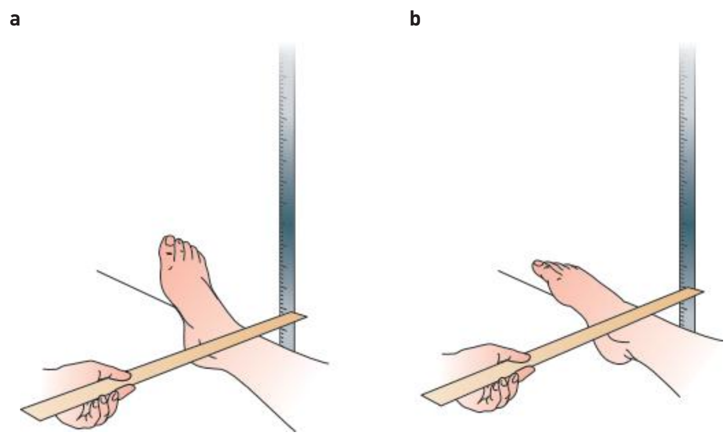
Lying prone on the floor with your hands clasped behind your back, raise your trunk as high as possible, keeping your hips on the floor. Use the vertical scale to measure the height of the tip of your nose above the floor (see right). Measure your trunk and neck length from the tip of your nose to the seat of a chair while sitting up straight on a chair. Subtract your best trial score from your trunk and neck length.

Ankle extension test

Equipment

A ruler and a wooden rod

Procedure



Correct ankle extension test procedure

1 Sitting on the floor with your right leg extended in front of you as straight as possible, place the zero end of the metre ruler on the floor and slide the stick along your leg until it is resting across the lowest point of the tibia.
2 Read the position of the stick against the ruler.
3 Extend your ankle and repeat the measurement, this time at the highest point on the dorsal surface of the foot (see part b of the illustration).
4 Read the position of the stick against the ruler, and record the difference between the upper foot line and the lower tibia line.
5 Repeat for the left ankle, and average the scores for right and left ankles.

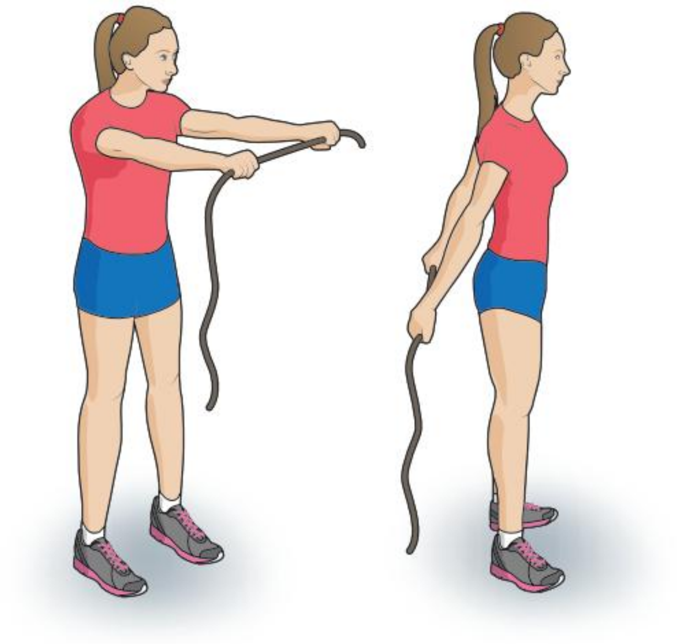
Shoulder rotation test

Equipment

A rope and a ruler

Procedure

Grasp one end of the rope with your left hand, then grasp the rope in your right hand a few centimetres further along. Extend both arms in front of your chest and rotate them overhead. As resistance is met, slide your right hand further along the rope until it can be lowered against your back (see below). Measure the distance between your fists as they hold the rope behind you. Measure your shoulder width from deltoid to deltoid and subtract this from your best trial score.



Correct shoulder rotation test procedure

Correct ankle flexion test procedure

Ankle (dorsi) flexion test

Stand facing the wall and keep your heels flat on the floor while leaning into the wall. Your hands, chin and chest should be touching the wall. Put as much distance between the wall and your heels as possible while keeping your body and knees fully extended and your chest in contact with the wall (see left). Measure the distance between your toe line and the wall. Refer to Table 11.19 on page 270 for norms.

Groin flexibility test

Equipment

You will need a ruler for this test.

Procedure

Sit on the floor with your knees bent and the soles of your feet in contact with each other. Allow your knees to drop sideways as far as possible while keeping your feet together. Grab your ankles with both hands, pulling them as close to your body as possible. Measure the distance from your heels to your groin.

TABLE 11.20 Ratings for the groin flexibility test

Excellent	Very good	Good	Fair	Poor
5 cm	10 cm	15 cm	20 cm	25 cm

Source: Courtesy of Topend Sports, www.topendsports.com

Body composition tests

Body composition is the proportion of body weight derived from fat compared to the proportion of weight derived from lean tissue. It has been clearly established that excess body fat, particularly around the abdomen, is associated with many health problems. Statistics show that obesity is continuing to increase in Australia. Excess body fat can also impede performance by lowering the power-to-weight ratio and by decreasing the effectiveness of muscle contractions.

Hydrostatic (underwater) weighing is considered to be the gold standard for determining body composition, though it is rarely used in testing due to both access and cost issues. In hydrostatic weighing, a performer's dry weight is compared to their underwater weight. Based on Archimedes' principle of water displacement, lean tissue will sink while fat will float. So a person with a higher percentage of body fat will weigh less underwater compared to a more muscular person of the same dry weight.

Dual energy X-ray absorptiometry (DEXA) was originally developed to scan bone density for diagnosing osteoporosis. It is non-invasive and can also measure regional and total-body lean and fat tissue, as well as bone density and bone mineral content. DEXA readings can give specific regional fat percentages, as well as overall percentage of body fat. DEXA scanning is also considered to be a gold standard test, though it can be very expensive.

Body mass index (BMI)

The body mass index (BMI) is a practical formula used to assess weight relative to height to determine whether an individual is within a healthy weight range. The formula is weight (in kilograms) divided by height (in metres) squared; that is, someone who is 175 centimetres tall calculates the height component as 1.75 × 1.75. A problem with the BMI is that it does not take into consideration the difference between lean body mass and fat mass, and may not be a suitable test for trained performers. BMI is classified in Table 11.21.

TABLE 11.21 BMI classification

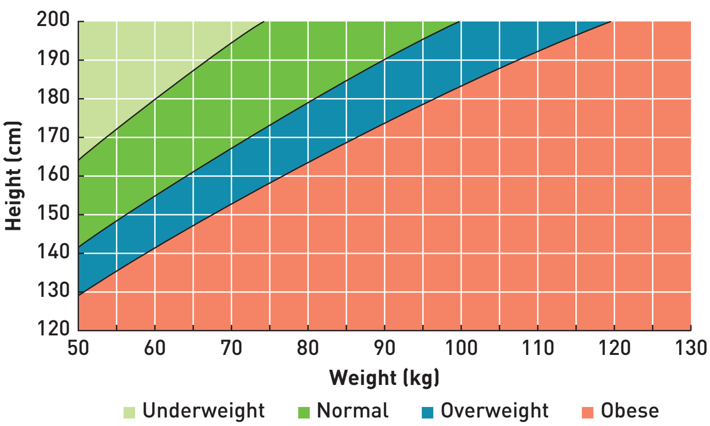
Underweight	<18.5
Normal	18.5–24.9
Overweight	25.0–29.9
Obese	30.0+

A goniometer is used more in a clinical setting to measure the angle of the joint at both extremes of the range of motion.

Dual energy X-ray absorptiometry (DEXA scanning)

FYI

BMI = weight (kg)/height (m)^2



A BMI chart

Waist circumference

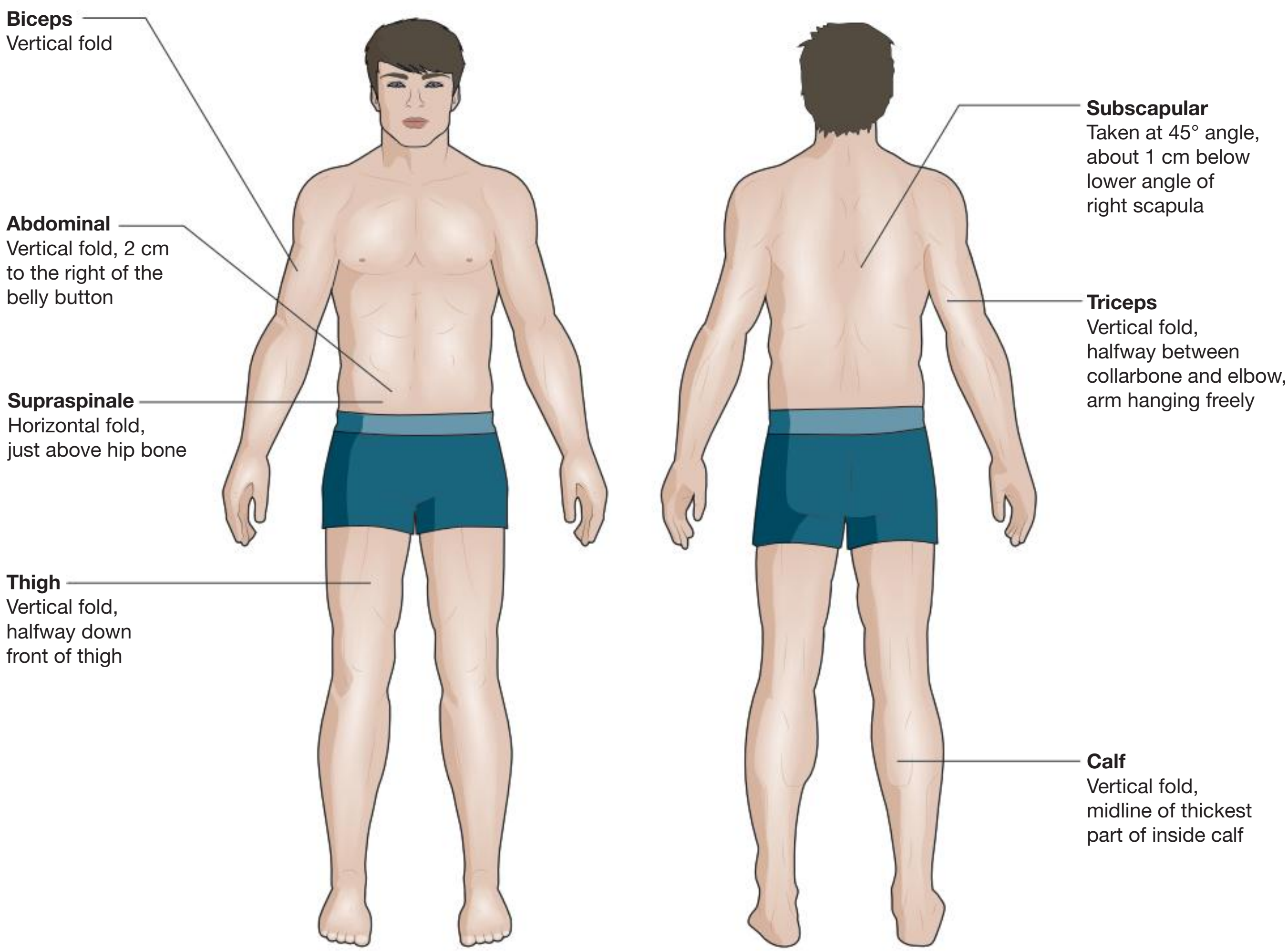
Health professionals are now recognising that the pattern of fat distribution is also an important health risk factor. Carrying fat around your abdomen (apple shape) is a greater health risk than carrying it around your hips (pear shape).

The federal government suggests that the following waist measurements are associated with an increased risk of chronic disease:

» Waist circumference of more than 94 centimetres (men) and more than 80 centimetres (women) = increased risk of chronic disease.
» Waist circumference of more than 102 centimetres (men) and more than 88 centimetres (women) = greatly increased risk of chronic disease.

Sum of skin folds

Sports performance testing now focuses on the sum of skin folds rather than the percentage of body fat. Percentage of body fat does not give the performer and/or coach any information on where changes in body composition have occurred.



The seven sites for the sum of skin folds

Seven testing sites on the body are used to calculate a total skin-fold measurement (see page 274).

The tester pinches the skin at the desired site to raise the underlying fat and skin, but not the muscle. Skin fold calipers are then applied to measure the raised skin. Two measurements are generally taken, to increase reliability. Measurements are usually taken from the right side of the body.

Alamy Stock Photo/imageBROKER

Calipers are used to take skin-fold measurements.

TABLE 11.22 Ratings for the 7-site sum of skin folds

		Excellent	Good	Average	Below average	poor
Normal	Male	60–80	81–90	91–110	111–150	150+
	Female	70–90	91–100	101–120	121–150	150+

Source: Courtesy of Topend Sports, www.topendsports.com

Muscular power tests

Muscular power is used in sports where explosive strength is required. It is critical in many sporting pursuits, from high-intensity running to the throwing of a projectile.

Vertical jump test

Equipment

Chalk and a measuring board

Procedure

Stand sideways to the wall with one arm extended. Make a chalk mark at the height of your reach. Don't elevate your shoulder. Lower your arm and, without moving your feet, squat down and jump as high as possible, making a mark on the wall as high as you can reach at the peak of the jump. Measure the distance between the starting mark and the jump mark. Three trials are allowed, with the best result used for rating (see Table 11.23 for ratings).

Getty Images/Robert Cianflone

A commercial product specifically designed for vertical jump testing

Vertical jump test

TABLE 11.23 Rating chart for vertical jump (centimetres)

	Poor	Fair	Average	Good	Excellent
Boys (15–16 years)	<43.2	43.3–50.8	50.9–55.9	56.0–68.6	>68.6
Girls (15–16 years)	<33.5	33.6–37.8	37.9–40.6	40.7–47.0	>47.0

Adapted from: Hoffman 2006

Standing long jump test

Equipment

A tape measure, a non-slip surface and preferably a soft surface on which to land

Procedure

Stand behind a line with feet slightly apart. A two foot take-off is required and the distance is measured from the take-off line to the back of the closer foot on landing. Participants should slightly bend their knees and swing their arms backwards before attempting to jump.

TABLE 11.24 Rating chart for power in standing long jump (centimetres)

Rating	Males	Females
Excellent	250+	200+
Very good	241–250	191–200
Above average	231–240	181–190
Average	221–230	171–180
Below average	211–220	161–170
Poor	191–210	141–160
Very poor	190 or below	140 or below

Source: Courtesy of Topend Sports, www.topendsports.com

REAL WORLD FOCUS

Sport-specific testing

The Australian Institute of Sport's National Sport Science Quality Assurance Program (NSSQA) has introduced several variations on the standing jumps test to cater for the specific requirements of individual sports.

Basketball: The vertical jump protocol for basketball incorporates a one-step movement prior to the jump.

Tennis: Vertical jump height is recorded for both legs as well as right and left legs independently. Also, the vertical jump protocol for tennis incorporates a one-step movement prior to the jump for the jump on both legs.

Volleyball: uses two sport-specific vertical jumps. The first is a two-handed block jump. The second is a one-handed spike jump.

Australian Rules football: footballers also complete a running vertical jump after completing the standard standing vertical jump protocol.

Questions

1 What fitness component is being assessed by the above tests?
2 Why has the AIS introduced these tests?
3 What norms, if any, would be available for these tests?

Seated basketball ball throw

There are very few norm-referenced upper-body tests for muscular power. While the seated basketball ball throw does not have suitable ratings, it could be used as a pre- and post-test comparison to assess the effectiveness of an upper-body power training program.

Equipment

Basketball and tape measure

Procedure

1 The performer sits with their back against a wall, facing in the direction of the intended throw. Their back must remain in contact with the wall.
2 The basketball is thrown as far as possible with a chest pass.
3 The distance is measured from the wall to where the basketball lands.

Scoring

Allow two practice attempts. Two throws are then completed and the better score is recorded.

Kneeling power ball chest launch

This test involves throwing a power ball as far as possible.

Equipment

2-kilogram fitness ball/power ball/medicine ball and a tape measure

Procedure

1 Start in a kneeling position with a straight back, facing the intended throwing direction. Toes should be pointed backwards.
2 Grasp the ball at the sides and hold it out and above your head.
3 Bring the ball down to the chest while lowering your hips to your heels, then in one action push the ball forwards and upwards. The hips or spine should not be rotated during this action, and the knees are not allowed to leave the ground.

Note: The angle of the throw is important – see chapter 4. Norms were not available at the time of publishing, but this test can still be used as a benchmark.

QUICKVID

Weblink

You can look at a demonstration of the kneeling power ball toss by clicking on http://vcepe34.nelsonnet.com.au.

Speed tests

Speed can refer to either whole-body speed or part-body speed. Testing is usually focused on whole-body speed, and involves timing how long it takes to cover a set distance. Typical sprint distances for assessing running speed are 10 metres, 20 metres, 35 metres, 40 metres and

Alamy Stock Photo/dpa picture alliance archive

Electronic light timing gates greatly increase the reliability of testing results.

50 metres. Specificity can be applied to speed tests by applying an appropriate distance; for example, the AFL draft camp uses a 20-metre sprint test.

There may be reliability issues when assessing speed over shorter distances, such as timing 10- or 20-metre sprints with a hand-held stopwatch. Testing at the elite level will often utilise electronic timing gates to increase reliability, but this may be too expensive for schools or non-elite sporting clubs.

35-metre and 50-metre sprint tests

Tables 11.25 and 11.26 show norms for 35-metre and 50-metre running sprint tests, respectively. There is a lack of available norms for the shorter sprint distances (10 and 20 metres), other than for elite performers. However, these distances are quite common in many team sports and could form part of a pre- and post-testing scenario to assess the effectiveness of a training program. Either distance could be timed as part of testing a longer distance, such as 35 metres.

Equipment

Measuring tape, stopwatch and cones

Procedure

Testing involves running a single maximum sprint over a set distance. A thorough warm-up should be completed first.

TABLE 11.25 Ratings for the 35-metre sprint test (seconds)

Rating	Male	Female
Excellent	< 4.80	< 5.30
Good	4.80–5.09	5.30–5.59
Average	5.10–5.29	5.60–5.89
Fair	5.30–5.60	5.90–6.20
Poor	> 5.60	> 6.20

Source: Courtesy of Topend Sports, www.topendsports.com

TABLE 11.26 Ratings for the 50-metre sprint test (seconds)

Rating	Male	Female
Excellent	7.57 or less	8.1 or less
Good	7.58–7.85	8.2–8.6
Average	7.86–8.40	8.7–8.9
Below average	8.41–8.78	9.0–9.3
Needs work	8.79 or more	9.4 or more

Source: https://sites.google.com/site/pefitnesstesting/50mSprint

Agility tests

Illinois agility test

Equipment

4 chairs, a stopwatch, and cones to mark out the course

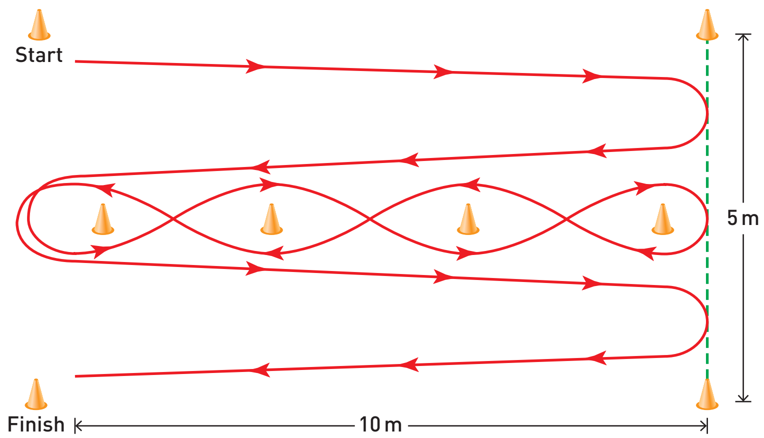
Procedure

1 Using the cones, mark out the course according to the illustration below.
2 Begin by lying behind the start line, with your hands near your shoulders and your head behind the line.
3 On the command 'go', jump up and run through the course. You must touch the end lines with your foot.
4 The time taken should be recorded as soon as you cross the finish line. Table 11.27 gives norms for this test.

TABLE 11.27 Ratings chart for the Illinois agility test (seconds)

	Excellent	Above average	Average	Below average	Poor
Girls	<17.0	17.0–17.9	18.0–21.7	21.8–23.0	>23.0
Boys	<15.2	15.2–16.1	16.2–18.1	18.2–18.3	>18.3

Source: Davis et al., 2000



Floor plan for the Illinois agility test

SEMO agility test

The SEMO agility test measures the general agility of the body in manoeuvring forwards, backwards and sideways.

Equipment

A smooth area of 3.6 × 5.7 metres with adequate running space around it, four plastic cones and a stopwatch

Procedure

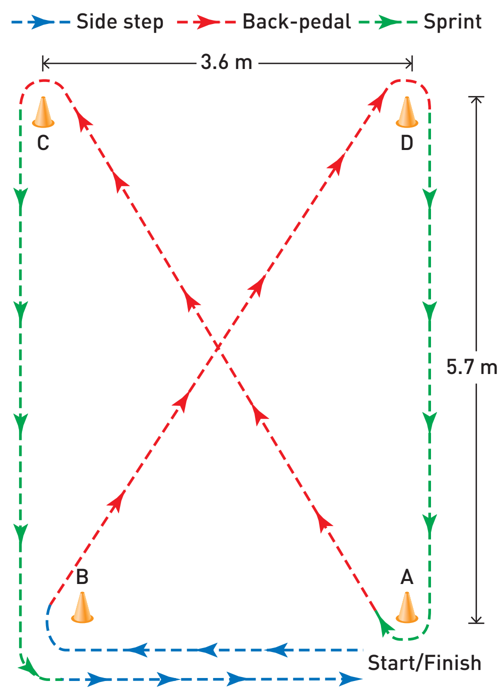
1 Place the cones in each corner of the area, as shown on the following page.
2 Line up at 'A' with your back to the square.
3 At the signals 'ready, go', sidestep from A to B and pass outside the corner cone; then run backwards, or backpedal, from B to D and pass to the inside corner of the cone; then sprint forwards from D to A and pass outside the corner cone; then backpedal from A to C and pass to the inside of the corner cone; then sprint from C to B and pass outside the corner cone; and finally sidestep from B to the finish line at A. Two trials are allowed.

Scoring

The better of the two trials (recorded to the nearest tenth of a second) is recorded as the score. Table 11.28 shows the appropriate norms.

Additional pointers

When performing the sidestep, the crossover step cannot be used. When performing the backpedal, you must keep your back perpendicular to an imaginary line connecting the corner cones. Incorrect procedure makes the trial invalid, and you should be tested until one correct trial is completed. At least one practice trial should be given.



The SEMO agility test course

Adapted from: Johnson & Nelson, 1986

TABLE 11.28 Norms for the SEMO agility test, US college students (seconds)

Performance level	Score	
	Men	Women
Advanced	10.72 and below	12.19 and below
Advanced intermediate	11.49–10.73	12.99–12.20
Intermediate	13.02–11.50	13.90–13.00
Advanced beginner	13.79–13.03	14.49–13.91
Beginner	13.80+	14.50+

Source: Johnson & Nelson, 1986

Other fitness component tests and the study design

Students are expected to be familiar with at least two different fitness assessment methods for the following fitness components: aerobic power, agility, anaerobic power, body composition, flexibility, muscular endurance, power, strength and speed.

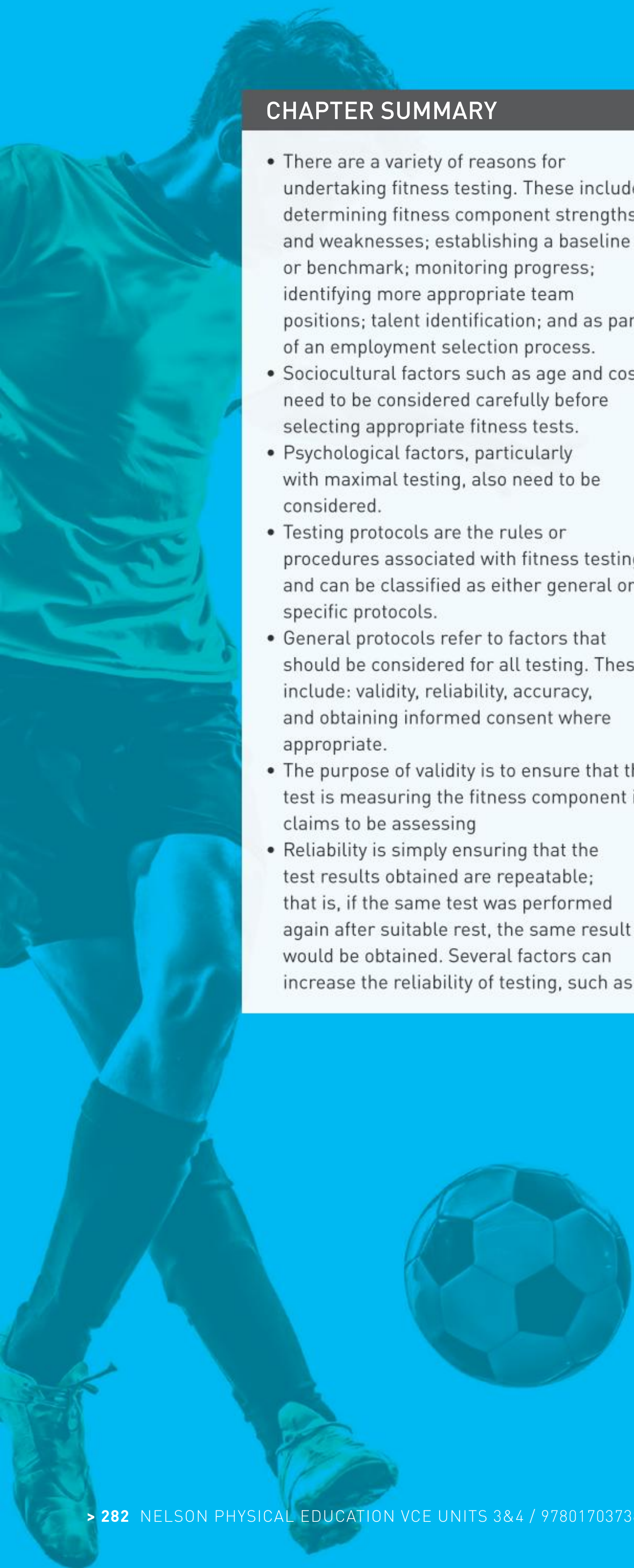
This means there is no need to be familiar with fitness testing methodologies for coordination, balance or reaction time. Tests for these components have been supplied for possible interest only. Access them on your student website, using your login code, via http://www.nelsonnet.com.au and navigate to the Factsheet on this page.

Fact sheet

QUICKVID

Watch an interview with Neil Craig, currently Director of Coaching, Development and Performance at the Carlton Football Club, on fitness assessment. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 11, page 281.

Video



CHAPTER SUMMARY

- There are a variety of reasons for undertaking fitness testing. These include: determining fitness component strengths and weaknesses; establishing a baseline or benchmark; monitoring progress; identifying more appropriate team positions; talent identification; and as part of an employment selection process.
- Sociocultural factors such as age and cost need to be considered carefully before selecting appropriate fitness tests.
- Psychological factors, particularly with maximal testing, also need to be considered.
- Testing protocols are the rules or procedures associated with fitness testing, and can be classified as either general or specific protocols.
- General protocols refer to factors that should be considered for all testing. These include: validity, reliability, accuracy, and obtaining informed consent where appropriate.
- The purpose of validity is to ensure that the test is measuring the fitness component it claims to be assessing
- Reliability is simply ensuring that the test results obtained are repeatable; that is, if the same test was performed again after suitable rest, the same result would be obtained. Several factors can increase the reliability of testing, such as ensuring the test is performed in the same environmental conditions.
- Accuracy of testing increases the reliability of results. Following testing protocols will increase accuracy.
- Informed consent minimises the potential harm to both the tester and the performer. It is vital that both parties are aware of the inherent risks with any test undertaken, as well as the benefits of performing the test.
- Pre-activity screening is valuable for the elderly or those with health risk factors.
- Specific testing protocols are based on the rules or procedures to be followed for each fitness test. Factors to be considered include specificity, result comparison, and the type of test to be undertaken.
- Specificity refers to choosing a test that closely resembles activities undertaken by the performer.
- Result comparison can be either norm- or criterion-referenced. Where these are not available, results can still be utilised to assess the effectiveness of a training intervention.
- Confidentiality needs to be considered before results are disseminated.
- There are a variety of fitness tests available for the various fitness components. These are classified as maximal or submaximal, direct or indirect, and laboratory- or field-based.

CHAPTER REVIEW

Multiple-choice questions

1 A state basketball coach would like to know which test would best measure power for her rebounding players. Which of the following tests would be the most appropriate?
   A standing broad jump
   B 1RM bench press
   C vertical jump
   D 35-metre sprint

2 Which of the following testing sequences would produce the most reliable results?
   A Sit and reach, 20-metre shuttle run, vertical jump, 50-metre sprint
   B 50-metre sprint, vertical jump, 20-metre shuttle run, sit and reach
   C vertical jump, 50-metre sprint, 20-metre shuttle run, sit and reach
   D vertical jump, 20-metre shuttle run, 50-metre sprint, sit and reach

3 When completing the 20-metre shuttle run test you will be disqualified if:
   A you fail to make the line.
   B you reach the end well in advance of the beep.
   C you fail to make the line twice consecutively.
   D you power walk the early stages instead of jogging.

Short-answer questions

4 For a sport of your choice, select five fitness components that you would choose to test as part of a fitness testing battery.
   a Define each fitness component you have selected.
   b Identify and justify the fitness component that you give the highest priority to.
   c List two fitness tests that you could use to assess each of the five fitness components you have identified.
   d i For the fitness component that you have ranked as the highest priority, select an alternative fitness test.
      ii Justify the exclusion of this test from your initial selection of tests.

5 The Yo-Yo Intermittent Recovery test can be used as an alternative to the 20-metre shuttle run test.
   a What fitness component are both tests aiming to measure?
   b Discuss the circumstances in which each test may be more appropriate.
   c Suggest two precautions you would implement before a sedentary person undertook the test.
   d Participants will usually show signs of fatigue towards the end of either test. Why is this?

6 There is a shortage of normative data available for 10-metre and 20-metre sprint times for non-elite performers. Suggest two likely reasons for this.

7 As the fitness advisor for a sporting team of your choice, design a specific agility test.
   a How could you establish norms for this test?
   b Without norms, how could this test be useful?
   c The coach of this team asks you why you didn't use the Illinois agility test. Defend the implementation of your test.

8 Informed consent is increasingly becoming part of physical activity.
   a What is informed consent?
   b Describe the process of informed consent.
   c Discuss the importance of informed consent.

9 'Fitness testing is a waste of time. Everyone at our club knows not to try as hard in the first lot of tests and then in the second lot of testing everybody will improve. Everyone's happy!'
   As a class, debate the above statement.

UNIT 4

TRAINING TO IMPROVE PERFORMANCE

AREA OF STUDY 2

HOW IS TRAINING IMPLEMENTED EFFECTIVELY TO IMPROVE FITNESS?

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CHAPTER 12

TRAINING PROGRAM PRINCIPLES

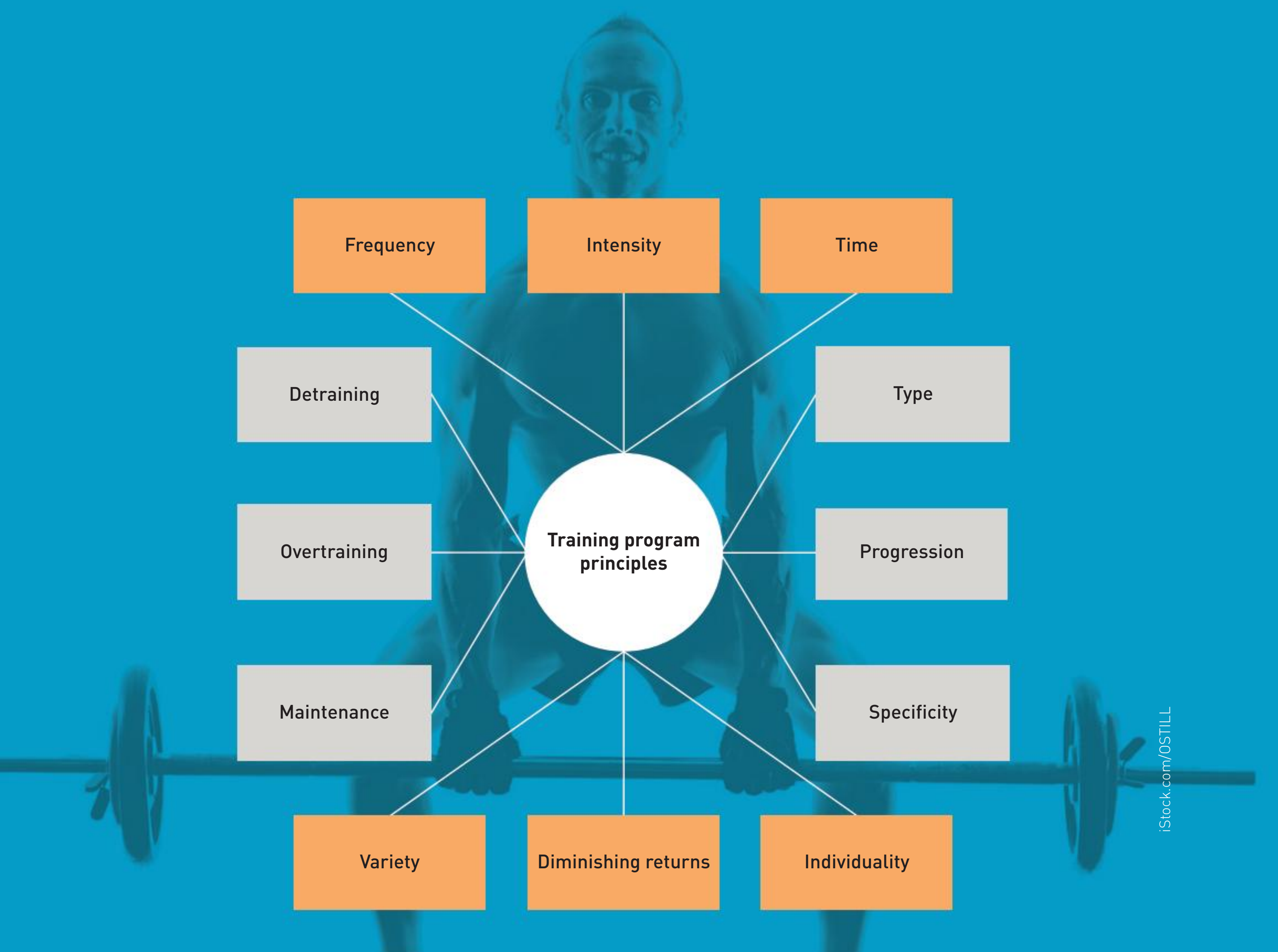
Key knowledge

» training program principles, including frequency, intensity, time, type, progression, specificity, individuality, diminishing returns, variety, maintenance, overtraining and detraining

Key skills

» design a training program that demonstrates the correct application of training principles and methods to enhance and/or maintain fitness components

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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TRAINING PROGRAM PRINCIPLES

In order to maximise fitness improvements, it is essential to apply fundamental training principles to training programs. This will ensure that physiological improvements or **chronic adaptations** occur (see chapter 15). It will also help reduce the frustration of inadequate progress and the likelihood of injury and **overtraining** that can occur as a result of a poorly planned training program. The correct application of the following principles to specific training methods will also guarantee that any possible improvements are achieved efficiently:

- specificity
- frequency
- intensity
- time (duration)
- type
- progression (overload)
- individuality
- diminishing returns
- variety
- maintenance
- overtraining
- detraining.

FREQUENCY

It is generally accepted that in order to improve a specific fitness component, training for that component must occur at least three times per week. However, this relies on the effective implementation of the other principles of training. Consideration must also be given to the amount of time the participant can commit to the training program, as well as their current level of training.

Rest and recovery are also important considerations that need to be built into the training program. Training will cause a **catabolic effect** on the body. It is during rest that the **anabolic effect** – the repair and, ultimately, the chronic adaptations – will occur. Without sufficient rest, these positive anabolic effects will be greatly reduced.

As performers become accustomed to their training program and are no longer novices (that is, when they have been training consistently for over six months), frequency may be increased to further accelerate chronic adaptations. It is not uncommon for athletes who rely heavily on anaerobic fitness components (such as speed) to increase training to five days per week. This may involve a combination of different training methods (such as short-interval work and plyometrics) on different days. Although one method is trained only twice per week, this will still elicit improvements because of the cumulative effect of the two different methods.

Performers involved in resistance training may begin with a workout suitable for novices that involves the entire body, conducted three times per week. Later they could split training into two different muscle-group sequences and train each of these twice a week, giving a total of four resistance training sessions per week. These are known as **split routines**.

Example of weight training split routines:

Monday and Thursday	Tuesday and Friday
Chest Shoulder Triceps	Back Legs Biceps

Looking at the table above, how else could split body routines be arranged?

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Weight training focuses on working specific muscle groups individually

Elite endurance athletes may train up to six or seven days per week, and even twice a day! This is possible for two reasons. First, there is less of a catabolic effect compared to training that is dominated by anaerobic exercise, which requires the performer to be working at near maximal intensities. Second, these elite athletes will build lower-intensity work, such as recovery runs, into their program.

INTENSITY

Intensity refers to the level of exertion applied during the work phase of a training session. Working at the appropriate intensity is critical in ensuring that the targeted energy system, fitness components and muscle groups are being developed. A training intensity above or below the required level may be counterproductive. Intensity underpins specificity.

The intended training intensity must be established before either frequency or duration can be effectively applied to a training program. Generally, higher training intensities will correspond to lower training durations.

Methods of ascertaining and applying intensity to training include the use of:

» percentage of maximum heart rate (% max HR), via heart-rate monitoring
» percentage of VO_2 max, laboratory calculation
» rate of perceived exertion (RPE), performer self-evaluation
» accelerometers, which provide movement speed that can be equated to intensity
» global positioning system (GPS) tracking, with attached accelerometers.

Heart-rate monitoring

Heart rate is measured in beats per minute and increases linearly with intensity until it reaches a maximum. From a practical viewpoint, % max HR is an easy way to measure intensity, particularly with the abundance of heart-rate measuring devices available on the market. Heart-rate monitoring is very effective for training that relies heavily on the aerobic energy system.

A formula commonly used to calculate maximum heart rate is:

$$\text{Maximum heart rate (bpm)} = 220 - \text{age (years)}$$

However, this may underestimate maximum heart rate in older adults (60+ years of age) and overestimate it in young people (under 10 years of age). A more valid method of predicting maximum heart rate (in beats per minute) is to use the equation:

$$\text{Maximum heart rate (bpm)} = 208 - 0.7 \times \text{age (years)}$$

Table 12.1 shows some values calculated in this way.

Adjustments need to be made when using % max HR for swimming and other upper-body exercises (such as boxing mitt work), as maximum heart rate in these instances is approximately 10 beats per minute lower. Therefore, 10 bpm needs to be subtracted from the age-predicted maximum heart rate.

TABLE 12.1 Prediction of maximum heart rate via 208 – 0.7 × age (years)

Age (years)	Max HR (bpm)	Age (years)	Max HR (bpm)	Age (years)	Max HR (bpm)	Age (years)	Max HR (bpm)
16	197	20	194	35	184	60	166
17	196	25	191	40	180	70	159
18	195	30	187	50	173	80	152

Rate of perceived exertion (RPE)

There is a lag associated with heart-rate monitoring; that is, someone could be working maximally but there is a delay before this will show on the heart-rate monitor, if at all. For short-duration (under 60 seconds) and high-intensity training, the rate of perceived exertion may be a more accurate indicator of intensity, particularly for performers in tune with their bodies. As a quantitative measure, RPE represents the performer's own perception of the training stress (both physical and psychological), which may assist with early detection of overtraining. RPE relies on athletes assigning a numeric rating to their perception of exertion (how heavy and strenuous the exercise feels), which is directly related to the intensity of the training stimulus. Table 12.2 provides a description of these ratings.

TABLE 12.2 Borg category–ratio (CR) scale

Rating	Description
0	No exertion at all
1	Very light exercise
2	
3	Moderate: it feels fine, no problem continuing with exercise
4	
5	Heavy: it feels hard and you are tired but there is no great problem with continuing
6	
7	Very hard and very strenuous: you need to push yourself to continue
8	
9	
10	Max: extremely strenuous, probably the most strenuous the performer has experienced

Adapted from: Borg, 1998

Training zones

FYI

Athletes can perform well above their VO_2 max when there is a significant increase in anaerobic energy supply (in most cases from the anaerobic glycolysis energy system).

It is essential to train at the correct intensity in order to maximise chronic adaptations. Table 12.3 demonstrates that training aimed at developing aerobic adaptations requires an **aerobic training zone** of 70–85% max HR or RPE 3–6. As highlighted above, both % max HR and RPE are practical and reliable methods of establishing intensity. On the other hand, training either of the anaerobic energy systems, or the majority of fitness components that rely on these energy systems, requires an intensity greater than 85% max HR or RPE 8. Training that is not performed at the correct intensity will diminish or nullify the potential for chronic adaptations.

We saw in chapter 7 (page 154) that the lactate inflection point (LIP) occurs at a lower percentage for untrained people than for more trained performers. For most people, training at 87% max HR (for example) would elicit anaerobic adaptations. However, it is possible for highly trained aerobic athletes to have a LIP at 92% max HR. At 87% max HR, they would still be training their aerobic energy system. To train their anaerobic energy systems, they would need to train above 92% max HR in this example.

TABLE 12.3 Suggested training intensities

Training zone	Energy system trained	% max HR	%VO_2 max	RPE
Recovery	Negligible adaptations	<70	<50	0–2
Aerobic or continuous	Aerobic	70–85	55–75	3–6
At lactate inflection point (LIP)	Aerobic	85–90*	75–80*	7
Anaerobic	Anaerobic glycolysis	85–95	75–95	8–9
	ATP–PC	95+	100–200	10

*LIP can increase via aerobic training adaptations and elite endurance athletes can have LIP occurring at around 90% of their max HR

CHAPTER CHECK-UP

1 Identify the minimum number of training sessions required per week to either improve or maintain a specific fitness component.
2 Identify two ways of measuring intensity.
3 Describe one problem associated with heart-rate monitoring.
4 Draw a simple graph showing the relationship between heart rate and intensity.

TIME

Exercise time (or duration) can refer to either:

» the length of a training program (for example, 12 months)
» the length of the actual training session (for example, a minimum of 20 minutes to elicit aerobic adaptations)
» the length of a bout of exercise during a training session (for example, the length of the work phase in an interval training program)
» the minimum time a training program needs to be performed before chronic adaptations will be evident (assuming the other training principles are being met).

Periodisation

In the continual quest for performance improvement, sports science has developed a structure known as **periodisation**. Periodisation simply means organising training into manageable blocks or periods of time. While sports scientists have developed several different periodisation methods, there is overwhelming agreement that a structured approach to training will result in the greatest potential for improvement. Periodisation allows training goals to be set and offers the athlete an insight into their future training regime.

Periodised programs build in **tapering** and **peaking** to ensure a performer will be at their prime for a major competition. Tapering involves the reduction (or **unloading**) of training volumes leading into competition. This minimises the effects of any residual fatigue from training, so that the performers feel recharged, both physiologically and psychologically.

Only the volume of training is reduced; the intensity will remain relatively constant to maintain specificity. Tapering may be further accompanied by carbohydrate loading for events more than one hour in duration (see chapter 6).

Sports scientists and coaches, particularly those working with seasonal team sports, overlay training phases onto their plan to emphasise the type of training done in this time. These phases are preparation or pre-season, competition or in-season, and off-season or transition (see chapter 14).

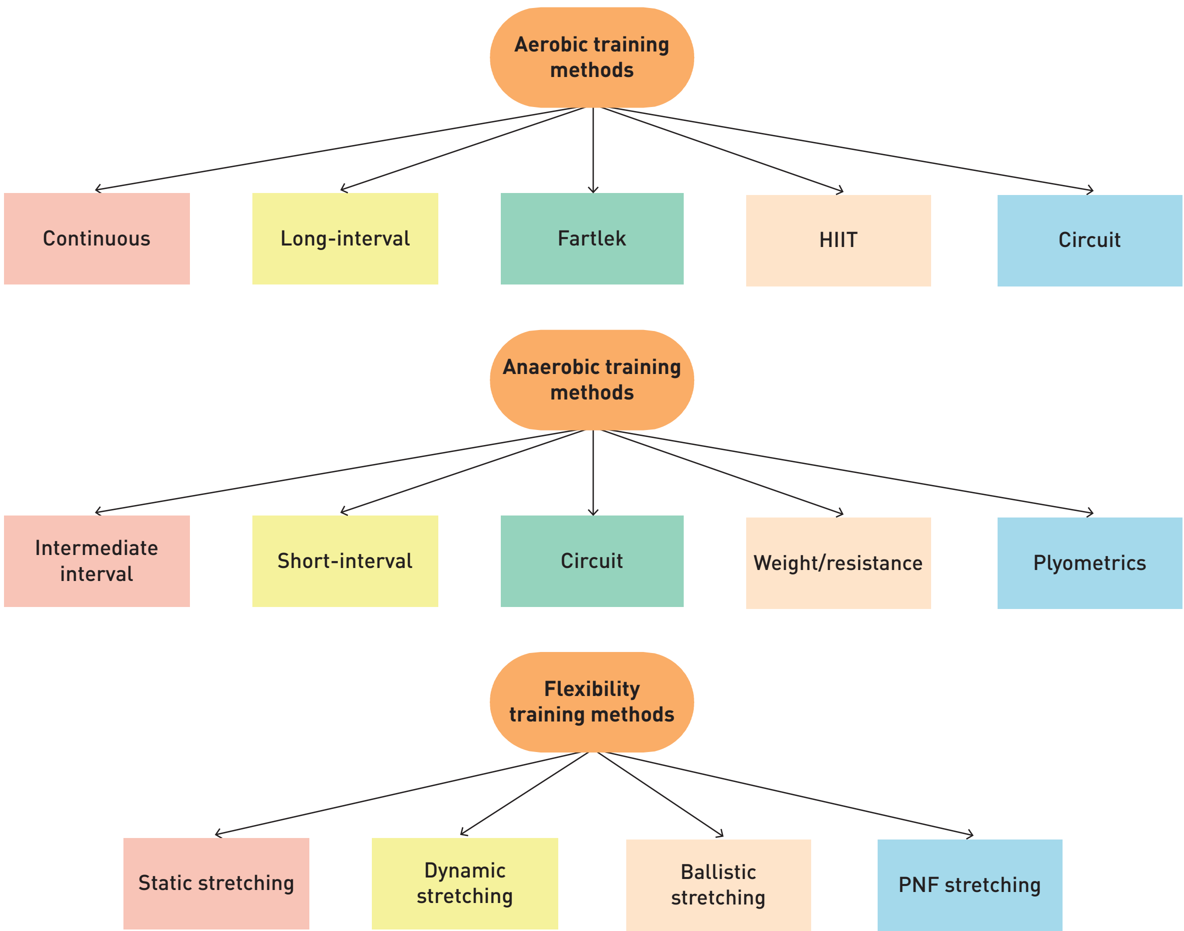
Every sport, athlete or individual will have different training goals, such as to complete a 5-kilometre fun run, or a full ironman triathlon. Regardless of the intended goal, a carefully structured training program with the correct application of training principles will enable the athlete to meet these goals in a safe environment.

The length of the training session itself is greatly influenced by the exercise intensity. Generally, as time increases, the intensity of the session will be lowered due to fatigue mechanisms (see chapter 7). For example, if exercising above the maximal lactate steady state (LIP), the accumulation of metabolic by-products (particularly hydrogen ions) will force the participant to train for a shorter time than when engaging in a continuous training session below their LIP.

This also applies to the work phase in an interval training program. Higher intensity intervals characterised by short-interval training (e.g. 4 × 50-metre sprints in 7 seconds per repetition) cannot be maintained for the same length of time as the work phase of a long-interval training program (e.g. 4 × 1-kilometre runs in 3 minutes per repetition).

TYPE

Type refers to the training method. Training methods can be classified as aerobic training methods, anaerobic training methods, or flexibility training (see chapter 13 for more detail).



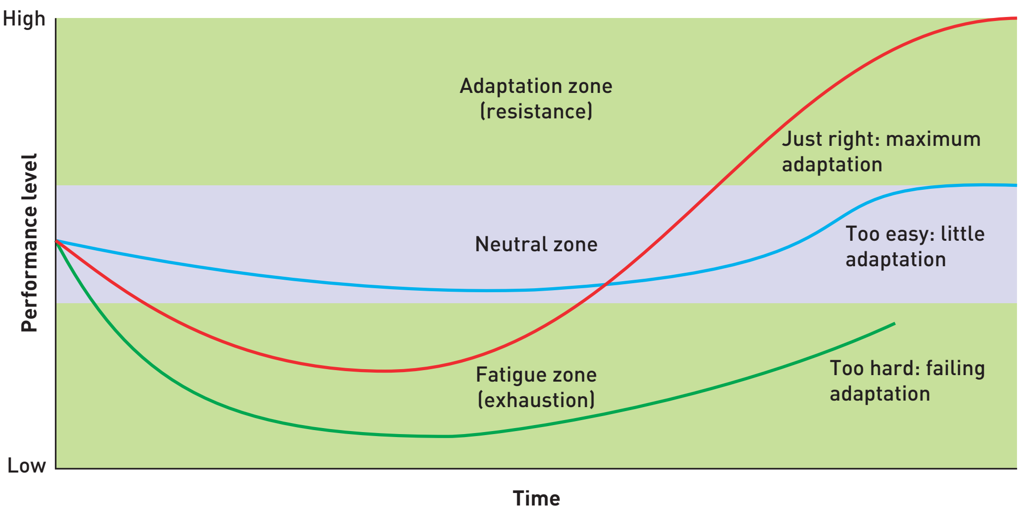
Aerobic, anaerobic and flexibility training methods

PROGRESSION

The goal of any training program is to cause positive long-term or chronic adaptations to enhance performance. Applying a new, unfamiliar workload stimulus to a performer (in any training method) will cause stress. The body's response to this stress, provided some fundamentals are met, will be to adapt in a positive manner. During this period of overload, performance parameters, from a physiological perspective, will likely decrease.

Once a performer becomes accustomed to this new training stimulus, adaptations will **plateau**. We need to apply progressive overload to training to ensure continual positive adaptations.

The first consideration is how much **overload** to apply. It is generally accepted that only one variable (training parameter) should be manipulated at a time, and that this overload should fall in the range of 2–10 per cent. Overload beyond 10 per cent may become too difficult and have the reverse effect, resulting in overtraining, increased risk of injury and performance setbacks. Conversely, an overload that is not challenging enough will cause minimal stress and therefore minimal, if any, adaptations. This is depicted below.



Performances of three athletes under three different training loads

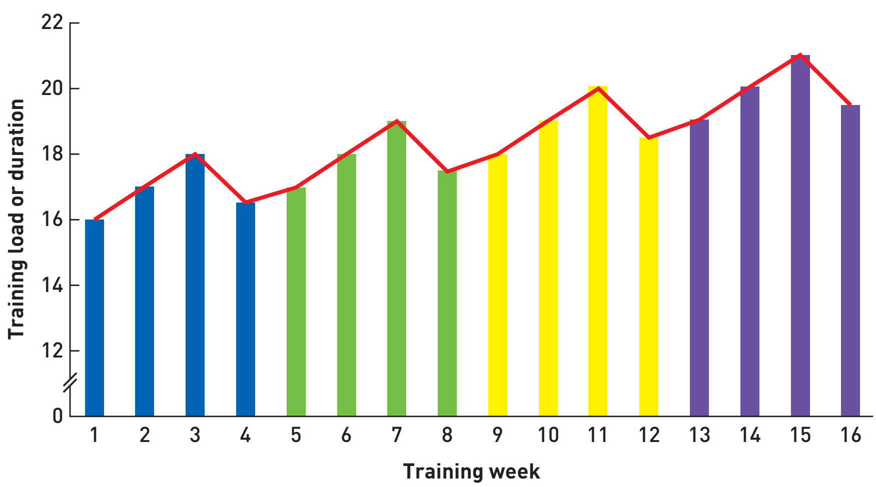
Adapted from: Pyke, 2001

When designing a training program, it can be difficult to know when to initiate an overload. In theory, this should occur when a performer has become accustomed to the existing workload, but this can be difficult to measure. This is why it is critical that participants keep records (a training diary) of both their training sessions and subsequent post-training wellbeing to provide qualitative insight into their response to their training program. This will be covered in greater detail in chapter 14.

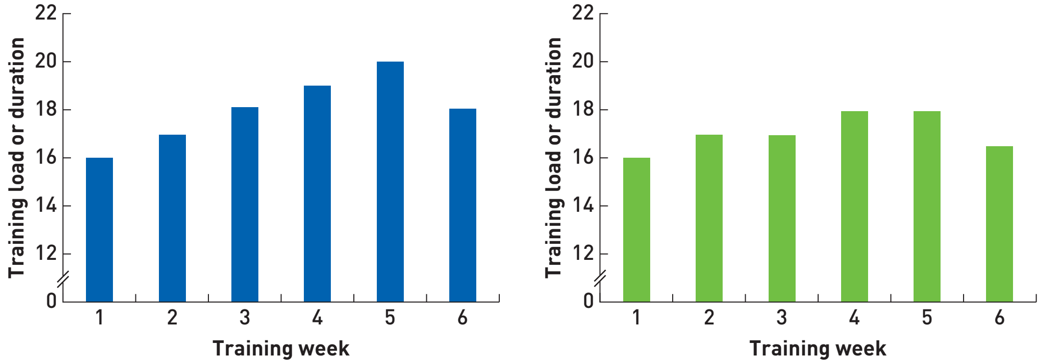
Overloading forms part of the overall program design. There are countless models that can be applied to manipulate training. One effective method is to apply a linear approach that focuses on training as a block of four weeks. In the first three weeks, overload is applied to the training program, and in the fourth week training is reduced. This reduction is known as unloading, and is important to counter the effects of cumulative fatigue, which may hinder adaptations and lead to overtraining. The assumption in this, and any, model is that the participant can cope with the overload.

When planned unloading occurs before an important competition or event it is usually referred to as tapering. The purpose in this instance is to reduce, and hopefully remove, any residual fatigue, allowing the participant to perform at their peak – that is, without any lingering physiological or psychological fatigue.

This four-week model could easily be modified to suit a six-week training cycle required as part of Outcome 2 for Unit 4. Two suggested models are shown in the graphs on the next page. The unloading in week 6 effectively introduces a taper into the program, allowing peaking to occur in the following week for any planned fitness retesting.



Four consecutive microcycles of four weeks (three weeks of overloading followed by one week of unloading)



Two models of progressive overload for a six-week training program. Which model has the greater potential to cause overtraining?

CHAPTER CHECK-UP

1 Outline the impact intensity has on the length of a training session.
2 List two aerobic training methods.
3 What is the purpose of unloading?
4 Distinguish between unloading and tapering.
5 What factors may lead to a training plateau?
6 'All tapering needs to be accompanied by carbohydrate loading.' Discuss.

SPECIFICITY

Specificity relates to tailoring a training program to the specific demands of an athlete's sport, position and other physiological requirements. Specificity should form the foundation of any training program to ensure the athlete achieves the maximum benefit from their training.

This is where data collection and activity analysis (see chapter 10) are essential in helping to identify the following factors: energy system usage, fitness components, major muscle groups and skill frequency, enabling the training program to meet the specific requirements of the activity.

Energy system usage

Energy system usage should be identified for the activity, and (if possible) for each individual position (or similar type of position) within the activity. This enables the appropriate training method to be selected.

If the dominant energy system is aerobic, one of the aerobic training methods (continuous, fartlek, long-interval) would be ideal. If one of the two anaerobic systems dominate and one of the anaerobic training methods (short-interval, medium-interval, plyometrics) is chosen, the duration of both work and rest must be considered carefully.

It is important to ensure that work-to-rest ratios used in training replicate those used in the game, and that the targeted energy system is not being compromised with a non-specific work-to-rest ratio that could change the intended emphasis of the training.

Fitness components

Fitness components that dominate the activity need to be identified, as do (where appropriate) fitness components that dominate for an individual in a team environment. A soccer goalkeeper, for example, would rely mostly on speed, agility and muscular power, whereas a midfielder would rely more on aerobic power and local muscular endurance. Short-interval sprints and plyometrics incorporating agility may be appropriate for the goalkeeper, whereas the midfielder may choose fartlek and continuous training to enhance their dominant fitness components.

Major muscle groups

Major muscle groups dominating the activity need to be identified to ensure that they are the focus of training. Balanced training of muscle groups also needs to be maintained, with the coordinated development of **synergists** and stabilisers, to ensure neuromuscular development. While a power forward in basketball may focus more on plyometrics training to develop leg power, a table tennis player may use plyometrics to focus on developing explosive upper body movements. The muscles involved with core strength should also be included in any training program, as they are integral to most sporting activities.

FYI

Initial improvements in strength and power are driven by neural adaptations without any increases in fibre size.

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Training must be sport-specific. What components would be important to an endurance cyclist but not to a sprinter?

Skill frequency

The most common skills of an activity need to be identified. While our focus in this chapter is on the physiological requirements, it is becoming increasingly popular to blend skills sessions with physiological training to more closely replicate the activity while developing fitness components. This is not to say that training for team events should only consist of practice games to mimic absolute specificity. Rather, parts of an activity can be incorporated into a training program to enhance skills, teamwork, strategies and physiological development. For example, for a basketball centre, practising rebounding would lead to improvements in both the skill of rebounding and the fitness component of muscular power, which is vital to this skill. Manipulating rest and number of repetitions would also enable the player to practise this skill while fatigued, which more closely resembles a game environment.

CHAPTER CHECK-UP

1. Without using the word 'specificity' or 'specific', describe the principle of specificity in your own words.
2. Chronic adaptations may still occur without applying specificity. What significant advantage does specificity add?
3. Push-ups form part of the training for many local sporting teams. Discuss whether push-ups meet the principle of specificity for a sport you are familiar with.

INDIVIDUALITY

Individuals tend to respond differently to a similar training stimulus. There are many reasons for this.

Genetic predisposition

Genetic predisposition includes fibre-type make-up. A person whose genetic predisposition includes a high percentage of slow-twitch fibres would respond more favourably to an aerobic-based program than someone with a high percentage of fast-twitch fibres. Conversely, a person with a high percentage of fast-twitch fibres will respond more favourably to a training method that is closely linked to the anaerobic energy systems, such as plyometrics and short-interval work. The mechanisms behind this are explained in chapter 15.

Initial fitness levels/training status

Performers with little exposure to a training method may need to begin with a reduced volume in order to avoid excessive fatigue, which can lead to overtraining injuries.

Preparedness

A performer returning from injury or illness may find that returning to a previous training stimulus causes excessive fatigue.

Adaptive response

Different people will have a different adaptive response to exercise, due to individual identity and physiological and psychological make-up. This includes factors such as hormonal, enzymatic, motivational and nutritional requirements.

Tailoring training to individual needs

Considering the above factors, it is clear that in order to optimise the potential for chronic adaptations, a training program must be tailored to suit the individual's needs. This can be exceptionally difficult to achieve in a team-sport environment, particularly at a local level, where there may be only one coach for the whole team.

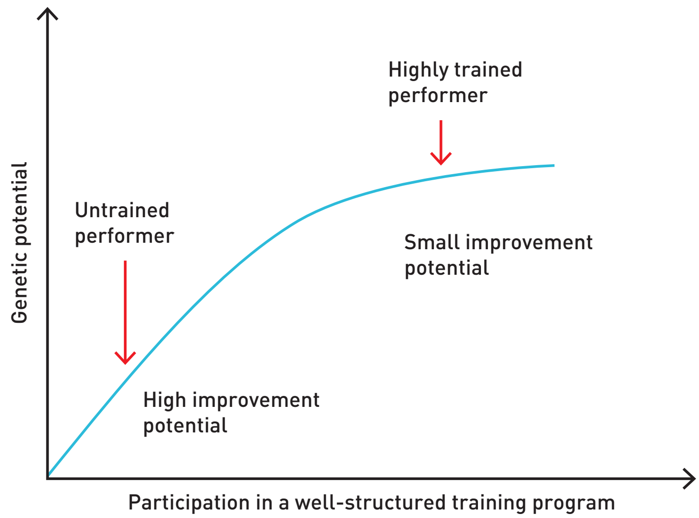
At a national level, particularly in well-funded sports, there is a growing trend towards a partially individualised program. Whole-team training is important to develop team cohesion, strategies and tactics, and to augment and strengthen the bond between team members. Areas where individualised supplementary training can be focused are identified through a needs assessment for each individual team member.

The transition, or off-season, phase of a training program is another important opportunity to address individual physiological weaknesses, so the individual can train specifically on these goals away from team-orientated training.

DIMINISHING RETURNS

Each individual has a genetic potential for fitness. An untrained performer will show greater initial improvements than their trained counterparts. As a performer gets closer to their ultimate potential, the rate of improvement significantly slows down. This is displayed in the graph at right.

A further consideration is that highly trained performers will need to spend considerably more time training for even the slightest improvements.



The law of diminishing returns

CHAPTER CHECK-UP

1. Outline two reasons why individuals may respond differently to the same training stimulus.
2. Draw a simple graph to show the principle of diminishing returns, using time and performance as the axes.
3. Discuss why individualising an off-season training program is a preferred option.

QUICKVID

Watch an interview with Neil Craig, currently Director of Coaching, Development and Performance at the Carlton Football Club, on training program principles. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 12, page 297.

Video

VARIETY

Varying a program may help to mentally reinvigorate a performer who is becoming bored. Variation may also lead to enhanced improvement through using a different training stimulus. An example is changing a barbell bench press to a dumbbell bench press. Although essentially a very similar exercise, the variation may provide a different stimulus.

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A change of scenery can add variety to a training program while maintaining specificity. What other changing variable do hills offer to a running-based program?

Runners may also choose different venues (such as hills, forests or beaches) to add variety and motivation to their training program. Performing a training program with a partner or group of friends may also add variety.

However, when considering adding variation to a training program, it is essential to remember specificity. If variety takes the training focus off the intended muscle groups, energy systems and fitness components, then specificity (and more importantly, the intended aim of the training program) may be lost. An occasional change of training type for a one-off session, such as competitors in a running-based team sport completing a swimming session, may be appropriate to combat mental staleness, but the focus of the training program should return to specificity as soon as possible.

MAINTENANCE

Fitness gains can be maintained by training twice per week, which is important in two scenarios. First, a needs analysis may have identified that a performer needed to improve a particular fitness component(s). Once the desired performance level has been met, the performer could move to a maintenance program, which requires less **training frequency**, freeing up available time for other priorities.

Second, maintenance is very relevant for those involved in seasonal sport. Players often welcome the end of the season as a time to relax, recover from niggling injuries and freshen up mentally after weeks of competition. However, given the amount of work that went into achieving fitness gains during the season, and the fact that these gains are almost immediately reversed if all training ceases, it is worth continuing to train at least twice per week. By maintaining fitness improvements during the off-season, participants avoid detraining and can return to a new pre-season with no loss of fitness, ready to develop their fitness further.

Finally, a coach may also decide that their player/s are at a physiological level they are comfortable with, and would prefer to maintain this fitness level so they can devote more training time to other parameters, such as tactics or set plays.

OVERTRAINING

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Recovery is the key to preventing overtraining.

The goal of any training program is to elicit chronic adaptations, which improve physiological performance. A carefully constructed training program will challenge the athlete by applying appropriate overload. The purpose is to stress the body, challenging it to respond in a positive manner through adaptations. This will often result in some soreness, which is part of the adaptive process.

The problem is when the athlete does not recover from this continual stress over a longer period of time, resulting in what is termed 'overtraining'. It is reported that 10–20 per cent of athletes experience the syndrome of overtraining or 'staleness' (McArdle et al., 2014). Overtraining is characterised by cumulative exhaustion that persists even after recovery periods. Overtraining causes long-term decreases in performance and an impaired ability to train – the exact opposite of training goals!

Preventing overtraining relies on a carefully constructed training program and appropriate recovery periods.

Applying the training program principles discussed in this chapter provides guidance in minimising the likelihood of overtraining. This is why planning (periodising) a training program is critical. Flexibility is also required to adjust the training program, if a performer is not sufficiently recovering from training sessions.

The challenge for any performer is to build sufficient rest and recovery into the training program. Positive chronic adaptations occur during rest, not during training. Insufficient rest means the performer will go into the next training session not fully recovered, compounding fatigue. Ultimately, if this imbalance between insufficient rest and excessive training without full recovery continues, performance will decline. The performer may then feel that they are not training hard enough and may attempt to increase training, compounding the problem further.

When recovering from an injury, why is it important to do as much training as possible without aggravating the injury?

Signs and symptoms of overtraining

There are more than 125 signs and symptoms of overtraining, making a definitive diagnosis challenging. The American College of Sports Medicine has identified as the most common symptoms:

» persistent heavy, stiff, and sore muscles
» persistent fatigue, washed-out feeling
» decrease in performance and ability to maintain the training regimen
» increased susceptibility to infections, colds, headaches
» nagging and somewhat chronic injuries
» sleep disturbances
» decreased mental concentration and restlessness
» increased irritability
» depression
» tachycardia and, in some cases, bradycardia
» loss of appetite and weight loss
» bowel movement changes
» absence of menstruation.

Monitoring for overtraining

Maintaining a training diary/log is valuable in helping to identify the signs of overtraining. The diary should record how you feel each day (your mood and motivation towards training) as well as entries on resting heart rate, sleep and overall physiological state (soreness).

Performances should be monitored for trends. A downward trend may indicate insufficient recovery. Regular fitness testing could also be beneficial in providing this type of information.

There is also some evidence to suggest that resting heart rate could be an early warning sign of overtraining. Having established a base heart rate over a week, any future increase of 10 or more above this should be seen as a warning that you have not fully recovered from a previous workout, are fatigued or stressed, and could be heading towards overtraining. In this instance, consideration should be given to either reducing any scheduled training for that day or simply resting.

DETRAINING

Detraining is often referred to as reversibility. As the name suggests, this is the termination of training (or more specifically, of a training method) and the corresponding and rapid return to pre-training levels.

The termination of training can occur for a variety of reasons, such as injury, illness, boredom or even a poorly planned training program. Regardless of the reason, the end result is still the same – the reversal of previously achieved improvements.

The effects of aerobic detraining are almost immediate. Insufficient aerobic training has been shown to decrease VO_2 max by 8 per cent in as little as three weeks, and 18 per cent in 12 weeks. Some of the parameters associated with detraining are presented in Table 12.4. Similar decreases in performance are also evident in other fitness components when detraining occurs.

TABLE 12.4 The effects of detraining on aerobic parameters

Variable	Percentage change (%)	
	Less than 3 weeks of detraining	3 to 12 weeks of detraining
VO_2 max	–8	–18
Cardiac output	–8	–10
Stroke volume	–10	–13
a-vO_2 diff	–2	–7

Adapted from: McArdle, Katch & Katch, 2015

Detraining occurs even more quickly for those with immobilisation injuries. This helps explain why some form of rehabilitation is often prescribed for a performer as soon as they are considered able to manage it.

Detraining also emphasises the importance of the transition or 'off-season' stage of a competition season. In most team sports there is usually a period of several weeks to a few months before the pre-season training program commences. Higher-level sporting competitions such as the AFL will prescribe transition training programs for their players, with the expectation that they will meet certain fitness requirements, via testing, on their return.

The transition phase is an appropriate time to add variety. For example, bicycle riding could be utilised as an effective training method for a running-based sport. While not specific to running, it will help to maintain aerobic capacity, avoiding the consequences of detraining.

CHAPTER CHECK-UP

1 The end of season often initiates a period of detraining. Discuss some alternatives that will still allow the performer time for regeneration.

2 Draw a T-diagram and label at least three benefits and three problems associated with variety.

CHAPTER SUMMARY

- To maximise fitness improvements, it is important to apply sound training principles to any training program. This will capitalise on the training effect and reduce the likelihood of injury.
- Specificity must form the foundation of any training program in order to maximise the desired outcome. Training should be specific to the energy system(s), fitness components and major muscle groups identified for a particular activity. Core strength development is now recognised as an important consideration for training.
- A minimum of three training sessions per week are required for improvement. Fitness gains can be maintained through two training sessions per week. Fitness gains are quickly reversed if training is not at least maintained.
- Intensity refers to the level of exertion and can be measured by heart rate, rate of perceived exertion, accelerometers and GPS tracking systems.
- For performance improvements to continue, training needs to be overloaded. This should occur when the performer has adapted to the current workload. Only overload one parameter at a time, and never by more than 10 per cent.
- Training induces a catabolic (destructive) effect followed by an anabolic (constructive) effect during the recovery period. It is during the recovery periods between training sessions that many of the physiological adaptations to training occur. Building sufficient recovery into a training program is vital.
- Periodisation is the structured planning of a training program to elicit optimal training and competition benefits, and includes both overload and recovery periods. Periodisation can be further classified into phases of pre-season, in season and transition.
- The risk of overtraining can be minimised by following a carefully structured training program, being prepared to adjust the training program and allowing sufficient rest and recovery. Maintaining a training diary is important in monitoring training.
- As performers continue to train, the rate of improvement will decrease (the principle of diminishing returns).
- Where possible, a training program should be individualised for each performer. A training needs analysis should be conducted before the commencement of any training program.

CHAPTER REVIEW

Multiple-choice questions

1 A telltale sign of lack of specificity in training is
  A muscle soreness.
  B tiredness.
  C dizziness.
  D moodiness.

2 Which of the following training intensities will improve aerobic capacity?
  A 90% of maximum heart rate
  B 50% of maximum heart rate
  C 60% of VO_2 maximum
  D RPE of 8 (on the CT scale)

3 The first consideration of any training program is
  A variety.
  B specificity.
  C maintenance.
  D progression.

Short-answer questions

4 James, a 27-year-old sedentary male, decides to commence an aerobic training program with the aim of completing a 10-kilometre fun run in six months' time. He engages in a long-interval training program seven days per week, believing that this will increase his fitness in the shortest possible time.
  a What will the likely outcome of the training program be?
  b Construct a more suitable six-week training program for James. Include frequency, intensity, time, type and progressions in the design of this program.
  c James follows your program for four months, then starts to feel a little stale. Suggest some alternative activities that could be completed without losing sight of the goal of the training program.
  d Two weeks before the event, James believes he will run 10 kilometres in 50 minutes. He seeks your advice on some new concepts he has heard about: tapering and carbohydrate loading. Advise James on these two concepts, including the suitability of each for this event.

5 Variety can either complement or be in contrast to the goal of a training program.
  a Discuss how variety can be utilised to complement a training program.
  b Discuss how variety could be in contrast to the goal of a training program.
  c Why would variety be used if it is in contrast to the goal of a training program?

CHAPTER 13

FITNESS TRAINING METHODS

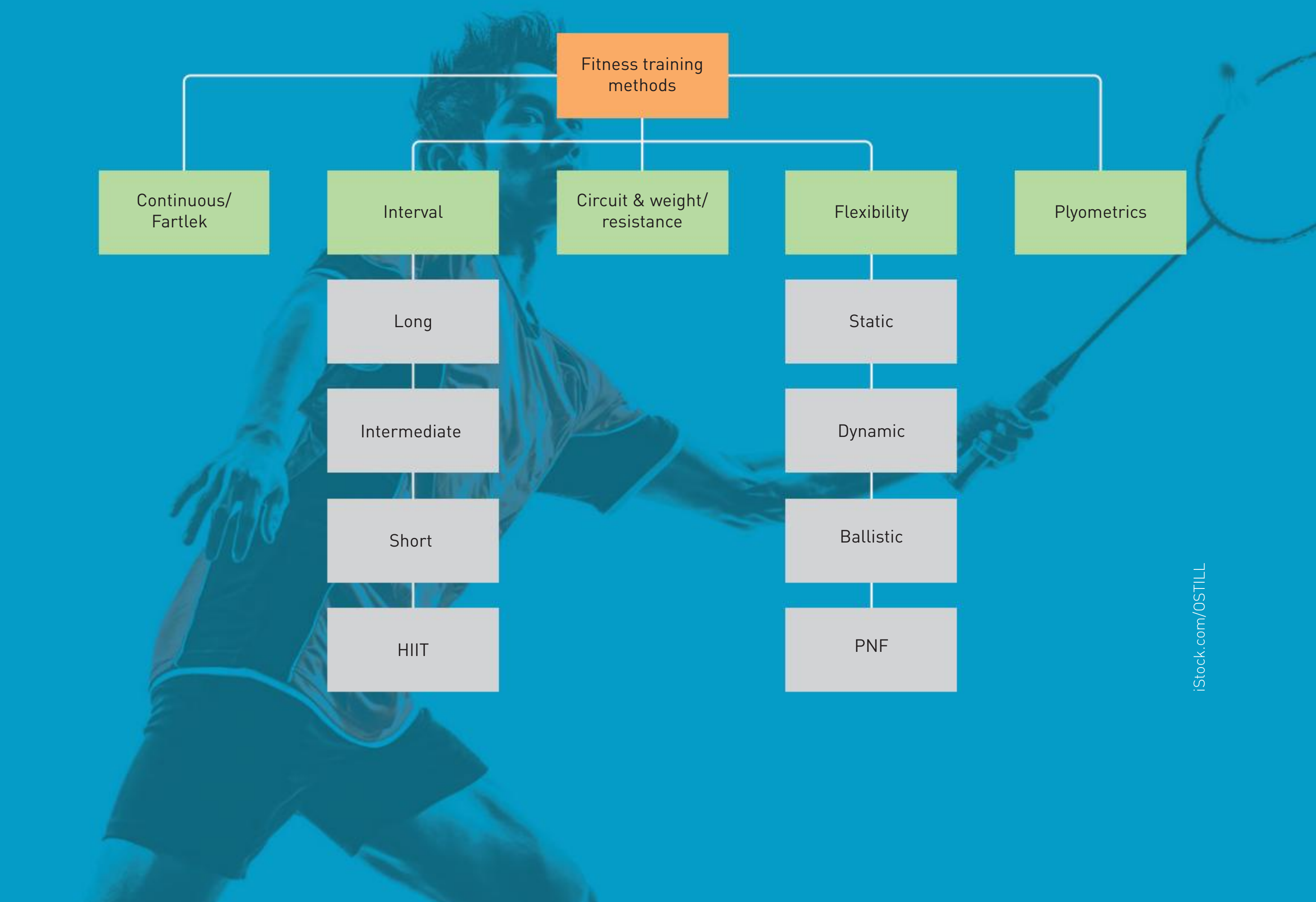
Key knowledge

- training methods including continuous, interval (short, intermediate, long and high intensity), fartlek, circuit, weight/resistance, flexibility and plyometrics

Key skills

- conduct and participate in all components of an exercise training session

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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METHODS OF TRAINING

The goal of any training program is to develop the sporting potential of a performer, from a physiological perspective. Table 13.1 summarises a number of training methods that a coach and/or performer can choose from, and the fitness components they will develop.

This table also highlights the energy system that initially dominates the training method. However, as discussed in detail in chapter 6, energy system interplay still forms the foundation of any training method.

TABLE 13.1 Training methods and the major fitness components they develop

Training method	Page number	Anaerobic capacity	Muscular power	Muscular strength	Speed	Local muscular endurance (LME)	Aerobic Power	Flexibility	Body composition
Energy system(s)[1]		ATP–PC and/or anaerobic glycolysis	ATP–PC and/or anaerobic glycolysis	ATP–PC and/or anaerobic glycolysis	ATP–PC and/or anaerobic glycolysis	Anaerobic glycolysis and/or aerobic	Aerobic		
Continuous	305						Yes		Yes
Fartlek	307						Yes		Yes
Long-interval	310						Yes		Yes
Medium-Interval	311	Yes			Yes	Yes			
Short-interval	312	Yes			Yes				
High-intensity interval	313	Yes					Yes	Yes	Yes
Resistance	315	Yes	Yes	Yes	Yes	Yes			Yes
Plyometrics	319	Yes	Yes		Yes				
Circuit	321	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flexibility	323							Yes	

[1] When ATP is depleted, the anaerobic glycolysis system will dominate energy supply for the fitness components initially dominated by the ATP–PC system.

CONTINUOUS TRAINING

Also known as long slow distance (LSD) training, continuous training involves performing an activity, such as jogging, cycling, rowing or swimming, at a submaximal intensity in the aerobic training zone of between 70–85 per cent of maximum heart rate. The activity needs to be nonstop, for at least 20 minutes.

Continuous training forms the foundation for other, more demanding, aerobic training methods, such as long-interval training or fartlek. As continuous training is a less demanding

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Continuous training can be performed using a variety of mediums

aerobic training method, it is also associated with a lower risk of injury. It is ideally suited for a beginner commencing an aerobic training program.

To maximise the benefits of continuous training, a heart rate range of 70–85% max HR should be maintained. This is known as the aerobic training zone, and is shown in the graph below.

The minimum length of time for an effective continuous training session is 20 minutes, but specificity also needs to be taken into consideration. If a performer intended to compete in an extended endurance event such as a marathon, completing continuous sessions of 20 minutes would not be sufficient to thoroughly prepare the performer. Extended sessions would need to be added to the training program.

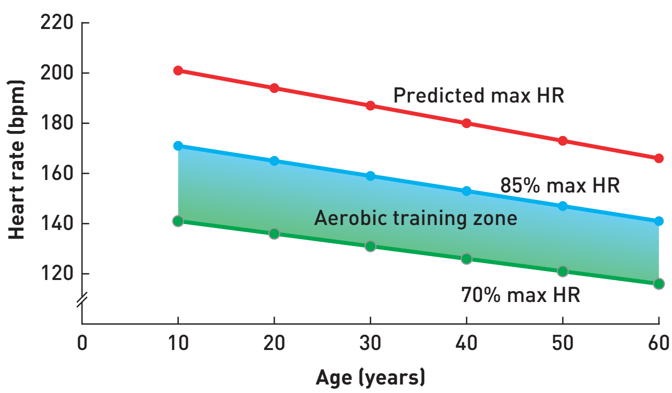
Continuous running frequently forms part of the initial pre-season training for team sports, and is often referred to as 'building a base'. In this instance its purpose is to prepare the body, and particularly the muscles associated with running, for more specific higher-intensity running that will inevitably occur later as part of the pre-season program.

Continuous training can be overloaded in a number of ways, including:

» increasing the running time
» increasing the distance
» increasing the intensity
» changing the terrain, such as running up hills or on sand
» reducing the time taken to run a particular distance.

FYI

At the lower end of the aerobic training zone you should be able to comfortably talk to a running partner for the duration of the run.



Aerobic training zone

PRACTICAL ACTIVITY
CONTINUOUS TRAINING

Complete a continuous training session. The training type could include running, swimming, cycling, rowing or using gym apparatus aimed at developing aerobic power, such as a cross-trainer or stationary bike.

TRAINING DIARY / LOG

Name: *Emily Brown*
Date & time: *24/1/16, 6 a.m.*
Location: *Norton's Park Weather conditions: 17 °C, cloudy*
Pre-training comments: *Mood 9/10. Energy levels 8/10. Motivation 9/10.*
Training session focus: *Aerobic power*
Planned session: *Continuous running; 10 km in 50 minutes*
Post-training reflective comments:

- *Part of long-term training for 2017 marathon.*
- *Took the first 1 km easy before increasing intensity to heart-rate target.*
- *HR maintained @ 145+/- 5 via Suunto GPS and heart rate strap.*
- *Ran a fraction easy; aim for under 49 minutes next time.*
- *Walked for 500 m after run and then completed usual stretching routine.*
- *Feeling really good.*

Completed training diary for a continuous training session

FARTLEK TRAINING

Fartlek is the Swedish word for 'speed play'. It combines continuous running with random bursts of speed, increasing the contribution of the anaerobic energy systems to help meet the increased energy demand during these random higher intensity periods. By definition, these bursts of speed (or higher-intensity periods) are random, and therefore fartlek is more suited to intermediate or advanced runners who have both the experience and discipline to engage in this type of training. A popular application of fartlek used by cyclists and endurance runners is 'hill work'. The hills force a random change in intensity.

The advantage of fartlek training is that it improves both the aerobic (primary focus) and anaerobic energy systems and related fitness components (aerobic power, anaerobic capacity and speed). However, the random nature of fartlek makes it difficult to overload, and considerable discipline is required to repeatedly perform random bursts of speed.

Fartlek training is usually associated with running, but it could be adapted to almost any kind of exercise. Although by definition fartlek training is unstructured, there are now several structured fartlek training sessions (see page 308). It could be argued that these sessions, with their floating recoveries, are versions of long-interval training programs.

It is also important to allow sufficient time to warm up before attempting any bursts of speed. The first 10 minutes of the training session should be devoted to gradually increasing the intensity of the continuous component of the fartlek session.

Fartlek training could be overloaded by increasing the:

» overall time of the fartlek session
» distance of each burst of speed
» intensity of each burst of speed
» frequency of the bursts of speed.

Sample fartlek running training sessions
Introductory fartlek training session This is an easy introduction to fartlek if you have access to an oval. After allowing sufficient time to warm up, you can either stride the straights and jog the bends or vice versa (stride the bends and jog the straights) for a set period of time. Remember to allow time to cool down.
Cross-country training fartlek session After warming up for 10 minutes: » run above your race pace for 3-4 minutes » use a recovery jog for 1 minute » repeat 4-8 times (depending on your fitness level and available time) » cool down.
Gerschler fartlek training session This session reduces the jog recovery by 15 seconds after every **repetition**. After warming up for 10 minutes: » near max effort for 30 seconds » recovery jog for 90 seconds » near max effort for 30 seconds » recovery jog for 75 seconds » near max effort for 30 seconds » recovery jog for 60 seconds » near max effort for 30 seconds » recovery jog for 45 seconds » near max effort for 30 seconds » recovery jog for 30 seconds » near max effort for 15 seconds » repeat 3 times » cool down.
Astrand fartlek training session (middle-distance runners) After warming up for 10 minutes: » near max effort for 75 seconds » recovery jog for 150 seconds » near max effort for 60 seconds » recovery jog for 120 seconds » repeat 3-4 times » cool down.
Whistle fartlek training session Your PE teacher (or coach/peer) controls this session with the use of a whistle. When the whistle is blown you increase your intensity until the whistle is blown again to signify a recovery jog. A typical session is to pyramid the 'work' phase, utilising a 60-second recovery jog between bursts of speed. Pyramids could be adjusted based on fitness levels. After warming up for 10 minutes: » increase intensity for 4 minutes » recovery jog for 60 seconds.

Sample fartlek training sessions

INTERVAL TRAINING

Interval training alternates higher-intensity work periods with rest or reduced intensity activity. Research has demonstrated that a greater volume of exercise can be performed by breaking the exercise into shorter, more intense bouts, interspersed with rest.

Depending on the length of the work and rest periods, interval training can be used to develop any of the three energy systems. Interval training can be further classified into long-interval, intermediate-interval (also known as medium) and short-interval training, and high-intensity interval training (HIIT).

Benefits of interval training

» Higher intensities can be maintained for the work phase of the program, enhancing the quality of the session.
» Pacing can be developed.
» Specific energy systems can be targeted.
» Lactate tolerance (medium-interval), which is crucial in many sporting pursuits, can be developed.
» Interval sessions can be specific to the game, with similar **work-to-rest ratios**.
» Sessions are highly structured, which enables progress to be measured.

Before exploring the different interval training modalities, it is important to have a basic understanding of the terminology associated with interval training. Table 13.2 highlights, with a running example, some of this terminology.

TABLE 13.2 Interval-training terminology

Term	Meaning	Example: running
Work interval	Period of time work is undertaken	6 seconds
Rest interval	Relief time between work periods	60 seconds
Work intensity	Required exertion level of work interval (either RPE or % max HR)	RPE 9–10
Repetition (rep)	Number of times the work interval is repeated	6
Set	A series of repetitions is deemed to be a set	3
Interval distance	Distance of each repetition, usually in metres	50 metres
Work-to-rest ratio	Work interval divided by rest interval, expressed as a ratio	6 ÷ 60 = 1:10
Total distance	Distance of each rep × number of reps × number of sets	50 m × 6 × 3 = 900 m
Recovery method	Method of recovery (active or passive)	Passive
Training frequency	Number of times per week the training session is repeated	3

Applying intensity to interval training

The correct application of intensity is vital to maximise the benefit of the training session. Common approaches to applying intensity to an interval training session include:

» Percentage of maximal heart rate. This method can be beneficial for long-interval training, but heart-rate lag means it's not really suitable for shorter-interval training sessions.
» Rate of perceived exertion (RPE). Particularly appropriate for shorter-interval training sessions.
» Time to complete a repetition. Assuming that an appropriate work-to-rest ratio has been assigned, quicker target times for the work period for a set distance will enforce a higher intensity, and vice versa.

Long-interval training

Long-interval training is where the work period is dominated by the aerobic energy system. This occurs when the work period is 1 minute or longer, or the work-to-rest ratio is 1:1 or greater (2:1, 3:1 etc.).

The aim of long-interval training is to increase the performer's lactate inflection point (LIP). As mentioned earlier, higher intensities can be achieved because of the provision for rest after each repetition. Long-interval training is usually performed at an intensity approximating a performer's LIP, or very slightly above this. Depending on the intensity of the work period, there may also be some lactate tolerance benefits as well.

FYI

Floating recovery is where the same activity is being continued at a reduced intensity, for example, when Tour de France cyclists are winding their way down a hill.

Long-interval training can be particularly beneficial in developing pacing (that is, the pace required to achieve a certain time in an aerobic-dominated event). For example, a 1500-metre swimmer would like to achieve a time of 15 minutes. The average pace to achieve this would be 100 metres in 1 minute. By performing five **repetitions** of 100 metres in 1 minute, each followed by 1 minute's rest, the swimmer could get the feel of the pace required to achieve the desired time.

It is not uncommon to use a 'floating recovery' during long-interval work. This is where the rest (or 'float') is simply a very slow jog for the allocated time, and perhaps to cover a certain distance. This could be considered an active recovery.

Long-interval training can be a great starting point for someone who has done little fitness work. By working at a lower intensity of 70% max HR, and alternating this with longer rest periods, a novice can be introduced to aerobic conditioning. See Table 13.3 for some sample training intervals.

TABLE 13.3 Sample long-interval training for running

Session A					
Sets	Reps	Distance	Time	Recovery time	Intensity
2*	3	400 metres	60–90 seconds	60–90 seconds	85% max HR
Session B					
1	4	1 kilometre	3–5 minutes	1 ½–2 ½ minutes	85% max HR

* 3–5 minutes' rest between sets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Participants involved in an interval running session

PRACTICAL ACTIVITY

Complete either a fartlek or long-interval training session (or both!). The training type could include running, swimming, cycling, rowing or using gym apparatus aimed at developing aerobic power such as a cross-trainer or stationary bike.

Intermediate (medium) interval training

In intermediate-interval training the work period is dominated by the anaerobic glycolysis energy system. This occurs when the work period is between 15 and 60 seconds and the work-to-rest ratio is either 1:2 or 1:3.

The aim of medium-interval training is to develop tolerance to metabolic by-products, particularly hydrogen ions, and it is often termed lactate tolerance training. This is particularly important for team sports that regularly require performers to maintain high-intensity output in the presence of metabolic by-products (often termed speed endurance).

The body needs to accumulate metabolic by-products in order to build a tolerance to their fatiguing effect. This means the intensity needs to be high, above a performer's lactate inflection point (LIP), in order for metabolic by-products to accumulate. This type of training can cause the highest levels of discomfort for a participant.

Due to the intense nature of this type of training, a thorough warm-up should be completed before commencing the conditioning phase (the interval work) of the training session. See Table 13.4 for some suggested training intervals.

TABLE 13.4 Sample intermediate interval training for running

Session A					
Sets	Reps	Distance	Time	Recovery time	Intensity
2*	4	200 metres	30–40 seconds	60–80 seconds	RPE 8 or 9
Session B					
1	5	400 metres	60–90 seconds	2–3 minutes	RPE 8 or 9

* 3 minutes' rest between sets

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Boxing mitt work can be an effective medium for interval training.

Short-interval training

In short-interval training the work period is dominated by the ATP–PC energy system. This occurs when the work period is under 10 seconds and the work-to-rest ratio is at least 1:5. The rest component should be passive and cannot be reduced below 1:5, as this would change the emphasis of the energy system being trained. The high-intensity nature of this type of training means it is critical that participants have thoroughly warmed up beforehand.

The aim of short-interval training is to improve speed. While there are a number of chronic adaptations being developed, increased PC stores is a desired adaptation. This will enable the performer to work at their highest intensity for longer. See Table 13.5 for some suggested training intervals.

TABLE 13.5 Sample short-interval training for running

Session A					
Sets	Reps	Distance	Time	Recovery Time	Intensity
2*	9	20 metres	Complete a repetition every 20 seconds		RPE 9 or 10
Session B – Pyramid					
Sets	Reps	Distance	Time	Recovery time	Intensity
1	4	50m	6–10 seconds	30–60 seconds	RPE 9 or 10
1	6	20m		20 seconds	RPE 9 or 10
1	8	10m		15 seconds	RPE 9 or 10
1	6	20m		20 seconds	RPE 9 or 10
1	4	50m	6–10 seconds	30–60 seconds	RPE 9 or 10

* 3 minutes' rest between sets

High-intensity interval training (HIIT)

High-intensity interval training (HIIT) is a relatively new aerobic training concept involving periods of short, high-intensity work followed by periods of lower intensity recovery. Limited research has shown that HIIT training can elicit many of the training effects usually reserved for more traditional aerobic training methods such as continuous training or fartlek. Most research methodologies have used stationary bicycles.

These sessions are shorter in duration than many of the more traditional aerobic training methods, and therefore offer an effective training alternative to people with limited time. As with both short- and medium-interval training, a thorough warm-up is vital before commencing the conditioning phase of the training session.

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Why have most HIIT studies focused on stationary cycling?

There is no set formula to HIIT training, but two different methods are presented in Table 13.6.

TABLE 13.6 Samples of HIIT training for cycling

Session 1	Session 2 (10–20–30 model)
After completing a thorough warm-up, attempt the following: » On a stationary bicycle* complete 30 seconds of maximal effort (RPE 9 or 10) followed by 4 minutes of rest. » Repeat 4–6 times.	After completing a thorough warm-up, attempt the following: On a stationary bicycle* cycle at » low speed for 30 seconds » moderate speed for 20 seconds » high speed (RPE 9/10) for 10 seconds. Total time for 1 repetition is 1 minute. Perform five repetitions continuously, followed by 2 minutes of low/moderate speed recovery. Repeat 3–4 times.

*substitute running if a stationary bicycle is not available

INVESTIGATION

Weblink

There are several different HIIT training methods. In small groups, research one of the studies on HIIT training, including the training prescription, and present your findings in class. Well-known HIIT researchers include Professor Martin Gibala, Professor Izumi Tabata and Thomas Gunnarsson.

Applying overload to an interval-training program

Overload can be applied by:

- » increasing the number of repetitions
- » increasing the number of sets
- » increasing the distance
- » increasing the intensity within the set zone
- » increasing the duration of work
- » decreasing the amount of rest.

Note that increasing the duration of work may change the dominant energy system, and decreasing the rest will change the work-to-rest ratio. Both may have an impact on the intended aim of the training program. For example, if the work-to-rest ratio is changed from 1:6 to 1:3, the emphasis has shifted from the ATP–PC system to the anaerobic glycolysis energy system.

CHAPTER CHECK-UP

1 Outline two benefits of continuous training.
2 Summarise the benefits of interval training.
3 Draw a Venn diagram for interval training. Include all three modalities (short-, medium- and long-interval).
4 Discuss some of the difficulties with overloading a fartlek training session.

PRACTICAL ACTIVITY

TRAINING SESSION

Complete either a medium-, short- or high-intensity interval training session. In your reflective folio entry ensure you comment on how you felt both during the high-intensity bursts and immediately post-session. If you completed a HIIT session, is this something that is sustainable for you in the long term?

RESISTANCE/WEIGHT TRAINING

There is an enormous amount of information available on weight-training programs, including the number of sets and repetitions that should be performed. As discussed in chapter 12, individualisation is an important training principle, particularly when it comes to resistance training. Many of the weight-training programs available through sources such as magazines or the internet are suitable for a specific participant only, and may lead to injury if followed without careful consideration of the individual's health status and needs.

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Safety can be improved by training with a partner. What is another advantage of training with a partner?

There is also conflicting information available regarding the correct training **load**, including **sets** and **repetitions**. There is no doubt that a properly constructed and individualised weight-training program will enhance sporting performance. The American College of Sports Medicine (ACSM) is considered the world's leading authority on exercise prescription. Weight-training guidelines from the ACSM are presented in Table 13.7.

Benefits of weight training

Weight training:

» increases strength; allows an increase in force production
» promotes weight loss and balance
» helps prevent osteoporosis
» improves psychological wellbeing
» improves dynamic stability
» forms the foundation for the development of speed, power and agility.

The following general guidelines are adapted from the American College of Sports Medicine (ACSM, 2010):

» The establishment of proper technique in the performance of weight-training exercises is paramount. Poor technique will significantly increase the risk of injury.
» Proper technique will increase the rate of improvement.
» **Multi-joint exercises** should be performed before **single-joint exercises**.
» Larger muscle groups should be exercised first.
» **Novices** should focus on whole-body programs.

TABLE 13.7 Weight-training guidelines

Desired outcome	Repetition maximum	Repetition range	Sets	Repetition speed	Rest periods
Novice and intermediate					
Muscular strength	60–70%	8–12	1–3	Slow and moderate	2–3 minutes between sets
Muscular hypertrophy	70–85%	8–12	1–3	Slow to moderate	1–2 minutes between sets
Muscular power	30–60%	3–6	1–3	As fast as possible	2–3 minutes between sets
Muscular endurance	40–60%	15–25	1–3	Slow to moderate	1 minute
Advanced					
Muscular strength	80–100%	1–12 (emphasis on 1–6)	3–6	CON* 1–2 seconds ECC** 1–2 seconds	2–3 minutes between sets
Muscular hypertrophy	70–100%	1–12 (emphasis on 1–6)	3–6	Continuum	2–3 minutes between sets
Muscular power	30–60%	3–6	3–6	As fast as possible	2–3 minutes between sets
Muscular endurance	40–60%	15–25	3–6	Slow to moderate	1 minute

*CON = concentric muscle actions **ECC = eccentric muscle actions

Adapted from: ACSM, 2010

Resistance-training intensity

Muscle fibres are recruited according to intensity levels. Slow-twitch fibres are recruited at lower intensities. As intensity increases, fast-twitch fibres are recruited. This is known as preferential recruitment of muscle fibres. Strength, power and hypertrophy training are purely anaerobic activities and need to be performed at an intensity that will not only recruit fast-twitch fibres but also place them under stress to elicit maximal chronic adaptations. To achieve this, the final repetition of a set must be to near exhaustion to ensure maximal recruitment of fast-twitch fibres.

Initial gains from a weight-training program can occur rapidly. These gains are neural-driven; that is, the neural pathways become more efficient in both recruitment and firing rates.

Studies have shown that combining resistance training with plyometrics will result in significantly greater muscular power improvements.

Resistance-training exercises

TABLE 13.8 Resistance-training exercises

	Free weights	Machine	Own body resistance
Back	 bent-over dumbbell row	 lat pulldowns	 chin-ups
Legs	 dumbbell squats	 seated leg press	 burpees
Shoulders	 upright row	 seated shoulder press	 handstand push-up
Chest	 bench press	 machine-assisted bench press	 push-up

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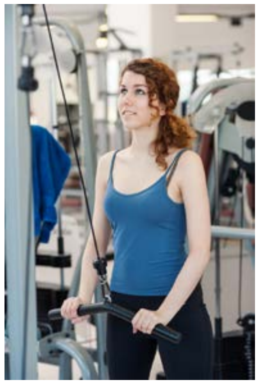
	Free weights	Machine	Own body resistance
Biceps	 biceps curl	 biceps curl using resistance machine	 pull-up
Triceps	 one-arm dumbbell extension	 triceps pushdown	 dip

Abdominals: It is extremely important to also add core/abdominal exercises to any workout		
 abdominal crunches	 plank	 opposite arm and leg raise

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INVESTIGATION

DEBATE: FREE WEIGHTS VERSUS EXERCISE MACHINES

Weight training can be performed using free weights (dumbbells, barbells and the like) or highly sophisticated equipment such as Cybex, Nautilus and Hydra-gym equipment. There are advantages and disadvantages for each.

Using a range of resources, including the internet, research the advantages and disadvantages of free weights compared with weight-training machines. Summarise your findings in a table and provide a conclusive statement. If time permits, debate the pros and cons in class.

PRACTICAL ACTIVITY

DESIGN AND PARTICIPATE IN A RESISTANCE TRAINING SESSION

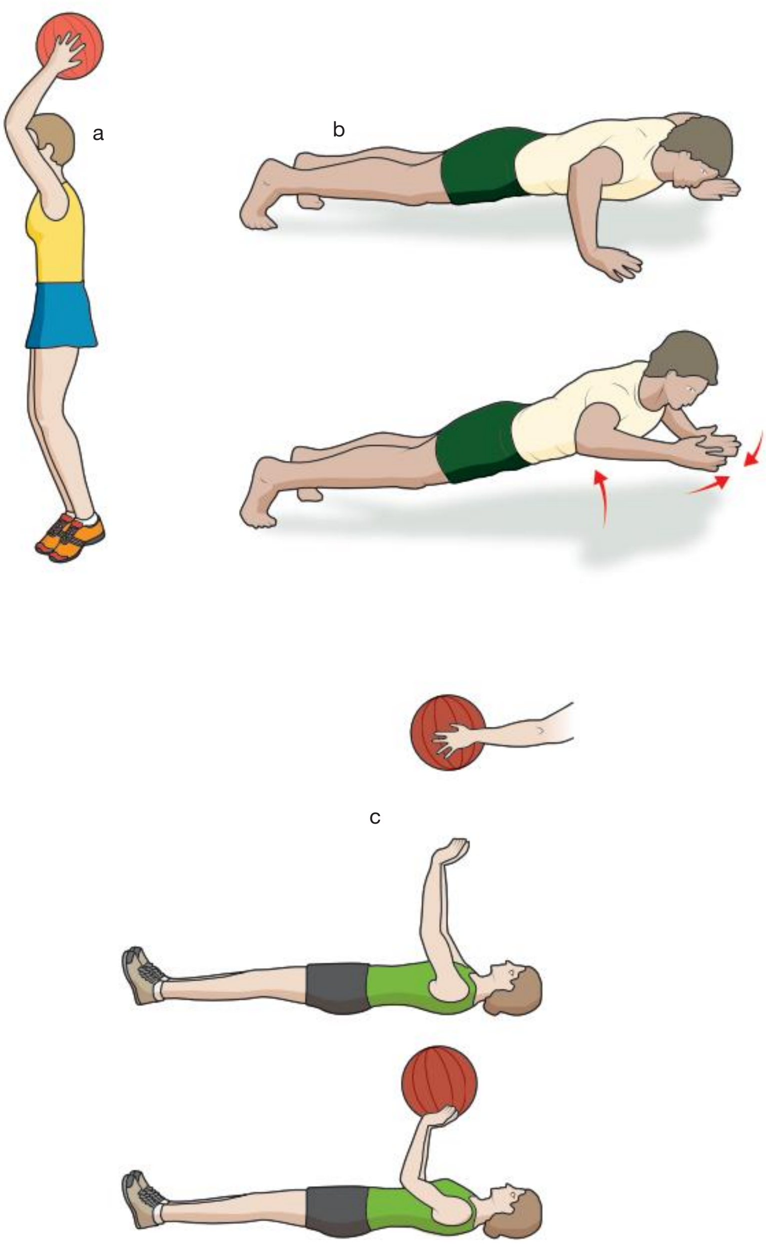
Referring to the examples in Table 13.8 on pages 317–318, design a resistance training program, utilising between six and eight exercises, aimed at developing whole-body strength.

PLYOMETRICS TRAINING

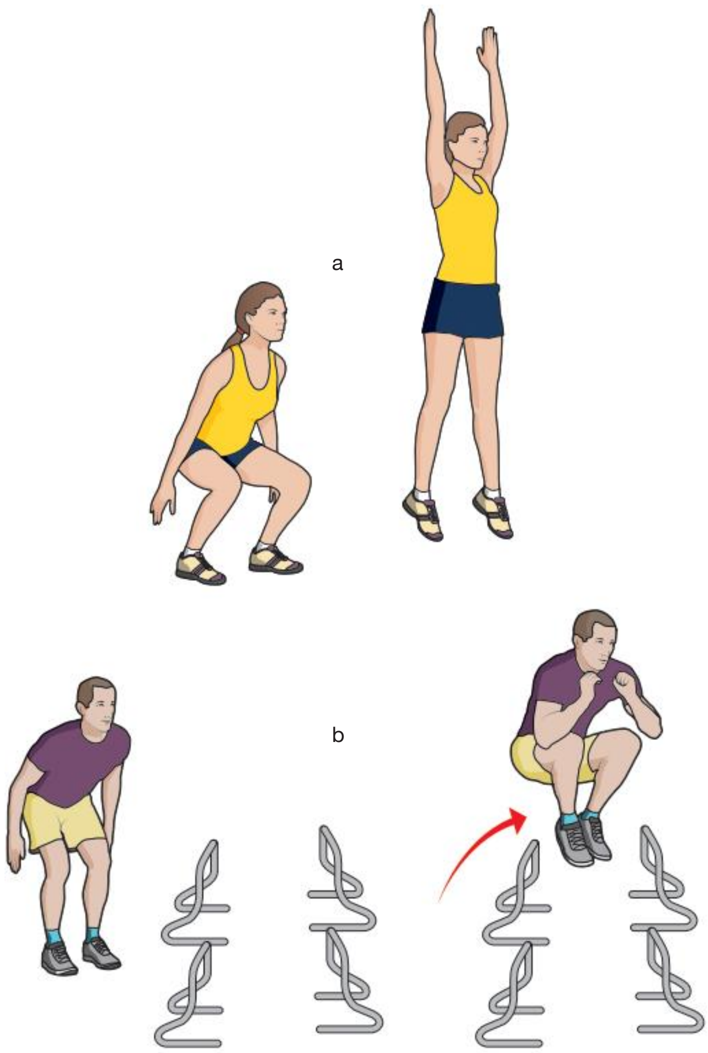
Plyometrics utilises the stretch-shortening cycle. Any time there is a rapid eccentric muscle contraction, the stretch reflex initiates a rapid concentric muscle contraction as a protective mechanism, to prevent the muscle overstretching. We utilise the stretch reflex in everyday sporting activities (for example, by bending at the hips, knees and ankles before jumping). The eccentric phase of this stretch-shortening cycle also stores elastic energy, which is immediately used in the concentric contraction, just like stretching a rubber band before releasing it.

Plyometrics training harnesses these two phenomena (the stretch reflex and stored elastic energy) to develop a more powerful muscular contraction, also further enhancing neural adaptations. Plyometrics has been well documented as an effective training method to enhance power. It is also effective in improving both speed and agility.

Recent research has demonstrated that plyometrics may be beneficial for endurance athletes by providing improvements in running economy; that is, less energy is required to produce each stride. Given that plyometrics can be used to develop speed, this may also benefit an endurance athlete who requires bursts of speed during an event.



Examples of upper-body plyometric exercises include: (a) basketball throw against a wall; (b) press-up and hand-clap; (c) catching a medicine ball.



Examples of lower body plyometrics exercises include: (a) jump and reach and (b) zig-zag hops.

Training considerations for plyometrics

Because of its explosive nature, care needs to be taken to minimise the risk of injury when introducing a plyometrics program. Consider the following guidelines:

- A strength base is recommended before commencement of a plyometrics program.
- Appropriate footwear, warm-up and surface are paramount.
- Lower-intensity plyometrics exercises should be used initially, before progressing to harder exercises.
- Ample rest (at least three minutes) is required between sets.
- When performed concurrently with another training method (such as short-interval or strength training), two sessions per week are sufficient to elicit improvement. Training frequency above this may increase the risk of injury.

PRACTICAL ACTIVITY
PLYOMETRICS TRAINING

Participate in a plyometrics training session. A thorough warm-up is essential. Remember to keep repetitions in the lower range of 4–8 per cent.

CIRCUIT TRAINING

Circuit training comprises a sequenced performance of exercises at different activity stations (typically, between eight and 12 stations). Completing each exercise in the circuit once is known as a lap. Two or three laps of exercises are usually performed in a circuit.

Circuit training is beneficial where the goal is to improve multiple fitness components (speed, muscular power, local muscular endurance, balance and agility). However, improvement of any one fitness component in a circuit will be less than if that component was individually targeted with a specific training method.

Circuit training can be tailored to suit individual needs. This may be appropriate where a games analysis and subsequent fitness testing have identified several weaknesses in a particular performer. A circuit can then be developed that is specific to these needs.

Conversely, a circuit may be utilised by someone who simply wants to improve their overall fitness. Many commercial gyms offer these general circuits.

The selection of exercises for a circuit depends upon matching the desired outcome (fitness components to be developed) with the available resources. Successful circuits can be developed with minimal equipment. When arranging the circuit, it is advisable to ensure that stations targeting the same muscle groups are not placed directly after each other. Circuit stations (exercises) should be arranged so that muscle groups have a chance to recover. For example, push-ups should be followed by a lower-body exercise before performing chair dips to allow the triceps to recover from the push-ups.

Benefits of circuit training

» Circuit training offers variety.
» Several fitness components can be targeted in the one training method.
» Specificity can be maintained.
» It can accommodate large groups of people and may be a good alternative for sporting clubs in inclement weather.
» Minimal equipment is required; body-weight exercises such as push-ups and sit-ups can be used as stations.

Fixed-time circuit training

In fixed-time circuit training, the performer completes as many repetitions of the exercise as possible in the allocated time (for example, the maximum possible number of sit-ups in 30 seconds). The time spent at each station can easily be varied, but 30, 45 or 60 seconds is usual. Short breaks (for example, 10 seconds) allow performers to move on to the next station. This is an easy type of circuit to manage and perform with larger groups, such as sporting clubs. Playing music can increase motivation, and programmed breaks in the music can be used to signify the end of each work period.

Fixed-load circuit training

In this type of circuit, the number of repetitions to be performed at each station is pre-determined (for example, six clap push-ups at station 1; four 10-metre shuttle sprints at station 2, and so on). The performer moves from station to station, completing the designated sequence.

One disadvantage of this type of circuit is that someone with more advanced fitness may complete the circuit far more quickly than other participants.

Individual circuit training

This circuit requires some initial set-up, but has the advantage of being tailored to suit the performer's individual needs. After selecting the exercises, the performer completes as many repetitions of each exercise as possible in one minute. This number is then halved, and the performer completes this circuit three times to establish a baseline time (pre-testing). The aim is to complete the circuit in a faster time at the next training session. A longer-term goal can be set (for example, to complete the circuit in 75 per cent of the initial time). When this is achieved, the circuit can then be overloaded or a new circuit devised.

Overloading circuit training

Overloading can be achieved by:

- increasing the resistance (if using weights)
- adding more stations
- adding more laps to the circuit
- increasing the time spent at each station
- attempting to complete more repetitions at a station (not applicable to a fixed-load circuit).

PRACTICAL ACTIVITY

DESIGN A CIRCUIT TRAINING SESSION

Design a fixed-load circuit training session with the facilities available at your school. Include 8–12 stations. Participate in this training session, either individually or as a class.

CHAPTER CHECK-UP

1 What is the stretch reflex?
2 List two benefits of weight training.
3 Why does plyometrics training have a greater potential for causing injury than many other training methods?
4 What risk-management strategies can be introduced to reduce the risk of injury from plyometrics training?

FLEXIBILITY TRAINING

As you learnt in Unit 1, flexibility training is important. Improved flexibility will:

» improve sporting performance
» reduce the likelihood of injury
» improve posture
» reduce the impact of DOMS
» release stress and tension.

Flexibility training should always be performed when the body has warmed up. However, flexibility training can also be done independently of any other training method.

The three recognised methods of flexibility (or stretching) training are:

Static stretching

Static stretching occurs when a person stretches to a position and holds it for 10 seconds or more. An example of this is the seated hamstring stretch. There has been considerable research into static stretching; evidence suggests that it should not be performed during a warm-up preceding other activities, as this may increase the risk of injury.

Dynamic and ballistic stretching

Dynamic stretching involves moving a joint through its range of motion with controlled momentum. Dynamic stretching is ideal as part of a warm-up and should mimic some of the movements about to be performed. A classic example of this is a footballer gently kicking their legs up to simulate kicking a football, or a swimmer rotating their arms at the shoulders to loosen up their upper body.

Ballistic stretching involves performing the same movements as dynamic stretching, but with much greater force. This can be potentially dangerous for most performers, as the increased momentum may lead to muscle strain. Ballistic stretching is only appropriate in very limited circumstances, such as ballet dancing, where the performers have spent years preparing their bodies for these types of movements.

Proprioceptive neuromuscular facilitation (PNF) stretching

When performed correctly, **PNF stretching** is a very effective method of improving flexibility. A muscle is gently moved through its range of motion until the first sign of discomfort. At this point, the muscle is contracted isometrically for 6 seconds. The performer then slightly relaxes the muscle before gently stretching it again until feeling slight discomfort. An isometric contraction is performed one more time for another 6 seconds.

QUICKVID

Video

Watch an interview with Neil Craig, currently Director of Coaching, Development and Performance at the Carlton Football Club, on fitness training methods. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 13, page 323.

CHAPTER SUMMARY

- The wide range of available training methods includes interval training, continuous training, fartlek, resistance training (weights), circuit training and plyometrics.
- Continuous training requires a participant to maintain intensity in the aerobic training zone for at least 20 minutes.
- Fartlek training involves random bursts of intensity and improves both the aerobic and anaerobic energy systems and related fitness components.
- Interval training involves periods of work alternated with periods of rest, and enables better-quality work to be performed because of the rest periods. Interval training can target either aerobic power (long or HITT) or anaerobic capacity (short or intermediate).
- Resistance training initiates neural adaptations important for sporting performance.
- Plyometrics improves the stretch reflex and is beneficial for power, speed and agility.
- Circuit training offers the performer the opportunity to train a variety of fitness components at once. Improvements will occur, but not to the same extent as when specifically training an individual fitness component.
- Flexibility training should be part of any training program in order to reduce the likelihood of injury and improve range of motion around a joint.

CHAPTER REVIEW

Multiple-choice questions

1 The method of training most suited to an athlete who competes in high-jump would be
   A circuit training.
   B plyometrics.
   C fartlek.
   D medium-interval training.

2 Which of the following training intensities will improve anaerobic capacity?
   A 90 per cent of maximum heart rate
   B 50 per cent of maximum heart rate
   C 60 per cent of VO_2 maximum
   D RPE of 6 (on the CT scale)

3 Flexibility gains can be significant using PNF flexibility training. This form of flexibility training involves
   A stretching with a partner.
   B holding an isokinetic contraction against resistance.
   C holding an isometric contraction against resistance.
   D gently bouncing while stretching.

Short-answer questions

4 The aerobic training zone is usually expressed as a percentage of maximum heart rate. It can also be expressed as a percentage of VO_2 maximum. Identify the training zones for both these parameters.

5 Explain why lactate tolerance training is usually incorporated into training programs for team sports.

6 Explain the term 'floating' recovery, including its purpose.

7 Compare and contrast continuous and fartlek training.

8 Complete the following table to distinguish between short-, medium- and long-interval training. You can fill it in online via http://nelsonnet.com.au, using your login code.

Weblink

	Example	Goal	W:R ratio	Recovery
Short-interval				
Medium-interval				
Long-interval				

9 a Draw or describe two plyometrics exercises for both the upper and the lower body.
   b Explain the benefit of plyometrics training.

TRAINING PROGRAM DESIGN: PLANNING, IMPLEMENTATION AND EVALUATION

CHAPTER 14

Key knowledge

» strategies to monitor and record physiological, psychological and sociological training data, including training diaries, digital activity trackers and apps

» components of an exercise training session including warm-up, conditioning phase and cool-down

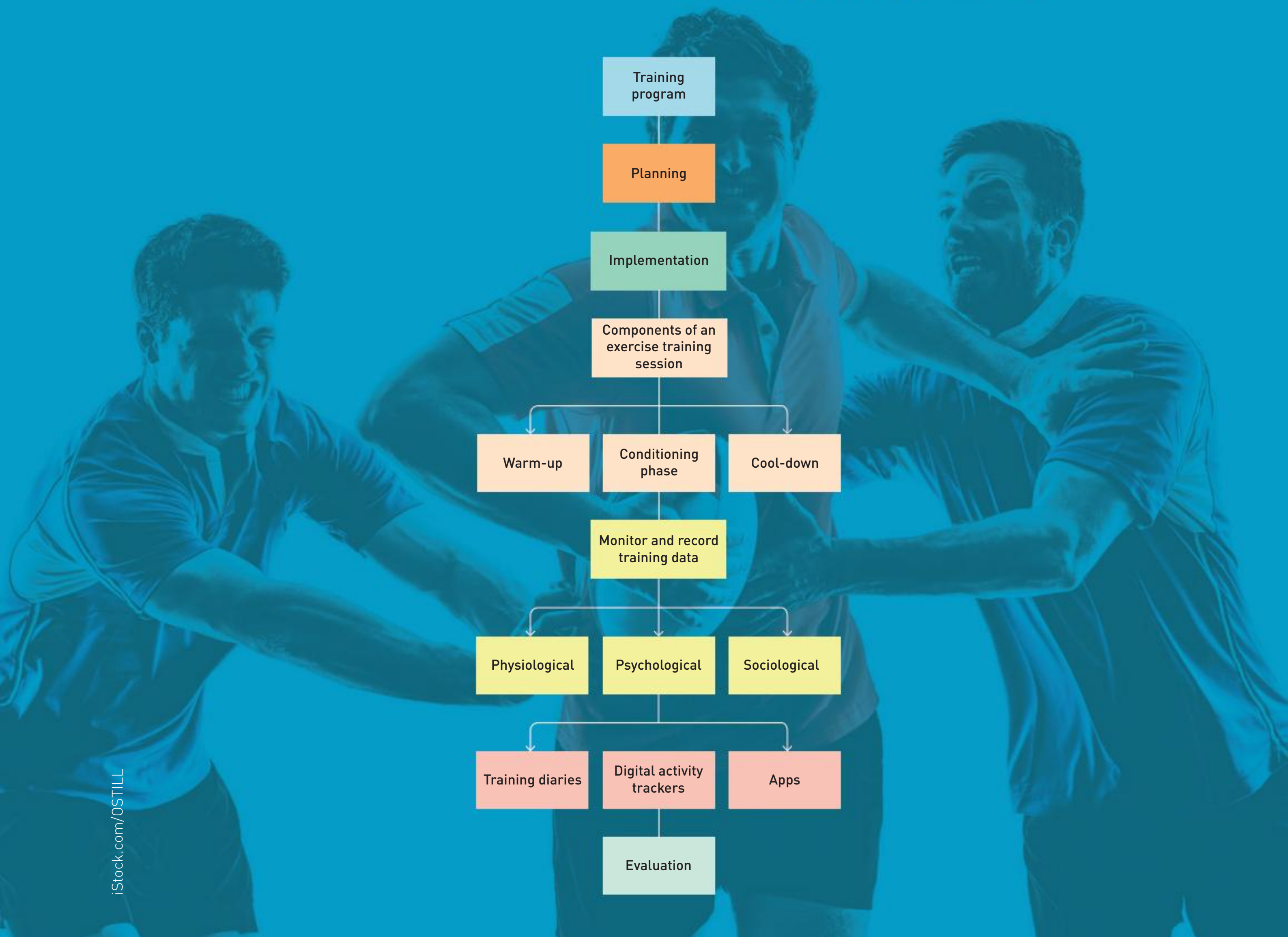
Key skills

» explain the importance of maintaining physiological, psychological and sociological records of training

» analyse training data to identify appropriate modifications to a training program

» evaluate and critique the effectiveness of different training programs

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



iStock.com/OSTILL

INTRODUCTION

Have you ever looked at a sportsperson who has reached the top of their field and wondered what they had to do to reach that point? What training and preparation have they done to reach that peak? Where does the journey begin?

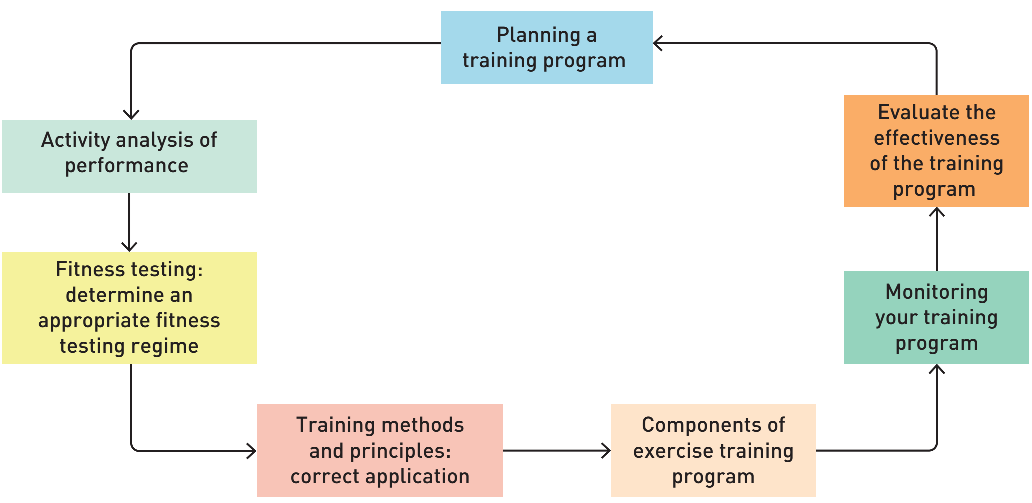
Designing a successful and purposeful training program is a complex but rewarding process. A training program has to be developed to meet the needs of each individual. Even within a team sport, players in different positions have different requirements. The body responds and adapts to the physical stress placed on it as a result of physical exercise. You need to develop a program that will elicit the right adaptations at the right time to ensure success in your chosen sport or activity.

Before we start the actual physical training outlined in our program, there are many factors that need to be considered. These include:

- the objectives of the program
- the physiological demands of the activity being trained for
- the physiological strengths and weaknesses of the individual
- the training resources and facilities available
- how to gauge progress so as to able to identify appropriate modifications that need to be made.

PLANNING A TRAINING PROGRAM

The main goal of any training program is to improve a person's physiological capacity, and to facilitate the chronic adaptations needed to meet the specific demands of an activity or competition. Ultimately, a training program should replicate the demands and requirements of the sport or activity. These are targeted through the application of specifically selected training methods, underpinned by the training principles.



Activity analysis

In order to ensure that specific training methods are applied appropriately and correctly, an activity analysis must first be conducted. This is the first step in designing a training program. Conducting an activity analysis will help a performer and/or coach prioritise the training required, underpinned by the principle of specificity. Activity analysis was discussed in detail in chapter 10.

An activity analysis will help identify the key element that shapes the training program, the physiological requirements, which then are subjected to fitness testing.

Energy systems, fitness components and muscle groups

Energy systems, fitness components and muscle groups are the key physiological requirements of performance in a chosen sport or activity. These can be identified by undertaking an activity analysis, which should be as specific as possible. Understanding how these physiological requirements underpin successful performance in your chosen sport or activity is the key to a successful training program. The skills used must be broken down into the major associated muscles, and specific fitness tests should be chosen to match (as closely as possible) the way muscles are used during the game. This is taken a step further when the muscles are trained specifically, utilising similar actions, as part of the training program.

Determining an appropriate fitness testing regime

Fitness testing is the second step in the overall training program design. Once you have completed the activity analysis and analysed the data, you can assess your own fitness levels relevant to the game or activity. The fitness test needs to be reliable and valid, and must be conducted using ethical protocols.

The fitness testing regime should be based on the physiological, psychological and sociocultural needs of the individual and the requirements of the activity. Selection of the most specific tests will be based on the results of your activity analysis. (See chapter 11 for information about fitness test selection.) The fitness tests will identify strengths and weaknesses, and the performer and/or coach can then prioritise areas to strategically focus training on, based on these results.

Pre-training screening and injury prevention

Pre-training screening or questionnaires can identify any predisposition to injury or illness, preventing the loss of training time due to non-participation. A typical pre-training screening should encompass both medical and physical screening.

Medical screening can identify if the performer is at risk of developing complications as a result of exercise, such as an individual with asthma or high blood pressure. Once identified, preventative guidelines and management strategies need to be implemented in consultation with a medical professional.

Physical screening tests a range of physical aspects such as joint range of motion, which can be useful for determining if the individual is susceptible to injuries, or whether there may be weakness or vulnerability due to a pre-existing injury. When implementing your training program as a part of your PE class, you should take into account physical limitations and pre-existing conditions.

Preliminary preparation: availability of time

A training program is only as successful as the individual's ability to commit to it. For most, training time is limited, so the key is to maximise each session by making them as specific and relevant as possible. Well-designed sessions will focus on either improving weaknesses or maintaining strengths.

For some, time constraints may mean a training program is overly ambitious. This is where a periodised training program and timeline is crucial – this will give the performer a clear vision of the commitments and direction of training into the future.

Application of the training principles of specificity, intensity, frequency and duration also helps shape each training session with progression (overload) and underpins genuine advancement in the overall training program. This will give each session a clear purpose, linking back to the physiological demands of the chosen sport or activity and specifically targeting identified areas for improvement. The application of frequency also allows sufficient recovery time between sessions, which is critical. The duration of the program will help shape realistic, obtainable goals.

IMPLEMENTATION

Appropriate training methods

The third step in the process of planning a training program is to determine which training methods you will employ. These need to bring about improvement in the areas identified by the fitness assessment, while also maintaining those areas that were deemed satisfactory. Are the chosen training methods the best option for the performer? Are they the most specific? Have they been applied correctly? Do performers have easy access to the appropriate facilities?

Training methods should be specifically tailored to the individual needs of the performer. For example:

» A mid-court player in netball requires high levels of aerobic power and anaerobic capacity, so fartlek and short-interval training may be employed.
» A volleyball player would benefit from explosive power in the upper legs; plyometrics will target power in the quadriceps.
» Rugby Union players need speed and explosive power, as well as quick recovery from sprints; high-intensity interval training will target these areas.

The selection of appropriate training methods is discussed in detail in chapter 13. You also need to ensure that you correctly apply the relevant training principles to your training program, especially the principles of specificity, intensity, duration, frequency and progression (overload). Training principles are addressed comprehensively in chapter 12.

CHAPTER CHECK-UP

1 Outline and explain the three steps in an overall training program design.
2 Explain why availability of time is an important consideration.
3 Explain why pre-training screening is important.

COMPONENTS OF AN EXERCISE TRAINING SESSION

Designing a training session

The appropriate sequencing of an exercise training session is vital in achieving the stated outcomes. Appropriate sequencing is underpinned by time efficiency and specificity of training, which also minimises the risk of injury. It is generally accepted that the three basic components of an exercise training session are:

1. the warm-up
2. the conditioning phase
3. the cool-down.

This sequence should be followed for every exercise training session. The more prepared your body is, the less likely you are to be injured.

Warm-up

The warm-up lays the foundation for the main workout or conditioning phase. The warm-up allows the body to adjust to the demands that are going to be placed on it during the session.

A warm-up prepares the performer, both mentally and physically, for the activity to follow. It also enables the performer to increase their arousal. Physically, a warm-up helps the body prepare for exercise by:

- increasing muscle temperature
- increasing core body temperature
- increasing respiration rate
- decreasing viscosity of joint fluids
- increasing the elasticity of the muscles
- increasing heart rate and blood flow to working muscles.

Warm-ups consist of two clear stages.

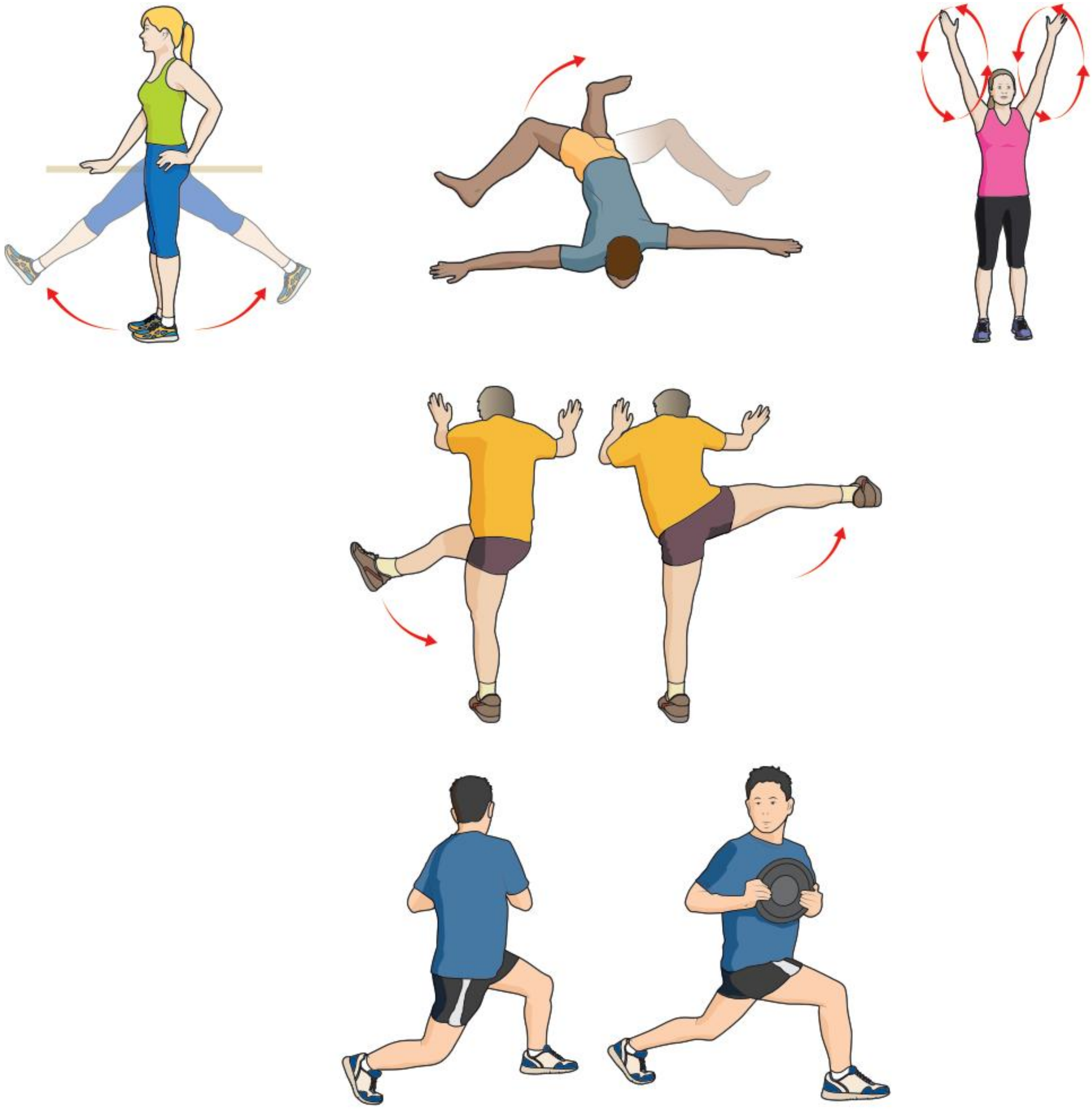
Stage 1

The first stage of the warm-up should be graduated. Start with 5–10 minutes of slow activity (at a low and easy intensity) comprising general aerobic exercise, such as walking, a low-intensity jog or a bike activity.

Stage 2

After the initial stage of the warm-up, it is important to transition seamlessly to the second stage: more specific movement-based activities at a gradually increased intensity. These should replicate the movements and actions that will be used in the main training session, focusing on the key muscle groups that will be used.

A smooth transition from stage 1 to stage 2 is critical to injury prevention. Flexibility is also part of every good warm-up, and can be incorporated into the warm-up strategically. **Dynamic stretching** can be introduced into this stage of the warm-up, further preparing the muscles, tendons and joints for the work that is to follow. For example, a basketball player could pass, dribble and shoot a basket, and a weightlifter could lift light weights before moving on to greater resistance. If aerobic training is to follow, the performer could gradually start to increase the intensity (after producing a slight sweat).



Dynamic stretching is often seen in warm-ups, particularly in team sports.

Video

QUICKVID

Watch an interview about training program design with physiotherapist Theo Kapakoulakis. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 14, page 330.

Duration

The duration and specificity of the warm-up is largely determined by the workout that will follow.

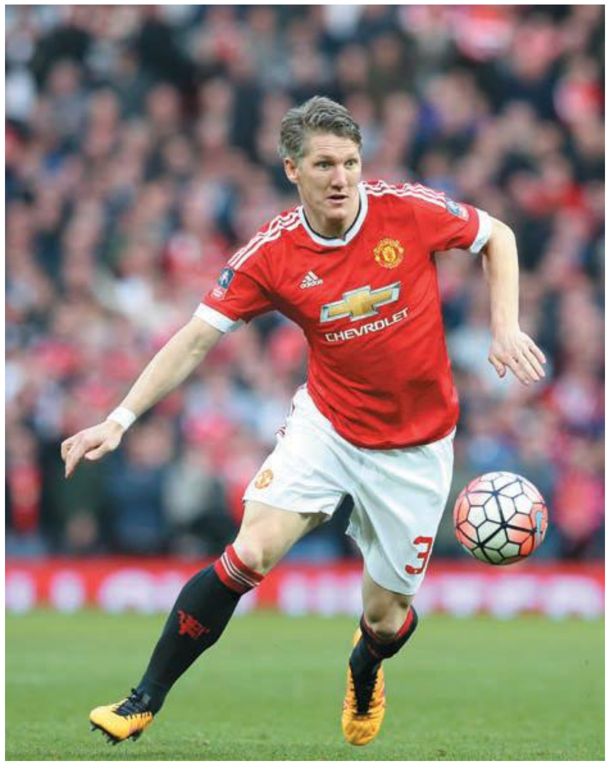
INVESTIGATION

Arjen Robben (left) and Bastian Schweinsteiger (right) are two world-class soccer players who have both captained their country at an international level.

1. Click on the link at http://vcepe34.nelsonnet.com.au and watch the activities both players undertake as a part of their training session at FC Bayern Munich.
2. Evaluate and critique the effectiveness of the different activities in the training session.

Weblink

Alamy Stock Photo/ITAR-TASS Photo Agency



Alamy Stock Photo/PA Images

TABLE 14.1 An example of a warm-up for a senior Australian Rules football team

Time	Activity
1.32 p.m.	Warm-up starts Progressive build-up of intensity. Start with general movement pattern work: stretches, predominantly dynamic in nature
1.34 p.m.	Lane work Straight hands; mix of ball delivery – straight hands, knee level, groundball, in the air – increase distance between the groups, pushing distance back
1.35 p.m.	Kick in lanes 20–25 metres – push right; off the line
1.36 p.m.	Leg swings
1.37 p.m.	Kick in threes. Gradual build-up to lead off the line, increasing intensity

1.40 pm.	In three groups, handball patterns /decision-making. Drop step/slice at about 60–70% intensity, two players with bibs on, changing players with bibs every 30 seconds
1.43 p.m.	Group kick from goal square to group on the angle. Mark – push back kick to a group at CHF, who run in shot on goal – 3 minutes
1.46 p.m.	Shots on goal. Forwards out, backs in
1.49 p.m.	Back into rooms; player own time
1.52 p.m.	Coach speaks – 1 minute
1.53 p.m.	Back onto ground
1.54 p.m.	Strides
1.55 p.m.	Stoppage work: midfield group from a ball-up work the ball around resulting in hitting up a forward lead Forwards: involved in leads. Those not leading, shots on goal Backs: kicking to those forwards having shots on goal
1.58 p.m.	All in: five 'token' tackles – concentrating on 'don't get stepped, watch the hips, small steps'
1.58 p.m.	Handball crossover with contact
2.00 p.m.	Game starts

Static stretching

There is no evidence to support the inclusion of static stretching in a warm-up, other than for the minority of sports that require participants to hold a static stretch as part of their performance. Static stretching may, in fact, be counterproductive. While the performer is performing static stretches (usually sitting down), the acute responses they have initiated in the warm-up (such as increased cardiac output and minute ventilation) will begin to reverse. Some researchers believe that static stretching before exercise not only has no effect on injury prevention, but may also reduce a person's strength and power.

Static stretching is appropriate at the end of a training session or as an independent training method performed in isolation.

The conditioning phase

The conditioning or sports-specific phase of the training session follows the warm-up. This is the main part of your exercise training session, where you specifically target the areas identified as weaknesses by your fitness testing, as well as maintaining the physiological requirements of your sport.

Different sports and physical activities have different physiological requirements. It is critical to have a clear understanding of the physical requirements of your identified sport or physical activity. This initial understanding is gained through your activity analysis.

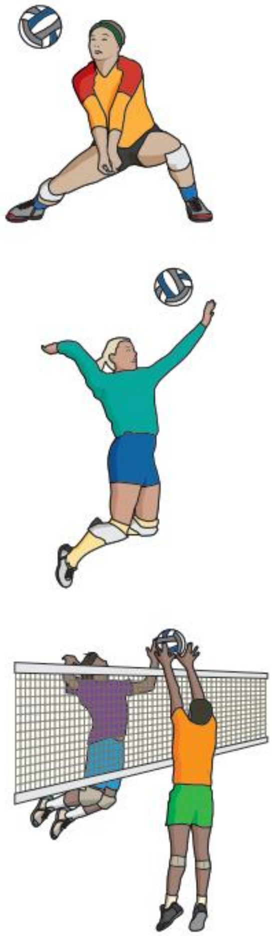
Tables 14.2 and 14.3, and the illustration on page 333, provide examples of the conditioning phase.

TABLE 14.2 Sample plyometric training session

Sample plyometric session for badminton	
Split squat jumps	5 × 8
Single arm overhead throws (medicine ball)	5 × 10
Lateral box push off	5 × 10
Side throws (medicine ball)	5 × 10

Source: Courtesy of Sports Fitness Advisor, www.sport-fitness-advisor.com

Basic speed and agility volleyball training drills



- Short sprints: Practise start and stop running on the court
- Ladder drills: Coordinated footwork running through a ladder on the ground
- Follow the leader: Shadow someone and run in different directions
- Snake drills: Run weaving in and out through cones set up as an obstacle course
- Abdominal muscles: Focus on strength exercises that improve the abdominal muscles
- Leg muscles: Strong legs will help with agility during volleyball plays as well as jumping
- Arm muscles: Upper-body strength is essential for digging, hitting and spiking the volleyball

TABLE 14.3 Sample circuit training session for a triathlete

	Weeks 1, 2	Weeks 3, 4	Weeks 5, 6	Weeks 7, 8
Load	**30% 1RM**	**30% 1RM**	**30% 1RM**	**30% 1RM**
Leg presses	Complete each exercise for 4 minutes nonstop. Rest for 1–2 minutes between exercises.	Complete each exercise for 7 minutes nonstop. Rest for 2 minutes between exercises	Complete each exercise for 10 minutes nonstop. Rest for 2 minutes between each exercises.	Complete 2–3 exercises back to back for 10 minutes each (i.e. 20–30 minutes continuous work). Rest for 3–4 minutes and repeat for next 2–3 exercises.
Bent over rows				
Leg presses				
Bench presses				
Calf presses				
Triceps extensions				
No. of circuits	1	1	1	1

Source: Courtesy of Sports Fitness Advisor, www.sport-fitness-advisor.com

Training volume and training intensity

Key considerations in the conditioning phase are the volume of work that is to be undertaken and the intensity of the work. **Training volume** is recorded in terms of time, that is, minutes per session or hours per week. However, it can also be reported in terms of distance covered. That is, 80 kilometres per week for a distance runner or 300 kilometres per week for a road cyclist. **Training intensity** refers to how hard an individual is training. There are many different methods that can be used to measure intensity. Some of the more common methods are heart rate, oxygen consumption, the weight lifted, blood lactate concentration levels or the athlete's perceived level of exertion during training. This was discussed in detail in chapter 8.

Cool-down

While the importance of a warm-up is well understood to be a key part of any training session, the importance of the cool-down has not always been recognised. This is changing, however. A well-planned, structured cool-down after the main workout plays a vital role in recovery. A cool-down aims to return the body to pre-exercise levels and, in doing so, reverse the effects of fatigue, removing waste products from the working muscles while they are still receiving oxygenated blood. It also allows for the gradual recovery of heart rate and blood pressure and helps reduce the effects of delayed onset muscle soreness (DOMS).

For the majority of sports, the best form of cool-down is performing the same locomotion patterns at a reduced intensity. It is not uncommon to see sportspeople working through a number of low-intensity aerobic exercises post-game.

Stretching

FYI

DOMS is muscle soreness that presents itself anywhere from 12–72 hours after a bout of strenuous exercise. DOMS occurs as the result of trauma to muscle cells at the microscopic level, and usually occurs when muscle groups perform eccentric contractions or are involved in actions they do not normally perform.

A cool-down also presents the best time to perform stretching exercises, while the body is warm and will benefit from some flexibility work. Stretching will also reduce the chance of muscle stiffness.

There are a number of ways to incorporate stretches into a cool-down, depending on the available resources. One popular form is stretching with the aid of a resistance band. Resistance bands provide many benefits. They:

» can be used for a comprehensive, full-body stretch that challenges virtually every major muscle group in your body
» are easy to use alone
» add variety to your program
» are cost-effective.

Foam rollers can also be used effectively as a part of a cool-down. Using a foam roller:

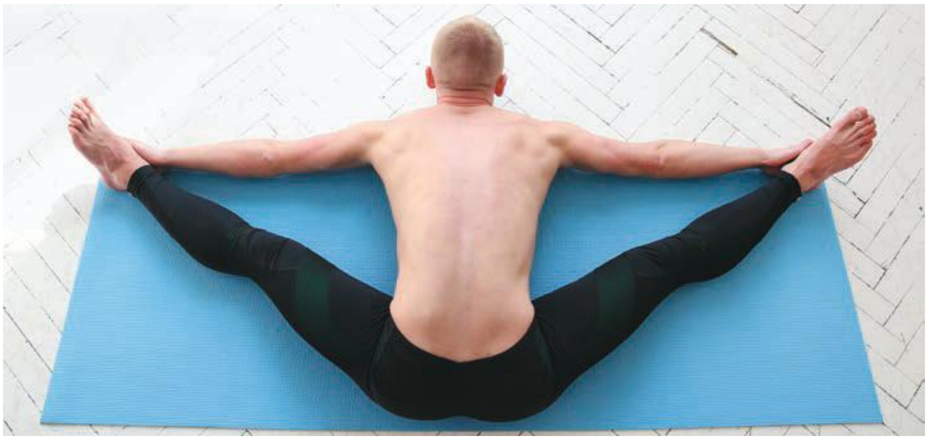
» increases blood flow
» maximises effectiveness of stretching
» eliminates painful trigger points in soft tissues
» accelerates removal of waste products after exercise
» increases oxygen to muscles.

Shutterstock.com/Halfpoint

Stretching with the aid of a resistance band

Shutterstock.com/Sebastian Gauert

Foam rollers can be used effectively as part of a cool-down.



Shutterstock.com/Yana Ermakova

What kind of stretching is this gymnast using?

CHAPTER CHECK-UP

1 What are the two clear stages of a warm-up?
2 Why is dynamic stretching a viable option in a warm-up?
3 How would you incorporate resistance bands into your cool-down?
4 How would you incorporate foam rollers into your warm-up or cool-down?
5 Draw a simple flow chart of the sequence of a training session.
6 Provide examples of dynamic warm-up activities a netball player and high-jumper might include in their warm-ups.
7 Why is it important to perform a cool-down?

Periodisation

Transition phase	Preparatory phase	Competitive phase										
Macrocycle												
Mesocycle	Mesocycle	Mesocycle										
Micro	Micro	Micro	Micro	Micro	Micro	Micro	Micro	Micro				
Training	Contest											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan

A sample of periodised training

Adapted from: Brandon Patterson, 'Strength 101: Part III - Organizing Training', 2011, Elite FTS, www.elitefts.com

Periodisation is the systematic planning of physical training. Periodisation is used by many coaches. At the elite level of sport, the aim is to reach the optimal level of performance at the most important competition of the year.

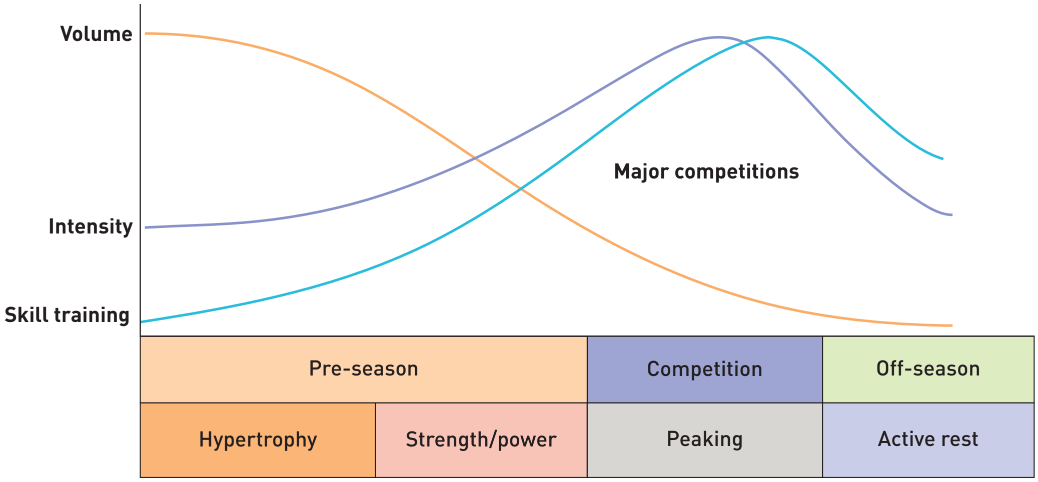
The schedule and design of a year-round training program is known as periodisation, or conditioning within cycles. Different physiological components are developed at different intensities, frequencies, durations and loads. Based on scientific principles and methodologies, periodisation represents the best method of conditioning.

The application of periodisation varies according to the sport and the level of performance it is being played at.

A **macrocycle** is an annual plan that works towards peaking for a major competition. The macrocycle can be divided into developmental periods called **mesocycles**.

A mesocycle is usually 4–8 weeks in duration, although this can vary between sports. Within this block of time, there is a specific training emphasis, for example, a general or specific preparation period.

Each mesocycle is broken into **microcycles**, which are shorter training periods of about 7–10 days each. A microcycle contains more specific exercise training sessions based on the overall purpose of the mesocycle. The more elite the athlete or sports program, the more complex and precise the planning needs to be to accommodate this.



A sample macrocycle, showing volume and intensity

Periodised conditioning is designed to optimise training results by breaking the competition year into cycles, with each cycle having a specific focus. Periodisation prevents overtraining and structures the routine, allowing the athlete to peak at key times throughout the year. The conditioning is specific to the physiological demands of the sport or physical activity, and is designed to elicit peak performance in games while simultaneously planning for the long term.

Developing the right formula for each individual athlete is one of the greatest challenges of exercise prescription. Periodisation requires an understanding of the variables that affect overtraining and injuries, how to enhance recovery, and how to refresh for the next game while managing ongoing training. Other key ingredients that tie into periodisation are rest and tapering.

Rest allows for repair and renewal of the body's tissues. No one can train day after day at specific intensities; the body needs time to regenerate. Sleep is the most important way to recover. Adequate levels of sleep help mental health, hormonal balance and muscular recovery.

Tapering is a short-term reduction in the training load (either volume, intensity or both) prior to an important competition, designed to optimise an individual's performance.

STRATEGIES TO RECORD AND MONITOR TRAINING DATA

It is important to maintain a record of training done so that progress can be monitored. A training record is an invaluable monitoring and reflective tool – physiological, psychological and sociological data gathered can be analysed, providing us with trend data. Maintaining records may seem tedious, but the positives far outweigh the negatives. With proper analysis, a record of training is a compendium of information, providing a strategic insight into an individual's systematic training. Entries in a training log, made both before and after training, can provide invaluable information to the performer and/or coach. Record keeping enables us to critically reflect on participation in training sessions, enabling ongoing evaluation and critique of individual sessions and the program overall. Records can also be used to identify the need for future strategic modifications in line with the physiological demands of the activity being trained for and the physiological strengths and weaknesses of the individual. The following example of a fundamental training log for a weight-training program would allow an individual to quickly and accurately record session details.

Exercise	Date		
		Weight	
		set	
		reps	
		Weight	
		set	
		reps	
		Weight	
		set	
		reps	
		Weight	
		set	
		reps	

Recording methods – digital recording trackers and apps

It is sometimes said that the value of the data recorded in any system is only as good as the person who enters the data. It is important to use a concise and intuitive recording method. Possible methods include training diaries, digital activity trackers and apps. Mobile apps provide an easy and accessible way to record and analyse movement statistics in real time. Due to their contemporary and compatible design, apps and digital trackers can serve as a constant reminder to record, monitor and reflect on individual progress. Some apps or digital trackers such as Garmin, Strava, Fitbit and others, connect individuals to a wider network of fellow users, allowing them to record their activities, compare performance over time and compete with each other, while providing individuals with a level of social support.

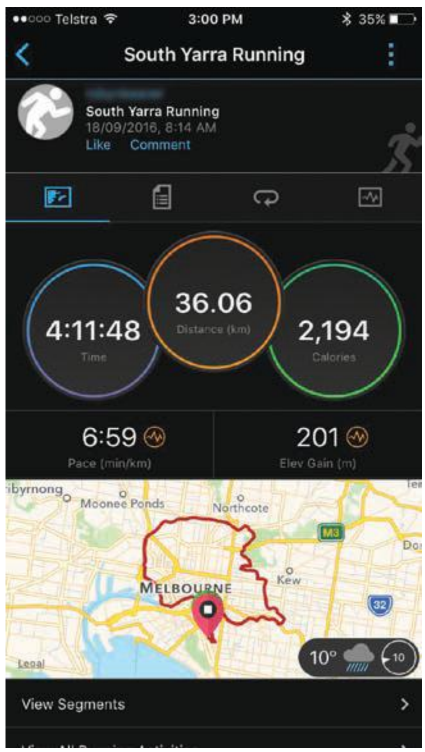
Record keeping allows you to:

» monitor your general performance and training load
» avoiding overtraining and injury
» evaluate and adjust training loads where necessary
» review microcycles and macrocycles
» stay motivated.

Regardless of the method or tool used to record training data, the information recorded can provide us with a complete picture of the training that has occurred. Importantly, we can evaluate the data to inform future training sessions.

The information gathered generally includes the physiological work undertaken – distances run, weight lifted, repetitions and sets completed.

There are some examples of training diaries on the next page, and also in chapter 13 on page 307.



Mobile apps such as Garmin Connect provide a wealth of information to assist with training.

FEB	COURSE	DISTANCE	TIME	PACE	COMMENTS	
22 SUN						
23 MON						
24 TUES						
25 WED						
26 THURS						
27 FRI						
28 SAT						MONTHLY TOTAL

RACE NAME		WEEKLY DISTANCE (km)	WEEKLY COMMENTS
COMMENTS			
		YEARLY DISTANCE (km)	
TIME	OVERALL PLACE		
PLACE	AGE DIVISION PLACE		

RUNNERS FEED TRAINING LOG									
Month/Week: 2/26	**Sun**	**Mon**	**Tue**	**Wed**	**Thurs**	**Fri**	**Sat**	**Goal**	**Actual**
Run								*100*	
Strides								*60*	
Post-run								*Daily*	
PAQ/Hurdle mobility								*2 x week*	
Cross training								*n/a*	
Nutrition								🙂	
Hours of sleep								*63*	
Workout notes									

Examples of training diaries

Getty Images/Bloomberg

Smart watches and smart phones can both be used to track and record training data.

Wearable devices

Wearable devices are increasingly being used to monitor training. Some wearable technologies allow you to enter an emoticon representing the way you felt before, during or after training. Others allow you to record only the actual data, while some also monitor sleep patterns. This is all valuable information for monitoring and evaluation.

Recording psychological and sociological data

We can also record psychological data such as how we were feeling before, during or after exercise. This data may also capture other sociological aspects of training such as access, transport and social support networks. For example, 'I had to ride my bike to training today because Mum was working and I really couldn't be bothered, but once I got there and started training I felt good', or 'I had planned to walk with a friend today but she was unwell, so I still went but I cut short my walk', or 'It was cold and raining this morning and I felt really unmotivated to go for my walk at 6.00 a.m. but I knew I had to meet Maree, Kate, Sarah and Emily so that made me get out of bed'. To refresh your understanding of sociocultural influences on participation in physical activity and physical activity enablers and barriers, refer to *Nelson Physical Education VCE Units 1 & 2*, Chapter 12.

TRAINING DIARY / LOG

Name: *Emily Brown*
Date & time: *27/1/16, 5.15 a.m.*
Location: *Bill Sewart Athletics Track*
Weather conditions: *17°C, cloudy*
Pre-training comments: *Mood 8/10. Energy levels 8/10. Motivation 7/10.*
Training session focus: *Anaerobic capacity (lactate tolerance)*

Planned session:

INTERMEDIATE INTERVAL TRAINING SESSION: RUNNING					
Warm-up: *2 laps of oval* *6 strides of 50 metres: 2 @ 70%; 2 @ 80 %; 1 @ 90 %; 1 @ 95%*					
Sets	Reps	Distance	Time	Recovery time	Intensity
1	*4*	*400 m*	*85-90 s*	*2 mins*	*RPE 8/9*
2	*3*	*200 m*	*30 s*	*60 s b/w reps. 2 mins after set 1*	*RPE 9/10*

Post-training reflective comments:

- *To develop lactate tolerance for surges and hills in marathon.*
- *400 m times: 87 s, 86 s, 87 s, 92s.*
- *RPE felt about a 9 for whole session.*
- *4 × 400 m too much; really blew out on last rep. Leave 200s as is.*
- *Walked then lightly jogged after every rep.*
- *Walked for 600 m after final 200 m and then completed usual stretching routine.*
- *Left track at around 6 am, feeling satisfied after completion.*
- *Post note: two days after session reasonable DOMS.*

Completed training diary for an intermediate training session

Training program evaluation

We established at the start of chapter 14 that a correctly administered training program has to be strategically developed and implemented to meet the needs of each individual. The correct application of fundamental training principles to a training program will elicit the right adaptations at the right time to ensure success in your chosen sport or activity. How, then, do we evaluate the successful of an individual training program? How do we evaluate and critique the program to ensure the objectives have been met? Monitoring each session through the use of training diaries, digital activity trackers and apps allows us to reflect on each session in real time, making modifications instantly. Once the training program has been completed, we can administer the same fitness testing regime, in the same order, to ascertain improvements to the targeted key physiological requirements of the chosen sport or activity, of which fitness components is one requirement. Once the post-fitness testing has been completed, an individual is then in a position to evaluate and critique the overall effectiveness of the training program. The redesign or modification of the training program, including the effectiveness of the recording tools used, is then possible.

CHAPTER CHECK-UP

1. Explain the concept of periodisation and why it is important.
2. Why is it important that we record and monitor training data?
3. Discuss two different methods of recording data and the advantages associated with each method.

CHAPTER SUMMARY

- A training program should be tailor-made for each individual.
- The body responds and adapts to the physical stress placed on it as a result of physical exercise. A program needs to be carefully designed and implemented to elicit the right adaptations at the right time in order to ensure success in your chosen sport or activity.
- The main purpose or goal of any training program is to improve a person's physiological capacity, and to facilitate the chronic adaptations needed to improve performance. Ultimately, a training program should replicate the demands and requirements of the sport or activity as closely as possible.
- In order to ensure the most appropriate and specific training methods are chosen, an activity analysis must first be conducted. This is the first step in the overall training program design. The second step is fitness testing and the third step is the correct application of training methods.
- The appropriate sequencing of a training session is paramount in ensuring the stated outcomes are achieved. Appropriate sequencing is underpinned by time efficiency and specificity of training, which also minimises the risk of injury.
- It is generally accepted that a training session is made up of three basic components: the warm-up, the main workout or conditioning phase, and the cool-down.
- The schedule and design of a year-round training program is known as periodisation, or conditioning within cycles. Different physiological components are developed at different intensities, frequencies, durations and loads. Based on scientific principles and methodologies, periodisation represents the best method for the conditioning of the relevant physiological components.
- It is important to record the training that has been undertaken so that progress can be monitored. Maintaining a record provides an invaluable monitoring and reflective tool. Physiological, psychological and sociological data can be analysed, providing trend data.

CHAPTER REVIEW

Multiple-choice questions

1 An activity analysis will help identify a number of key physiological requirements that help shape a training program. These include
   A energy systems, fitness components and muscle groups.
   B muscle groups, fitness tests and energy systems.
   C fitness tests, fitness components and muscle groups.
   D muscle groups, fitness components and skills.

2 It is generally accepted that an exercise training session includes three basic components
   A a good warm-up followed by an aerobic run.
   B an aerobic activity in isolation.
   C the warm-up, the conditioning phase and the cool-down.
   D a conditioning phase followed by a few light stretches.

3 Different sports and physical activities require the development of physiological requirements unique to that sport or activity. These can be identified by
   A speaking to your coach.
   B conducting an activity analysis.
   C watching some clips of the sport or activity on television.
   D reading a newspaper report on the sport or activity.

4 Periodised conditioning exists to optimise training results by
   A completing an activity analysis.
   B breaking the competition year into two halves.
   C training according to how your body feels.
   D breaking the competition year into cycles, each with a specific focus.

Short-answer questions

5 What is the main purpose or goal of any training program?

6 What is the first step in a training program?

7 How can the physiological requirements of performance in a chosen sport or activity for an individual be determined?

8 What role does fitness testing play in the design of a training program?

9 Define what is meant by the conditioning phase of a training session.

10 What is the benefit of recording training sessions?

CHAPTER 15

CHRONIC ADAPTATIONS TO TRAINING

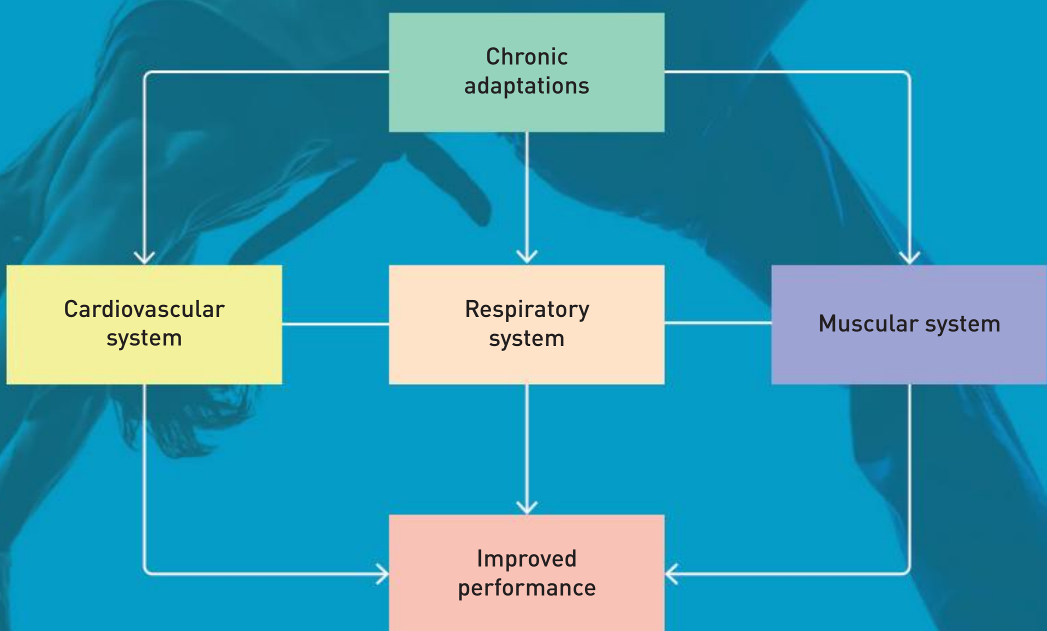
Key knowledge

» chronic adaptations of the cardiovascular, respiratory and muscular systems to aerobic, anaerobic and resistance training

Key skills

» explain how the cardiovascular, respiratory and muscular systems' chronic adaptations to training lead to improved performance

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



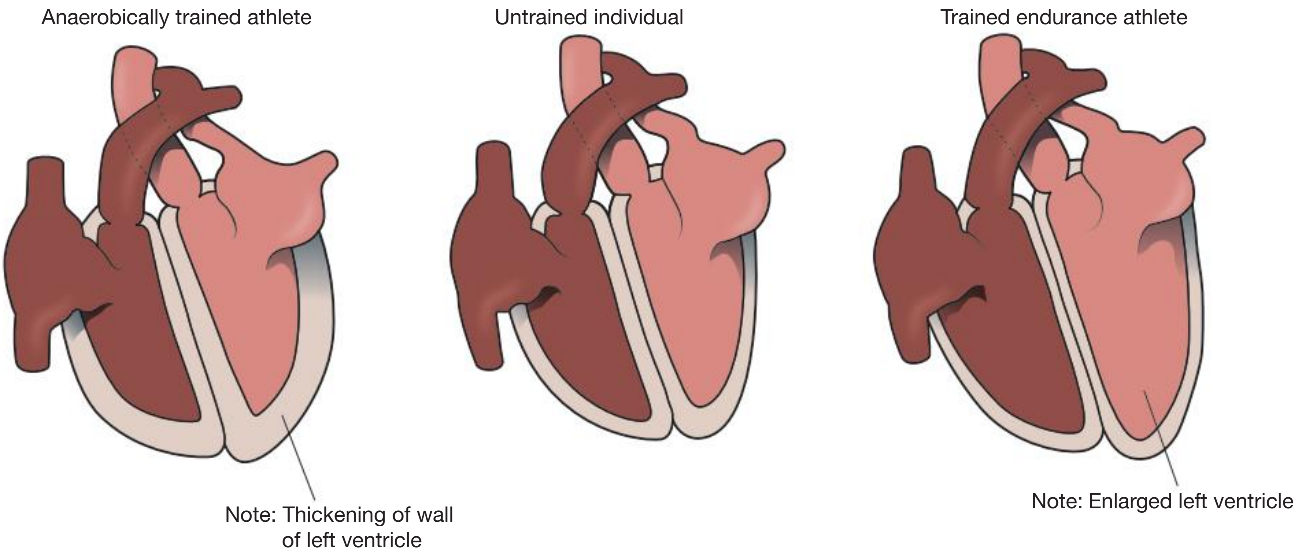
iStock.com/OSTILL

CHRONIC ADAPTATIONS

Individuals and athletes train in order to improve performance. **Chronic adaptations** to training are the physiological changes that occur in response to the increased demands placed on the body through training. Adaptations can be structural or functional, but all adaptations lead to improved performance. The effects of training are specific to the type of training undertaken (aerobic or anaerobic) and to the system in which the physiological change is occurring. (Refer back to chapter 11 to read more about the training principle of specificity.) Training needs to be tailored to the specific demands of the activity and the goals of the athlete.

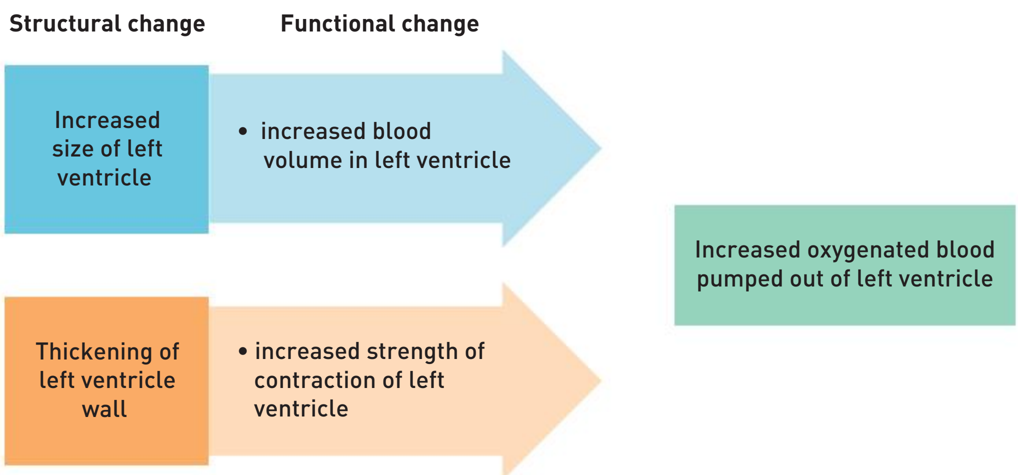
FYI

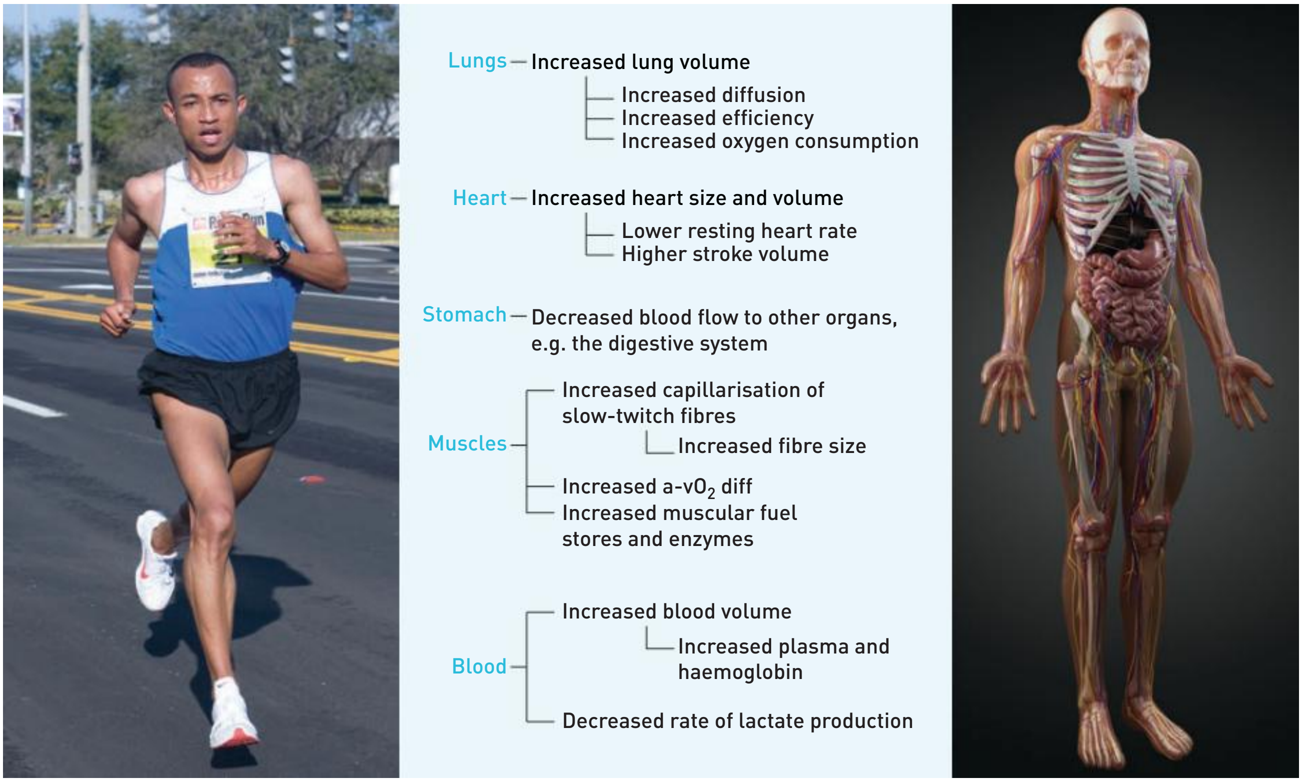
Men and women respond and adapt to training in essentially the same way!



Structural changes of the heart

The structure of the heart muscle will change as a result of training. Aerobic training results in a larger left ventricle, and anaerobic training results in a thickening of the left ventricle wall. These structural changes lead to changes in the function of the heart muscle (see below).





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Chronic adaptations in endurance athletes

Chronic adaptations occur in the respiratory, cardiovascular and muscular systems as a result of training. The purpose of training is to improve your performance. This could be performance in sport, fitness or any physical activity. The next section looks at the chronic adaptations that result from aerobic training in each of the three systems, and how these changes lead to an improvement in performance.

CHRONIC ADAPTATIONS AS A RESULT OF AEROBIC TRAINING

Adaptations resulting from aerobic training improve the efficiency with which the aerobic energy system provides energy to the working muscles and removes waste products. This improved efficiency is the result of a number of factors that increase the ability of the body to take up, transport and use oxygen. The degree to which the body responds to training is influenced by initial aerobic fitness level, training intensity, frequency and duration (see chapter 12 for more on training principles).

Cardiovascular adaptations

Chronic cardiovascular adaptations are changes to the structure and function of the heart, blood vessels (arteries, veins and capillaries) and the blood. Cardiovascular adaptations resulting from aerobic training increase oxygen delivery to the working muscles.

The heart

The heart is a muscle. Like any other muscle, it will respond to training by becoming bigger and stronger (see page 343).

Aerobic training leads to an increase in heart mass and volume – specifically, **hypertrophy** of the heart muscle, which is characterised by an increase in the size of the left ventricular cavity (mass) and in some thickening of the ventricle walls. In the illustration on page 343 you can see the increase in both ventricular wall thickness and ventricular cavity as a response to aerobic training. Aerobic training provides the greatest change in left ventricle capacity (see graph, right).

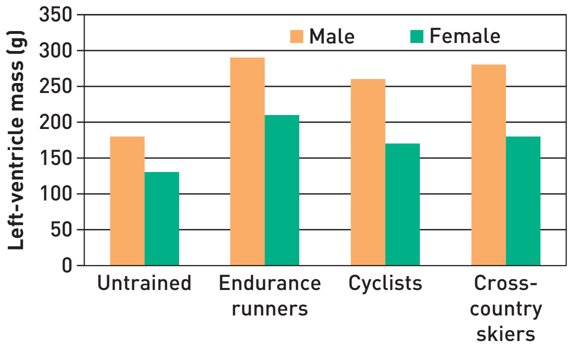
Increased size of the left ventricle cavity is linked to increased cardiac output during exercise. You will remember from chapter 4 that cardiac output is the product of stroke volume and heart rate ($Q = SV \times HR$).

At rest following an aerobic training program, heart rate and stroke volume will change, but cardiac output will remain the same. This is because the increased volume of blood in the left ventricle can be ejected with each contraction of the heart (increased stroke volume). This means the heart does not have to beat as often (decreased resting heart rate) to maintain the required cardiac output. Endurance athletes have very low resting heart rates – around 55–60 beats per minute (bpm) for women, compared with 60–65 bpm for untrained 18–25 year olds, and 50–55 bpm for males, compared with 56–60 bpm for untrained males.

Bradycardia, or decreased heart rate, is an easy and accurate measure of increased cardiovascular efficiency. This increased efficiency of the heart is also seen during exercise; submaximal heart rates are lower and stroke volume is increased in trained athletes.

FYI

The heart is the hardest working muscle in the body. In a typical lifetime it will beat more than 3 billion times without stopping!



Left-ventricle mass of untrained and endurance athletes

Adapted from McArdle, Katch & Katch, 2015

FYI

Heart volume in endurance-trained athletes is on average 25 per cent larger than in untrained people.

PRACTICAL ACTIVITY

MEASURING RESTING HEART RATE (RHR)

Your resting heart rate can give an indication of your fitness level. Measuring your resting heart rate over a period of time is one way of monitoring your body's response to training designed to increase cardiovascular fitness.

HOW TO MEASURE RHR

Lie down for at least 15 minutes before measuring your heart rate. The best time to do this is early in the morning, before you get out of bed. Even getting up and walking around your bedroom can increase your heart rate. However, do not start measuring your heart rate as soon as you wake up. Allow your body a few minutes to relax, then use one of the following methods.

» Radial pulse (wrist): place the tips of your index and third fingers on the thumb side of one of your wrists. Press gently and you will sense the beats. Timing yourself with a clock (or the stopwatch on a mobile phone), count the beats for 10 seconds. Multiply the result by 6.

» Carotid pulse (neck): measure as for radial pulse, but place your fingertips below your jaw, along the windpipe and throat.

DISCUSSION

1 Compare your resting heart rate with those of your classmates.

2 Who has the lowest resting heart rate? What factors might contribute to a low resting heart rate?

>

3 Why is it important to rest quietly before taking a resting pulse?
4 How could you lower your resting heart rate?
5 Identify some factors that may contribute to an increased resting heart rate.
6 Explain how a lower resting heart rate is indicative of a more efficient cardiovascular system. (Hint: remember Q = SV × HR.)

If cardiac output is unchanged but heart rate decreases, there must have been an increase in stroke volume. The increase can be attributed to:

» increased left ventricle volume and mass
» reduced cardiac and arterial stiffness
» increased diastolic filling time
» increased cardiac contractility.

The increase in stroke volume is apparent both at rest and during exercise, as a number of the factors are structural and do not change when exercise conditions change. Greater ventricular filling occurs with a decrease in heart rate because the heart has more time to fill up between contractions. With an increase in venous return, left ventricle volume and elasticity, more blood is able to fill the ventricle during **diastole**, which is then forcefully ejected during **systole**. This contraction is more forceful, and empties the heart of the volume of blood ejected under normal conditions, as well as the extra blood that entered and stretched the ventricle. A much greater volume of blood is therefore ejected with each heartbeat.

During submaximal exercise, cardiac output is unchanged or slightly decreased. This is due to the increase in stroke volume and a decrease in heart rate. Submaximal heart rate responses are significantly lower as a result of an aerobic training program. A heart that beats more slowly is more efficient; it requires less oxygen than a faster beating heart for the same cardiac output. The increased efficiency of the cardiovascular system means that at submaximal exercise intensities, trained athletes will achieve steady state (where oxygen demand equals oxygen supply) at a lower heart rate. Recovery heart rates are also decreased with aerobic training. This means that it takes less time for the body to return to resting levels following exercise.

Table 15.1 summarises the changes at rest and during submaximal and maximal exercise to the heart, cardiac output, stroke volume and heart rates.

TABLE 15.1 Chronic adaptations of the heart to aerobic training

	Rest	Submaximal exercise	Maximal exercise
Ventricle size	Increase		
Heart rate » Recovery heart rate » Steady state heart rate	Decrease n/a n/a	Decrease Decrease Decrease	No change Decrease n/a
Stroke volume	Increase	Increase	Increase
Cardiac output	No change or slight decrease	No change or slight decrease	Increase

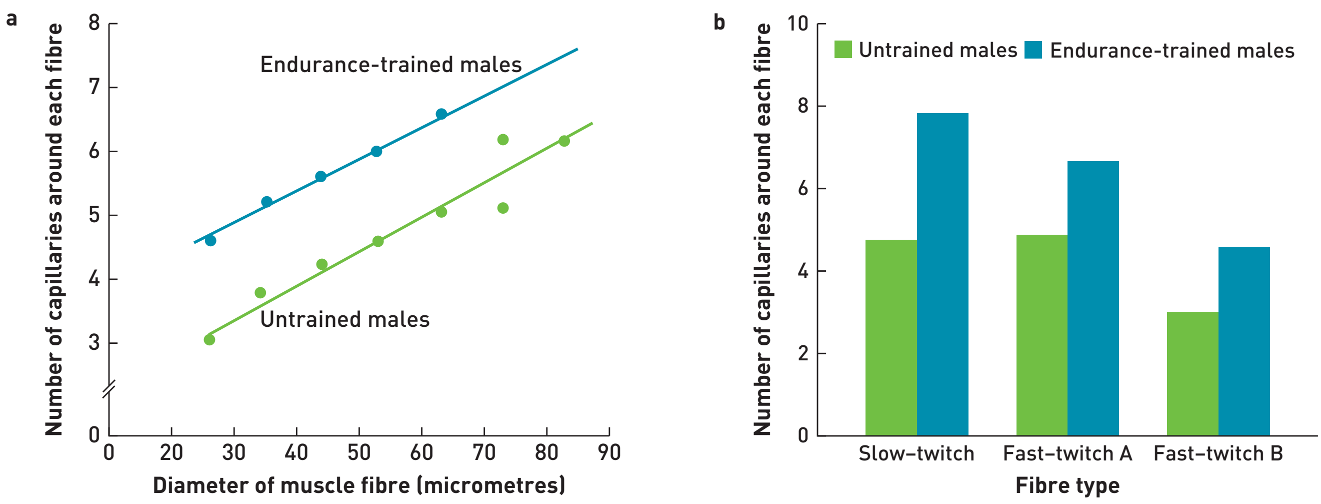
The increase in left ventricle volume and subsequent increase in stroke volume increase the efficiency of the heart. This means that at rest and at submaximal exercise levels, the heart doesn't have to work as hard to provide the required oxygen and nutrients to the muscles. The reduction in cardiac output at submaximal workloads is thought to reflect more effective redistribution of blood flow and the increased ability of the muscle to generate ATP aerobically with less oxygen concentration.

At maximal workloads, the increased cardiac output increases the amount of blood (and, therefore, oxygen delivered to the working muscles), and allows the by-products of aerobic respiration to be removed more rapidly. Increasing the amount of oxygen available for energy production allows greater aerobic glycolysis to occur.

Blood vessels

Aerobic training increases the cross-sectional area of the coronary arteries and the capillaries that feed the heart. This increased capillarisation improves blood flow to the heart, delivering more oxygen to the heart muscle to meet the energy demands of the **myocardium**. Blood flow to the heart muscle decreases slightly at rest and during submaximal exercise. Myocardial oxygen consumption decreases with aerobic training through increased stroke volume and decreased heart rate.

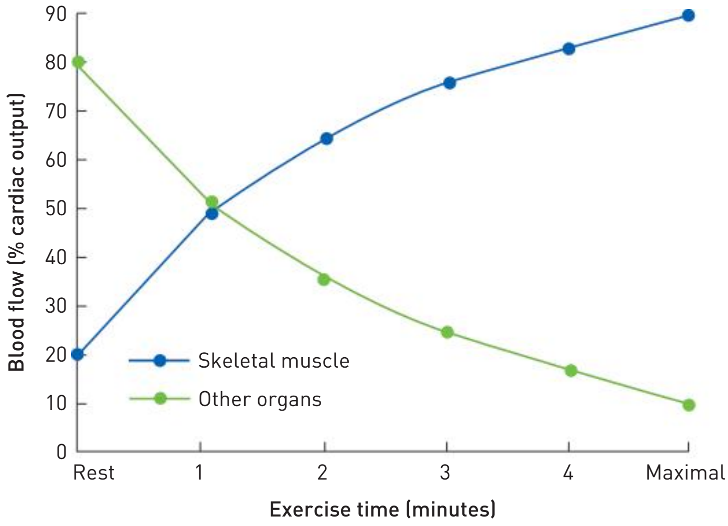
Long-term aerobic training also results in increased capillarisation of skeletal muscles. This change is most evident in slow-twitch muscle fibres. The number of capillaries that surround the muscle fibre (the capillary density) is usually linked to muscle hypertrophy. That means that the larger the muscle fibre, the greater the number of capillaries around it. The other factor linked to the number of capillaries surrounding a muscle fibre is the fibre type. Slow-twitch fibres, which have increased numbers of mitochondria per fibre, will also have a greater number of capillaries around each fibre compared to fast-twitch fibres (both type FTA and FTB). These relationships are shown below.



The relationship between the number of capillaries around each fibre and (a) muscle fibre size; (b) fibre type

(b) Adapted from: Fox, Bowers & Foss, 1993

Increasing the number of capillaries around the muscle leads to an increase in the supply of oxygen and other nutrients, and enhanced removal of waste products from the muscle.



During exercise, blood flow to the skeletal muscles increases, and blood flow to other organs is reduced.

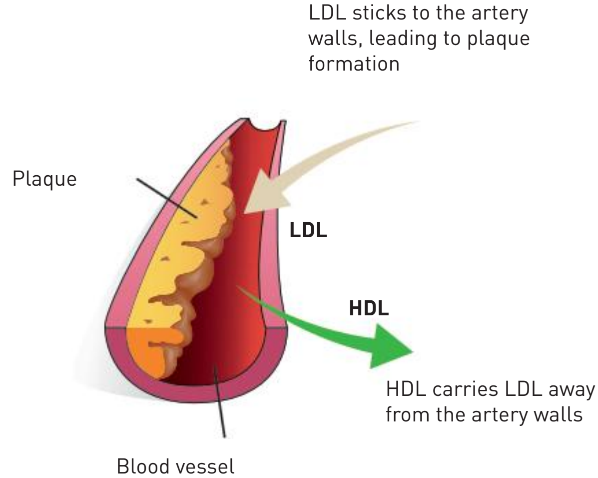
Redistribution of blood flow was discussed in chapter 7. The effect of aerobic training on blood flow distribution depends on whether the exercise is submaximal or maximal.

At rest and submaximal intensities, blood flow to the active muscles is decreased (remember, cardiac output is slightly lower in aerobically trained individuals). A larger volume of blood is directed to muscles that have a high oxidative capacity, at the expense of those that have a larger percentage of type IIB fibres (low oxidative capacity). Chronic adaptations resulting from aerobic training increase the ability of the muscles to deliver, extract and use oxygen; therefore, the oxygen demands of the active muscles are reduced, so the muscles require less blood flow to them. Improved fitness also increases blood flow to the skin, which allows for faster removal of heat and better thermoregulation of the body.

During maximal exercise, blood flow to skeletal muscles increases as a result of aerobic training. This is due to three factors:

» increased maximal cardiac output
» redistribution of blood to working muscles
» increased size of blood vessels and number of capillaries per gram of muscle.

Aerobic exercise can reduce the amount of low-density lipoproteins (LDLs) in the body and increase the high-density lipoproteins (HDLs). As discussed in Unit 1 (chapter 7), LDLs carry cholesterol to the arterial walls and deposit it there as plaque (atherosclerosis). This damages the arteries and causes narrowing of the blood vessels, which hinders blood flow through the vascular system. HDL acts as a bounty hunter, removing plaque from artery walls and delivering it to the liver, where it can be synthesised.



HDLs remove LDLs from the artery walls

Blood

Aerobic training increases the volume of both the plasma and red blood cells in the blood, increasing the overall blood volume. Increases in blood volume occur within only days of training; however, red blood cell increases take weeks to achieve. Highly trained endurance athletes have a blood volume 20–25 per cent greater than an untrained person.

Increases in blood plasma help increase stroke volume, due to the increase in the volume of blood that can fill the heart during **diastole**. Plasma volumes can also assist in regulating body temperature. Trained individuals are able to remove heat more quickly and economically than untrained individuals. This improves performance, reducing the impact of the heat generated by energy metabolism.

The total amount of haemoglobin in the blood increases with aerobic training. Haemoglobin is important for the transport of oxygen from the lungs to the working muscles. Increases in blood volume are associated with greater amounts of haemoglobin, but the haemoglobin concentration does not increase, as shown in Table 15.2. In this case, while the absolute volumes of both blood and haemoglobin increased, the haemoglobin concentration decreased slightly.

TABLE 15.2 Changes in haemoglobin and blood volume following physical training (males)

	Pre-training	Post-training
Total haemoglobin (g)	805.0	995.0
Total blood volume (L)	5.25	6.58
Haemoglobin concentration (g/100 mL of blood)	15.3	15.1

Adapted from: Fox, Bowers & Foss, 1993

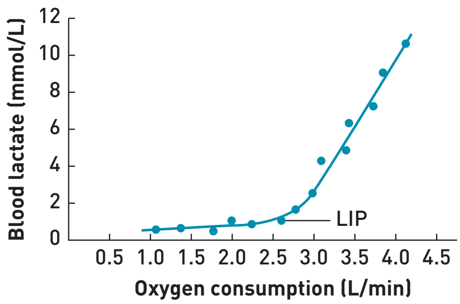
Aerobic training may reduce blood pressure at rest and during submaximal exercise, but it does not affect blood pressure during maximal exercise. The greatest reduction in systolic blood pressure occurs in subjects who were hypertensive (had mild to moderate high blood pressure) to begin with.

Blood lactate concentration has been shown to decrease with aerobic training. An overall decrease in blood lactate enables endurance-trained athletes to work aerobically at higher exercise intensity levels before the lactate inflection point (LIP) is reached.

This adaptation is thought to be the result of a decreased rate of lactate production during exercise, an increase in the rate of lactate removal from the blood, or a combination of both factors. The ability to sustain high exercise intensities without accumulating lactate is strongly related to performance in endurance events.

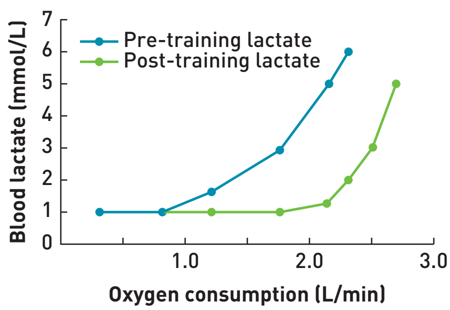
The lactate inflection point (LIP) reflects the balance between lactate entry into and removal from the blood. The upper graph on the right shows how lactate remains steady at the onset of exercise but increases dramatically as the intensity increases, because the body cannot remove it as quickly as it is accumulating.

With aerobic training, endurance athletes become better at clearing the lactate because of an increase in oxidation and gluconeogenesis. This means they are able to work at higher intensities for longer before reaching their LIP. This is a distinguishing factor in elite endurance athletes. If you compare two athletes with the same VO_2 max, the performer with the higher LIP will have an advantage over their opponent (see graph on page 350).



Lactate inflection point and oxygen consumption

Adapted from: McArdle, Katch & Katch, 2015



Aerobic training increases the exercise intensity at which the lactate inflection point is reached.

Adapted from: McArdle, Katch & Katch, 2015

FYI

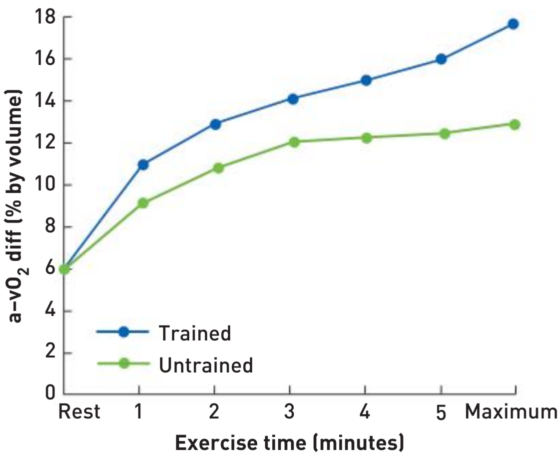
Fast-twitch fibres will produce lactate when they are recruited for muscular contraction, whether oxygen is available or not.

Lactate accumulation is affected by muscle fibre type, capillary density, mitochondrial size and number and enzyme concentration, whereas VO_2 max is determined by the functional capacity of the cardiovascular system to transport oxygen, and the muscle mass activated during exercise.

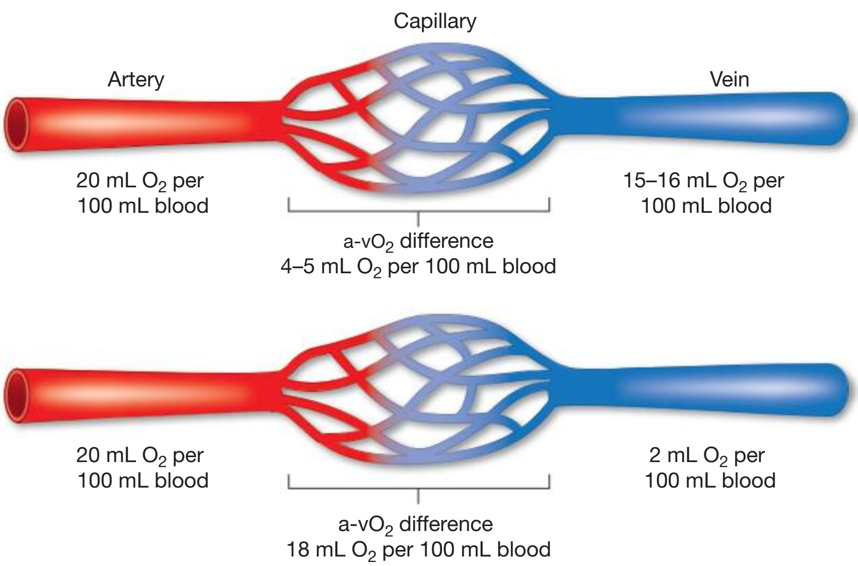
Oxygen extraction (a-vO_2 diff)

Aerobic training leads to an increase in the amount of oxygen extracted from the blood by the muscles, or arteriovenous oxygen difference (a-vO_2 diff) (see graph, left, and below). A combination of more effective blood distribution to working muscles and the ability of those muscles to extract and process the available oxygen leads to an increase in a-vO_2 diff.

The a-vO_2 diff is a measure of the amount of oxygen the working muscles are using. It is the difference in the oxygen concentration in the arterioles compared to the venules, after passing through the muscle. Table 15.3 shows an example of the increase in a-vO_2 diff as a result of training.



Aerobic training contributes to improved oxygen extraction from blood and increases the a-vO_2 diff in trained individuals.



a-vO_2 diff at rest (top) and during intense aerobic exercise (bottom)

Source: McArdle, Katch & Katch, 2015

FYI

Active skeletal muscles are able to extract maximal amounts of available oxygen. It is therefore hypothesised that oxygen supply, rather than oxygen use, is the limiting factor in aerobic power.

TABLE 15.3 Example of arteriovenous oxygen difference increases in response to exercise and aerobic training

	Oxygen concentration in blood (mL/100 mL)			Maximum a-vO_2 diff	
	In arteriole	In venule (rest)	In venule (exercise)	At rest	During exercise
Untrained subject	20	14	8	20 – 14 = 6	20 – 8 = 12
Trained subject	20	14	2	20 – 14 = 6	20 – 2 = 18

CHAPTER CHECKUP

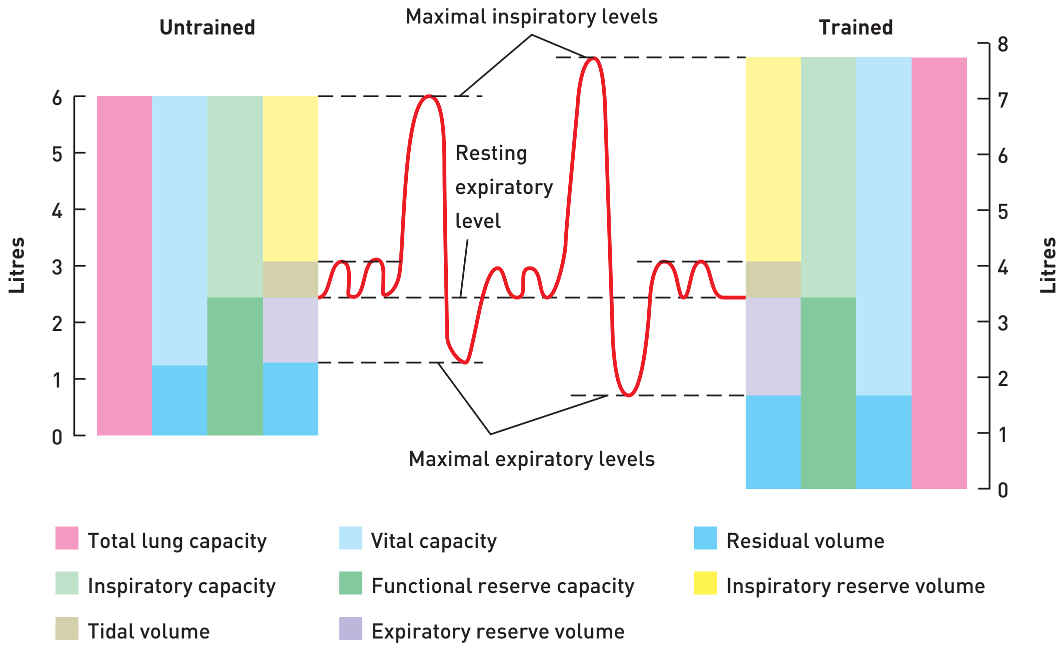
1 What is the relationship between left ventricle volume, stroke volume and cardiac output?
2 Summarise the chronic adaptations to the heart, blood vessels and blood that result from aerobic training.
3 What is the most important function of the blood in improving aerobic capacity?
4 Explain how chronic adaptations to the cardiovascular system make the heart and blood vessels more efficient in delivering oxygen to the working muscles.
5 Explain how the increases in cardiovascular parameters lead to an increase in the exercise intensity at which the LIP occurs.

Respiratory adaptations

Although there are fewer adaptations in **pulmonary** structure and function compared with the cardiovascular and neuromuscular adaptations, aerobic training allows for greater amounts of oxygen to be taken in and used by the body. The mechanisms responsible for this increase are either structural (changes to the respiratory system) or functional (improved function of the respiratory system).

Structural adaptations

Measured at rest, lung volumes (except tidal volume) increase with training (see graph below). Aerobic training increases pulmonary function, which causes the increase in lung volume. Total lung capacity is the amount of air in the lungs at the end of a maximal inspiration, or the largest amount of air you can breathe in (in one breath). Vital capacity is the volume of air that can be forcefully expired after maximal inspiration.



Untrained and trained lung volumes and capacities

Adapted from: Fox, Bowers & Foss, 1993

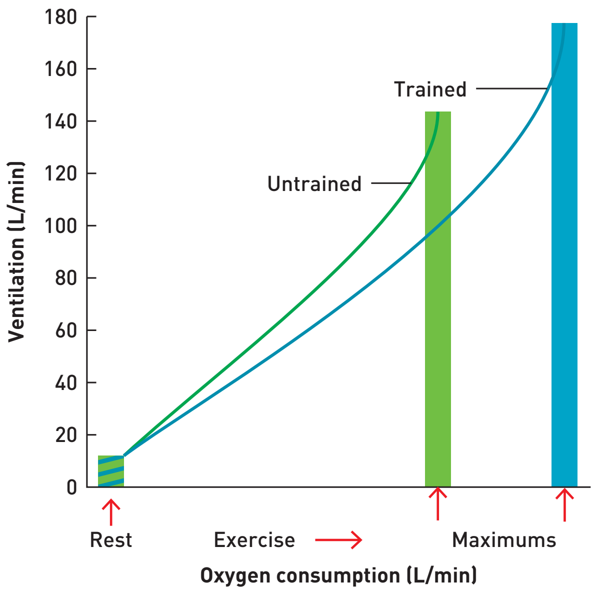
FYI

Diffusion capacity of male marathon runners at rest is nearly as high as the diffusion capacity of untrained men during maximal exercise.

Diffusion of oxygen across the alveolar–capillary membrane and of carbon dioxide across the tissue–capillary membrane is greater in trained athletes. This increase in diffusion is seen both at rest and during submaximal and maximal exercise intensities. The increase in diffusion is thought to be the result of structural changes; the increase in lung volumes provides greater alveolar–capillary surface area, and hence more sites where diffusion can occur.

Functional adaptations

During submaximal intensity workloads, endurance-trained athletes have lower ventilation rates compared to untrained people (see below left). You will remember from chapter 7, page 143, that ventilation is the product of tidal volume and respiratory rate.



Ventilation of endurance-trained and untrained subjects

Adapted from: Fox, Bowers & Foss 1993

At maximal intensity workloads, ventilation increases following aerobic training. An increase in tidal volume and breathing rate leads to the increase in maximum ventilation. As exercise intensity increases, oxygen requirements also increase. Maximal oxygen consumption increases, resulting in more carbon dioxide that needs to be removed. This is the trigger for the respiratory system to increase ventilation. Ventilation increases proportionally with carbon dioxide production.

Ventilatory efficiency occurs as a result of training. This means that the muscles responsible for breathing (the intercostal muscles and diaphragm) require less oxygen in order to work. Aerobic training–induced changes to the respiratory muscles increase aerobic enzymes and oxidative capacity, and the muscles' capacity to generate force, leading to improved exercise performance. The reduced energy demands of the respiratory muscles leaves more oxygen available to be delivered to the working muscles. This means less lactate is produced and can be more efficiently metabolised. Training increases tidal volume and decreases breathing rate. This allows the air to remain in the lungs for longer between breaths, meaning more oxygen can be extracted from the air that has been breathed in.

Oxygen consumption

Oxygen consumption (VO_2) is the amount of oxygen taken up and used by the body. As a result of aerobic training, for a given workload, oxygen consumption is the same or slightly lower at rest and during submaximal exercise. The mechanisms responsible, however, do change. As discussed earlier, stroke volume increases and heart rate decreases, both at rest and at submaximal workloads. The greater amount of blood ejected with each beat means that the oxygen requirements of the activity are being met more efficiently.

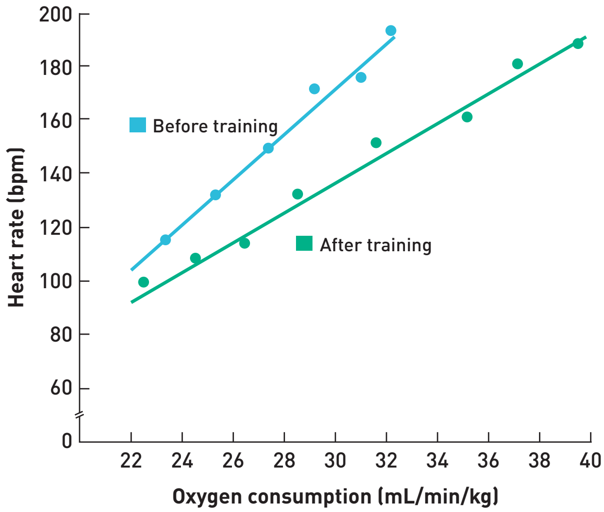
Maximal oxygen consumption (VO_2 max) has been shown to increase with aerobic training (see graph on next page). Improvements of between 5 and 20 per cent can be achieved with 8–12 weeks of training, depending on the training principles and methods used (see chapter 13). We have already discussed the training-induced changes to stroke volume (SV), heart rate (HR) and arteriovenous oxygen difference (a-vO_2 diff). VO_2 max is the product of these three variables:

$$VO_2 \text{ max} = SV \times HR \times a\text{-}vO_2 \text{ diff}$$

The change in VO_2 max is a result of both an increase in oxygen delivery to the working muscles and an increase in the ability of the muscles to extract the oxygen from the blood (the a-vO_2 diff).

The increase in cardiac output is a result of an increase in heart rate and stroke volume at maximal intensities, and the increase in a-vO_2 diff is a result of changes within the muscle (see pages 354–356).

Oxygen extraction approaches a maximum during high-intensity exercise. This means that the limiting factor in maximum oxygen consumption is the supply of oxygen to the working muscles.



Improvement in heart rate response to exercise with aerobic training

Source: McArdle, Katch & Katch, 2015

TABLE 15.4 Chronic adaptations of the respiratory system to aerobic training

	Rest	Submaximal exercise	Maximal exercise
Total lung volume and vital capacity	Increase	Increase	Increase
Tidal volume	No change	Increase	Increase
Diffusion	Increase	Increase	Increase
Membrane surface area	Increase	Increase	Increase
Ventilation	Decrease	Decrease	Increase
Ventilatory efficiency	Increase	Increase	Increase
Oxygen consumption	No change/ slight decrease	No change/slight decrease	Increase

CHAPTER CHECK-UP

1 What is diffusion? Where, why, when and how does it occur?
2 The trigger for increased ventilation is increased carbon dioxide levels, not increased demand for oxygen. What evidence supports this statement?
3 Explain why an elite endurance athlete would have a lower VO_2 at a submaximal workload than an untrained individual.
4 Identify the three factors that impact on oxygen consumption. Discuss the changes to each of these three factors at the submaximal and maximal level as a result of aerobic training.

Muscular changes

At the muscular level, chronic adaptations to aerobic training are characterised by changes that increase maximal oxygen consumption with little or no change in muscle strength or power. In the muscle, the adaptations facilitate an increase in the production of ATP by the aerobic system. Aerobic training occurs when there is an increase in the activation frequency of the motor units and they are contracting against a submaximal load, such as in running, swimming, cycling or cross-country skiing. Muscular adaptations are specific not only to the training undertaken but also to the muscle fibres within the muscle.

REAL WORLD APPLICATION

Which muscle fibre is that?

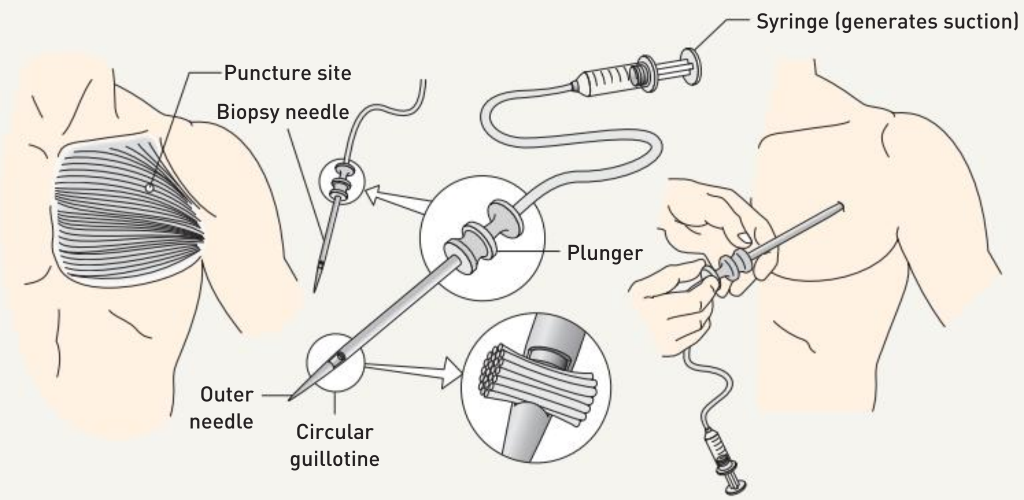
Muscle biopsies are used to examine small pieces or samples of muscle tissue. The sample can be obtained by either an 'open' or 'needle' method, and is usually performed under local anaesthetic.

Open biopsies involve a small incision through the skin and into the muscle so that a sample of tissue can be removed and sent off for analysis.

Needle biopsies are less invasive than open biopsies. A small 'plug' of tissue remains in the needle when it is removed from the muscle, and this is sent to a pathologist for examination.

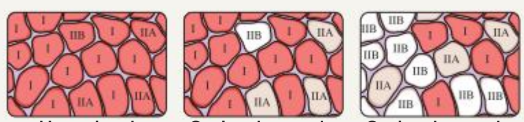
Muscle biopsies are used to:

- distinguish between neurogenic (nerve) and myopathic (primarily muscle) disorders
- identify specific muscular disorders such as muscular dystrophy or congenital **myopathy**
- identify metabolic functions occurring in muscles
- diagnose infections that affect the muscles
- determine the structure of muscle cells (fibre composition).



Muscle biopsies using a needle are done under local anaesthesia. A small plug of tissue is removed for analysis.

Histology tests (histo = tissue) use chemical stains to see the muscle's overall appearance and the structure of the muscle cells. These tests are often used to determine the fibre 'make-up' an athlete possesses in certain muscles, and to analyse how muscle fibres are responding to different training conditions.



Muscle biopsies and staining reveal different fibre compositions in 100-metre and 1500-metre swimmers. Both samples are taken from the pectoralis major muscle. I = slow twitch fibres; IIA and IIB = fast-twitch fibres.

Muscle structure

Muscles contain a mix of slow-twitch and fast-twitch fibres, and aerobic training will have an effect on each muscle fibre type. The aerobic capacity of the slow-twitch fibres will increase as a result of aerobic training. Fast-twitch fibres (type A and B) don't become slow-twitch fibres, but they do maximise their aerobic potential or take on the characteristics of slow-twitch fibres as a result of aerobic training. Recruitment of muscle fibres was discussed in chapter 7. Slow-twitch fibres are preferentially recruited over fast-twitch fibres for aerobic training, and therefore have the greatest adaptations to this type of training. Endurance-trained athletes will have larger slow-twitch fibres than fast-twitch fibres in the same muscle. The following section will specifically focus on the effect of training on slow-twitch fibres. Changes also occur in fast-twitch fibres, but to a lesser extent.

Slow-twitch fibres will increase in size (hypertrophy) as a result of aerobic training. The increase in the size of slow-twitch fibres is closely associated with the increased capillary density surrounding the fibres (see graph page 347). In endurance athletes, slow-twitch fibres take more of the muscle than fast-twitch fibres.

Mitochondria

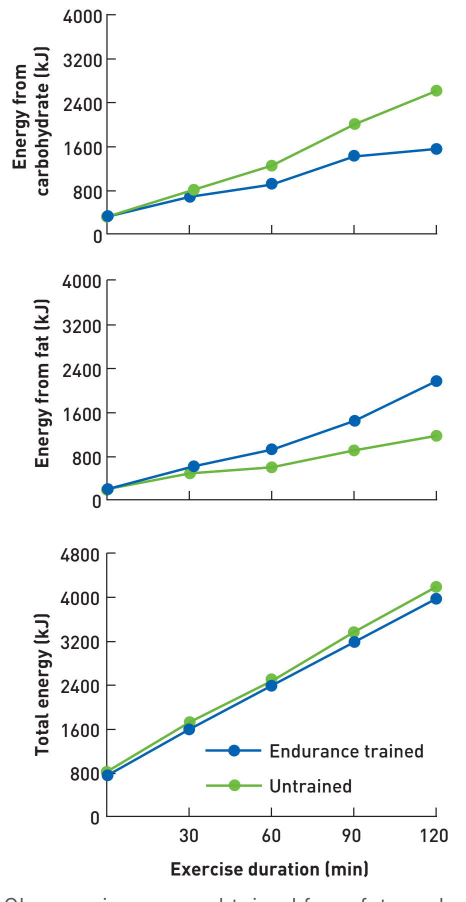
Mitochondria increase in size, number and surface area following aerobic training, enhancing the capacity of the muscle to generate energy (ATP) aerobically. This increase in the number and size of the sites available for the release of ATP (aerobically) enhances the ability of the body to perform aerobically. Mitochondria are the site of aerobic ATP production. The bigger the sites are and the more sites you have, the greater the amount of ATP that can be generated aerobically! Mitochondrial potential, not lack of oxygen, is the limiting factor in the oxidative capacity of untrained muscles. The increase in mitochondria coincides with an increase in the oxidative enzymes that allow endurance athletes to work at higher percentages of their aerobic capacity for sustained periods without accumulating blood lactate. Being able to run, swim or cycle at a faster speed while still producing ATP aerobically is a significant factor affecting overall performance in endurance events.

Myoglobin

The **myoglobin** content in slow-twitch fibres, which are capable of generating ATP aerobically, is higher than in fast-twitch fibres. Myoglobin assists in delivering oxygen across the cell membrane to the mitochondria, where it is used in the process of energy production. Increased myoglobin levels increase the available oxygen for aerobic respiration; however, any effect of regular physical activity on myoglobin levels is negligible.

Oxidation of fats

Aerobic training causes changes to the metabolic functioning of muscles. Changes within the muscle (discussed previously) significantly improve the function of the muscle during sustained aerobic exercise. One effect of these changes is the increased oxidation of free fatty acids for energy.



Changes in energy obtained from fats and carbohydrate as a result of aerobic training

Adapted from: McArdle, Katch & Katch, 2015

At rest and during submaximal exercise, endurance-trained athletes are able to oxidise fatty acids more readily. Fat is a major fuel source for muscular contraction during exercise, and an increased ability to oxidise fat is advantageous in endurance activities. The three factors that result from aerobic training and increase the ability of the muscles to oxidise fat are:

» an increase in intramuscular triglycerides
» an increase in free fatty acids
» an increase in oxidative enzymes.

Increased oxidation of fat at submaximal intensities is beneficial to endurance athletes as it allows them to conserve glycogen stores. The three graphs on the previous page show how aerobic training enhances the use of fat as a fuel during extended submaximal exercise. The glycogen sparing occurs because of the release of fatty acids.

Oxidation of glycogen

Aerobic training increases the ability of the skeletal muscle to oxidise glycogen (carbohydrate), particularly during maximal exercise.

The adaptations that cause an increase in the energy-generating capacity of the muscle are:

» an increase in number, size and surface area of mitochondria
» an increase in enzyme activity and concentration
» an increase in muscle glycogen stores.

These three factors work together to improve all aspects of the aerobic ability of the muscle.

TABLE 15.5 Chronic adaptations of the muscular system to aerobic training

Adaptation	Rest	Submaximal exercise	Maximal exercise
Fibre size	Increase		
Capillary density	Increase		
Myoglobin	No change/slight increase		
Mitochondria (size, number and surface area)	Increase		
Glycogen stores	Increase		
Triglyceride stores	Increase		
Oxidative enzymes	Increase		
Oxidation of fat	Increase	Increase	
Glycogen sparing		Increase	
Oxidation of glycogen		Decrease	Increase
a-vO_2 difference		Increase	Increase

Other changes as a result of aerobic training

As well as changes to the cardiovascular, respiratory and muscular systems, a number of other physiological and psychological benefits may occur as a result of aerobic training.

TABLE 15.6 Physiological and psychological benefits of aerobic training

Body composition changes	Psychological benefits
↓ body fat ↑ fat-free mass	↓ anxiety ↓ depression ↓ neuroticism ↑ self-esteem, mood and self-concept ↓ stress levels

↑ increased, ↓ decreased

FYI

To lose weight through physical activity alone requires at least 60 minutes of physical activity at an intensity that expends more than 1200 kJ (e.g. brisk walking pace) at least three times per week. In general, longer exercise duration counterbalances lower exercise intensity in terms of benefits gained!

CHAPTER CHECK-UP

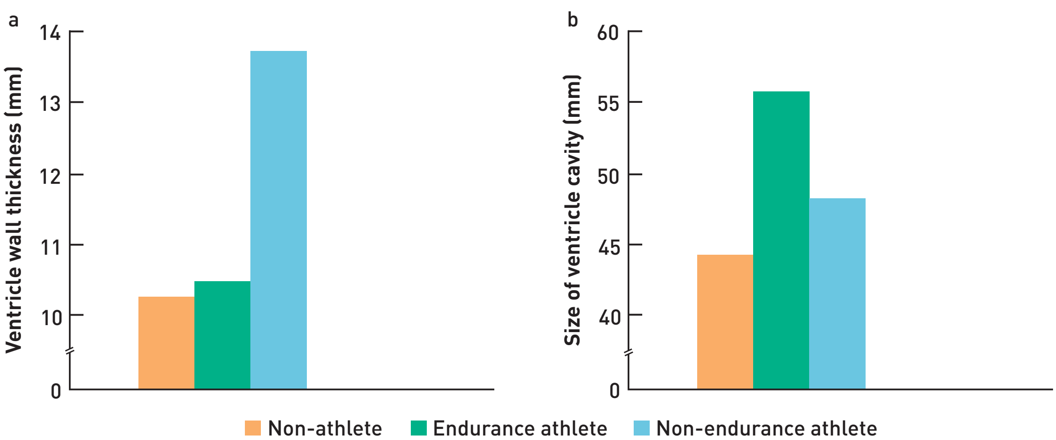
1. What is the role of mitochondria in aerobic energy production? Outline the three changes that occur as a result of aerobic training and how this impacts on aerobic respiration.
2. What is meant by glycogen sparing? How does this relate to an increased ability to oxidise fats as a fuel source for aerobic energy production?
3. Discuss why a-vO_2 difference could be considered a muscular adaptation and/or a vascular adaptation.
4. Using correct terminology, describe the process of taking in, transporting and using oxygen.
5. Create a concept map showing how the aerobic changes that occur within each system (cardiovascular, respiratory and muscular) are all related to increasing aerobic capacity.

CHRONIC ADAPTATIONS AS A RESULT OF ANAEROBIC TRAINING

Anaerobic training effects are seen mainly in the muscular system, although some changes also occur in the cardiovascular system. The effect of anaerobic training on the respiratory system is negligible, so won't be discussed here. Anaerobic training focuses on the development of the ATP–PC and anaerobic glycolysis energy systems. Chronic adaptations to anaerobic training may lead to improvement in the anaerobic capacity, strength, power and speed of an athlete. The manipulation and application of the training principles and program variables will determine the degree to which the muscular system adapts to exercise.

Cardiovascular responses to anaerobic training

As shown in the left graph below, the thickness of the left ventricle wall increases as a result of anaerobic training (in non-endurance athletes – see illustration on page 343). However, if these changes are expressed relative to the surface area of the body, or to lean body mass,



Cardiac hypertrophy of non-endurance athletes: (a) ventricle wall thickness; (b) size of ventricle cavity

Adapted from: Fox, Bowers & Foss, 1993

the increase is not as evident. With anaerobic training, the systolic function (contraction) of the left ventricle may increase slightly because the volume of the ventricle only increases slightly. The heart can eject the blood more forcefully from the left ventricle, but the stroke volume will remain unchanged.

Anaerobic-trained athletes usually have lower systolic and diastolic blood pressure at rest and at a given submaximal workload compared to untrained individuals.

Muscular adaptations to anaerobic training

Anaerobic training increases the capacity of the ATP–PC system and the anaerobic glycolysis system. The changes that occur in the skeletal muscle as a result of anaerobic training include increased energy substrate levels, enzyme activity and glycolytic capacity. These changes occur in both fast- and slow-twitch fibres, although the changes observed in slow-twitch fibres are negligible. The most dramatic increases are seen in fast-twitch fibres, particularly type B.

FYI

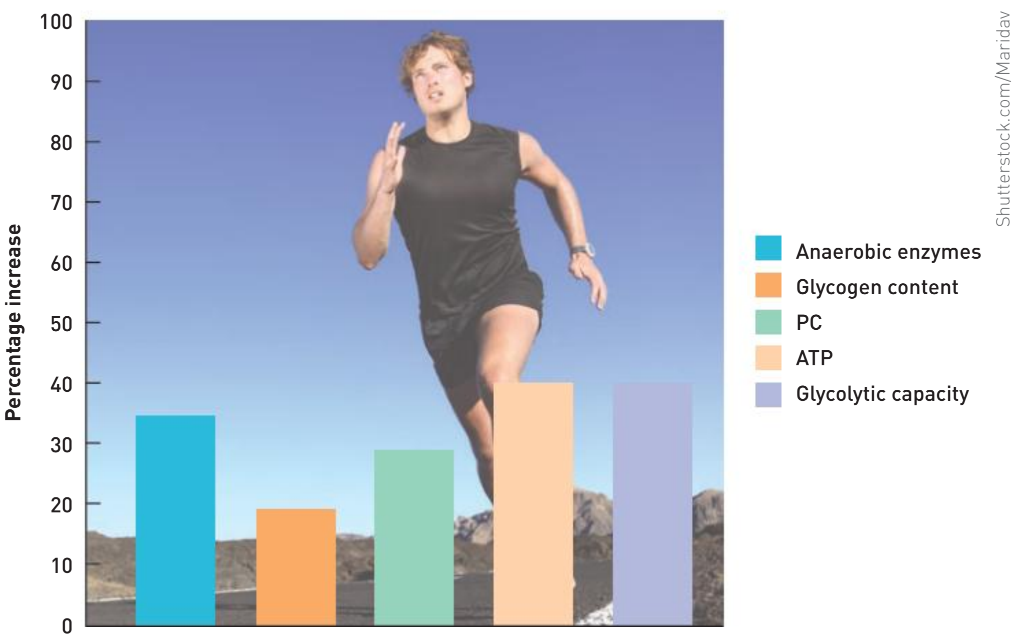
Fast-twitch muscle fibres store up to six times as much PC as ATP.

Anaerobic training increases the muscular stores of anaerobic energy substrates:

» ATP
» PC (phosphocreatine)
» free creatine
» glycogen.

ATP and PC are the most readily available sources of energy for muscular contraction. Increasing fuel stores corresponds to improved performance in activities and events that require high power output, such as sprinting or throwing events. By having more fuel available for immediate energy supply, the body reduces its reliance on aerobic energy substrates. The rate of ATP production in both of the anaerobic systems is much higher than in the aerobic system, which increases the rate of energy output.

Anaerobic training increases the quantity and activity levels of the enzymes associated with the breakdown of ATP anaerobically. ATPase is an enzyme that facilitates the breakdown of ATP to ADP. Other enzymes assist in the resynthesis. Combined with the increased stored energy substrates, increased enzyme activity increases the turnover of ATP (breakdown and resynthesis). This allows for a more rapid release of energy.



Chronic adaptations to skeletal muscle as a result of anaerobic training

Source: McArdle, Katch & Katch, 2015

Glycolytic capacity is also increased with anaerobic training. Due in part to the increase in glycolytic enzymes, and also to the increases in glycogen stores, the rate at which glycogen can be broken down into lactate is increased. This leads to an increase in the amount of ATP that can be derived from anaerobic glycolysis, resulting in an increase in performance in activities that depend on the anaerobic glycolysis system for energy, such as a 400-metre race.

With anaerobic training, athletes are able to generate and tolerate higher levels of blood lactate during maximal exercise. The reasons for this (as discussed previously) are the increase in glycogen and glycolytic enzymes. Combined with an increased tolerance for the by-products associated with anaerobic metabolism, these increases allow athletes to continue to work at high intensities, while tolerating the pain associated with the fatigue that is caused by the physical activity. Research suggests that motivation is probably a factor in improving tolerance, but there is no evidence to suggest that the buffering capacity is increased with training.

TABLE 15.7 Chronic adaptations to anaerobic training in fast-twitch muscle fibres

Physiological effect	Significance
↑ ATP and PC stores	↑ capacity of the ATP–PC system
↑ glycogen stores	↑ utilisation of glycogen as a fuel source
↑ glycolytic enzymes	↑ rate of ATP release from glycogen
↑ ATPase	↑ turnover of ATP (breakdown and resynthesis)
↑ tolerance to metabolic by-products	↑ ability to continue working at high intensities

↑ = increase

CHRONIC ADAPTATIONS AS A RESULT OF RESISTANCE TRAINING

Muscular adaptations to resistance training

Chronic adaptations to skeletal muscles as a result of resistance training include increases in muscular strength due to the increased levels of anaerobic substrates (see Table 15.8) and muscle hypertrophy. Skeletal muscles are very adaptive. If you stress a muscle (that is, increase the load it has to move or lift), it will adapt, both structurally and functionally.

TABLE 15.8 Changes in resting concentrations of anaerobic energy substrates following heavy-resistance training

Anaerobic substrate	Pre-training (mmol/kg)	Post-training (mmol/kg)	Difference (%)
PC	17.07	17.94	+5.1
Creatine	14.52	10.74	+35.2
ATP	5.07	5.97	+17.8
Glycogen	113.90	86.28	+32.0

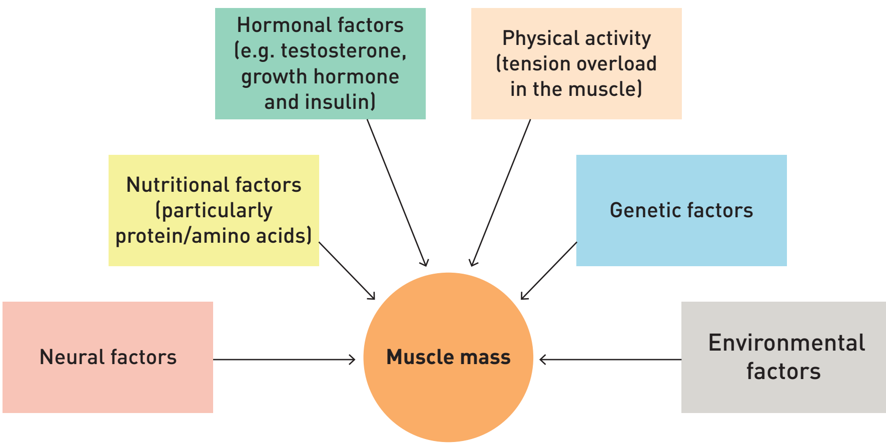
Adapted from: McArdle, Katch and Katch, 2015

Shutterstock.com/holbox

Lifting free weights will cause the muscles to adapt

The opposite is also true for skeletal muscles: if they are not used (stressed), they will decrease in size (atrophy). This can be seen when someone breaks their leg; after being in a cast for six weeks, the muscles of their leg are smaller and weaker.

Developing and maintaining muscle mass (and strength) relies on the interaction of a number of factors (see below).



The factors that contribute to developing and maintaining muscle mass

In chapter 9 (page 196), we defined muscular strength as the capacity of the muscle to produce force in a given situation. The amount of force developed is a result of the number, size and orientation of the fibres within the muscle. However, muscles very rarely generate force in isolation; they work together to produce the desired movement. Physiological adaptations to resistance training occur within the muscle itself and also within the nervous system (neural adaptations). Adaptations that occur within the muscle increase the force-generating capacity of the muscle, while neural adaptations enhance the effectiveness of muscular coordination.

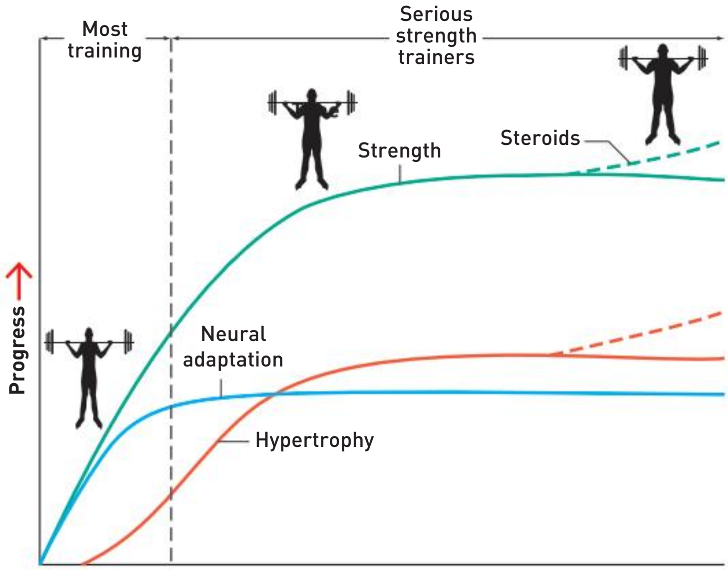
Neural adaptations

Resistance training programs typically produce increases in strength within the first few weeks. The initial changes in strength (shown below) as a result of training occur without any increase in muscle size or cross-sectional area. The most likely cause of this initial increase in strength is neurological adaptations to the training, including:

- greater efficiency in neural recruitment patterns
- increased motor neuron excitability
- increased central nervous system activation
- improved motor unit synchronisation and increased firing rates
- decreasing neural inhibitory reflexes
- inhibition of **Golgi tendon organs**.

Resistance training enhances motor-unit recruitment. The greater the number of motor units that can be recruited, the greater the force that can be developed in the muscle. To exert maximal force requires the recruitment of as many motor units as possible.

As well as being able to recruit more motor units, there is also an increase in the ability to recruit high-threshold motor units. Muscle fibres are recruited according to size. Larger, stronger motor units are recruited last; these are typically fast-twitch fibres. With resistance training, there is an increase in the recruitment of fast-twitch fibres. These adaptations result in increased force production, rate of force development (power) and length of time for which the contraction can be maintained.



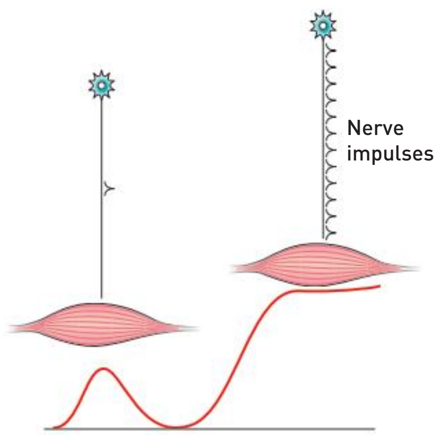
The relative roles of neural and muscular adaptations (hypertrophy) to strength training

Adapted from Sale, 1988

Resistance training increases the firing rate of a motor unit. This leads to an increase in the strength and duration of a muscular contraction (see below right).

Fast-twitch fibres have higher firing rates than slow-twitch fibres, and the maximal force that can be generated can increase by up to 1500 per cent when the firing rate is increased from minimum to maximum. Firing rates affect the rate of force development, which is important in activities that require quick, powerful movements, such as high jump.

Elite athletes have the ability to perform powerful movements with exceptional timing and little apparent effort. The increase in motor-unit coordination is a result of a number of neural adaptations. The first is in the neural facilitation of movement. Plyometric resistance training causes the nervous system to develop reflexes to high-stretch loads, which increases the power in movements such as jumping. Co-contraction of antagonist muscles increases control of movements by increasing stabilisation in rapid and precise movements and acting as a braking mechanism in ballistic movements. Increased synchronisation of motor-unit firing rates occurs as a result of



Increasing the firing rate of motor units increases the strength and duration of a muscle contraction.

Source: Brooks et al., 2005

resistance training. This increased synchronisation leads to smoother acceleration of body parts, greater power and increased duration of high-intensity contractions.

Muscle cross-training occurs as a result of resistance training. Cross-training refers to training the muscles on one side of the body and seeing improvements in strength in the same muscle on the other side of the body, even though it has not been trained. Cross-training improves performance through integration of strength gains, timing and muscle stretch-shortening reflexes. The Golgi tendon organs in the muscle prevent full contraction of the muscle. Resistance training inhibits this action, allowing more forceful contractions to occur.

TABLE 15.9 Summary of neural adaptations from strength training

Physiological effect	Significance
↑ motor unit recruitment	↑ force of contraction
↑ rate of motor unit activation	↑ rate of force development (speed of contraction)
↑ recruitment of fast-twitch fibres	↑ rate of force development ↑ time for which maximum force can be maintained
↑ motor unit coordination	↑ force ↑ efficiency and effectiveness of force application

Adapted from: Brooks et al., 2005

FYI

Muscle growth is a result of repeated injury to the muscle fibre and the overcompensation of the protein synthesis to make new and bigger muscle cells.

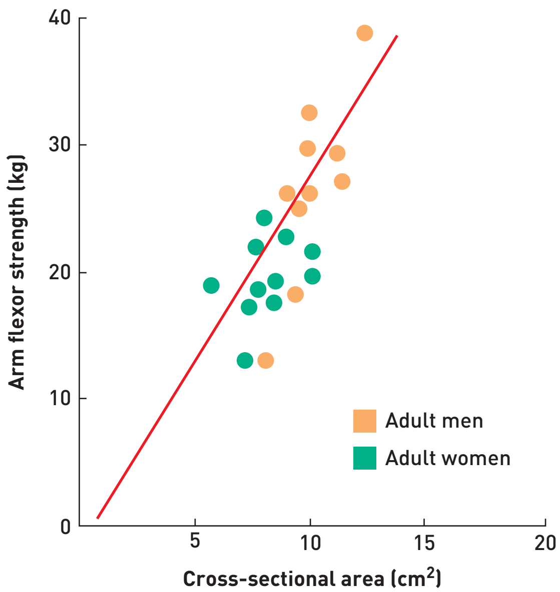
Hypertrophy

An increase in muscle size (hypertrophy) due to resistance training is a result of one or more of the following changes to the muscle fibres:

» increased number and size of the **myofibrils**
» increased contractile proteins
» increased size and strength of connective tissue (tendons and ligaments).

An increase in the cross-sectional area of the muscle is a result of the increased number and size of the myofibrils. The actual number of fibres within a muscle does not change, but the size of the fibres does.

Resistance training produces the greatest increase in the size of fast-twitch B fibres. This in turn increases the area of fast-twitch fibres compared to slow-twitch fibres. The increases in contractile proteins (myosin and actin) increase the contractile capacity of the muscle, as well as the overall size of the muscle fibre. Larger cross-sectional area is directly related to increased muscular strength (see graph at left).



Relationship between cross-sectional area of a muscle and strength

Source: McKardle, Katch and Katch, 2015

Larger fibres are capable of storing more ATP, PC and glycogen. Increased anaerobic energy substrates then increase the capacity of the anaerobic systems to provide rapid energy for high-intensity activities. This effect is twofold. The increases in ATP and PC stores also decrease the reliance on anaerobic glycolysis, so less lactate is produced.

With resistance training, connective tissue will thicken and strengthen. This improves the structure and function of the tendons and ligaments. Increases in tendon thickness allow for greater attachment of muscle to bone, which assists in force production.

CHAPTER CHECK-UP

1 Explain how an increase in the energy substrates stored in the muscle can lead to improved performance in a long-jump event.
2 Increases in enzyme activity in the muscle lead to an increase in the breakdown and resynthesis of ATP. Differentiate between these two processes and determine the chronic effect on each process as a result of training.
3 There are six factors that interact to determine muscle strength. Outline each of them.
4 Neural adaptations can result in rapid increases in strength. Describe the neural factors that lead to the initial improvements in strength. Using a specific example, explain how the changes that occur at the muscular level equate to improved performance.
5 'Hypertrophy of muscle leads to an increase in strength.' To what extent do you agree or disagree with this statement?

DATA ANALYSIS

CHRONIC ADAPTATIONS TO TRAINING

METHOD

1 Complete a series of fitness pre-tests, followed by participation in a variety of training sessions over a period of 2–4 weeks. Then complete the same series of fitness tests (post-testing).
2 Record all your results in a table and calculate the percentage change for each result. For the sample entry in the table below, the calculation is:

$$\text{Change} = \frac{\text{post-test} - \text{pre-test}}{\text{pre-test}} \times 100\%$$

$$= \frac{47.4 - 43.9}{43.9} \times 100\% = 8\%$$

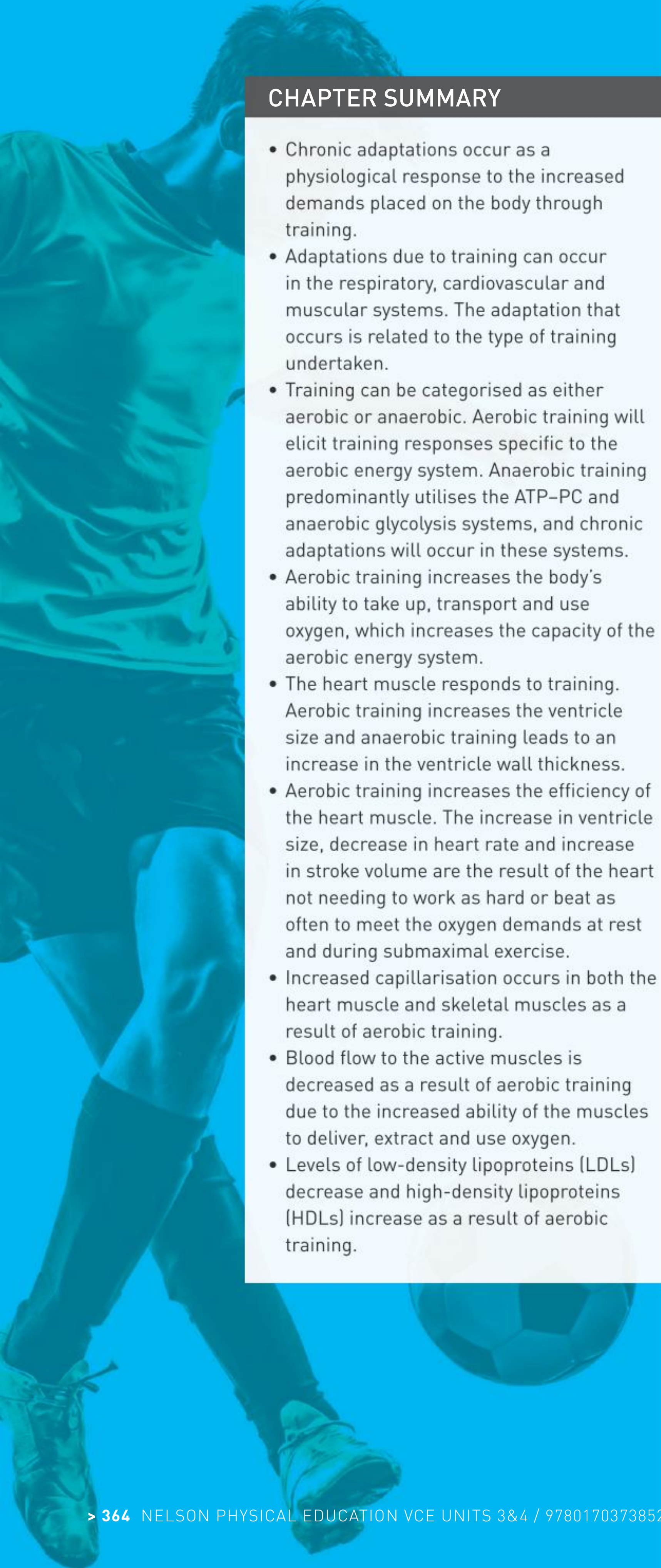
3 Indicate if there has been an increase, a decrease or no change in each fitness component.
4 Use your own data to answer the questions below.

RESULTS

Fitness component	Pre-test	Post-test	Change
Aerobic capacity (20-m shuttle run)	Stage 9.2 (43.9 mL/min/kg)	Stage 10.2 (47.4 mL/min/kg)	8% increase

QUESTIONS

1 Suggest reasons (other than physiological responses to training) for the changes recorded between pre- and post-testing.
2 Which fitness components reported the greatest change? Suggest reasons for this.
3 Select three fitness components that you recorded a change in.
   a Explain the physiological changes in the cardiovascular, respiratory and muscular systems that are reflected in your post-test result.
   b Identify how the changes may lead to an improvement in your selected sport.
4 Explain how initial fitness level, training frequency, duration and intensity impact on the chronic adaptations that occur in the cardiorespiratory and muscular systems.



CHAPTER SUMMARY

- Chronic adaptations occur as a physiological response to the increased demands placed on the body through training.
- Adaptations due to training can occur in the respiratory, cardiovascular and muscular systems. The adaptation that occurs is related to the type of training undertaken.
- Training can be categorised as either aerobic or anaerobic. Aerobic training will elicit training responses specific to the aerobic energy system. Anaerobic training predominantly utilises the ATP–PC and anaerobic glycolysis systems, and chronic adaptations will occur in these systems.
- Aerobic training increases the body's ability to take up, transport and use oxygen, which increases the capacity of the aerobic energy system.
- The heart muscle responds to training. Aerobic training increases the ventricle size and anaerobic training leads to an increase in the ventricle wall thickness.
- Aerobic training increases the efficiency of the heart muscle. The increase in ventricle size, decrease in heart rate and increase in stroke volume are the result of the heart not needing to work as hard or beat as often to meet the oxygen demands at rest and during submaximal exercise.
- Increased capillarisation occurs in both the heart muscle and skeletal muscles as a result of aerobic training.
- Blood flow to the active muscles is decreased as a result of aerobic training due to the increased ability of the muscles to deliver, extract and use oxygen.
- Levels of low-density lipoproteins (LDLs) decrease and high-density lipoproteins (HDLs) increase as a result of aerobic training.
- Blood volume increases as a result of an increase in both plasma levels and haemoglobin levels, but haemoglobin concentration does not increase with aerobic training.
- Blood pressure can be reduced with aerobic training, if it is high to begin with.
- Aerobic training increases the body's ability to remove lactate. This allows endurance athletes to work at higher intensities for longer before lactate accumulates.
- The chronic adaptations to skeletal muscles that result from aerobic training increase oxygen consumption. These changes occur in the slow-twitch fibres and include increases in fibre size (due to increased capillarisation); capillary density; myoglobin, mitochondria, glycogen and triglyceride stores; oxidative enzymes; oxidation of fat; glycogen sparing and a-vO_2 diff.
- Chronic adaptations that occur in the respiratory system as a result of aerobic training include increases in lung volume, diffusion, surface area of the alveolar–capillary interface and ventilator efficiency. These contribute to increased VO_2 max.
- Chronic adaptations to skeletal muscle as a result of anaerobic training occur mainly in the fast-twitch fibres. These adaptations include increases in fibre size, fuel stores, glycolytic enzymes and ATPase, and tolerance of by-products.
- Resistance training results initially in neural adaptations, followed by hypertrophy. These adaptations increase the force of contraction and rate of force development, resulting in increased strength.
- Adaptations are reversible and will be lost when training ceases.

CHAPTER REVIEW

Multiple-choice questions

1 Which of the following would most likely result in a decrease in resting heart rate, an increase in myoglobin and an increase in muscle capillarisation?
   A resistance training
   B continuous training
   C sprint training
   D plyometric training
2 Which of the following are likely chronic adaptations to anaerobic training?
   A increased heart volume, increased size of fast-twitch fibres, increased ventilation
   B increased left ventricle thickness, increased ATP and PC stores, increased glycolytic enzyme activity
   C decreased left ventricle volume, decreased ATPase, increased force of contraction
   D decreased resting heart rate, decreased cardiac output, decreased ATP and PC stores

Short-answer questions

3 List three changes that occur in fast-twitch fibres as a result of anaerobic training, and explain how they lead to improved performance.
4 Identify three chronic adaptations to aerobic training in the cardiovascular, respiratory and muscular systems (one per system). Compare the role each plays in increasing the aerobic capacity of an athlete.
5 How does an increase in mitochondria density resulting from aerobic training improve the aerobic energy system, and what impact does this have on performance?
6 Contrast the differences in cardiac hypertrophy as a result of aerobic and anaerobic training.

Extended-response question

7 Discuss the mechanisms responsible for the decrease in lactate accumulation during submaximal exercise as a result of aerobic training.

CHAPTER 16

PSYCHOLOGICAL STRATEGIES TO ENHANCE PERFORMANCE AND RECOVERY

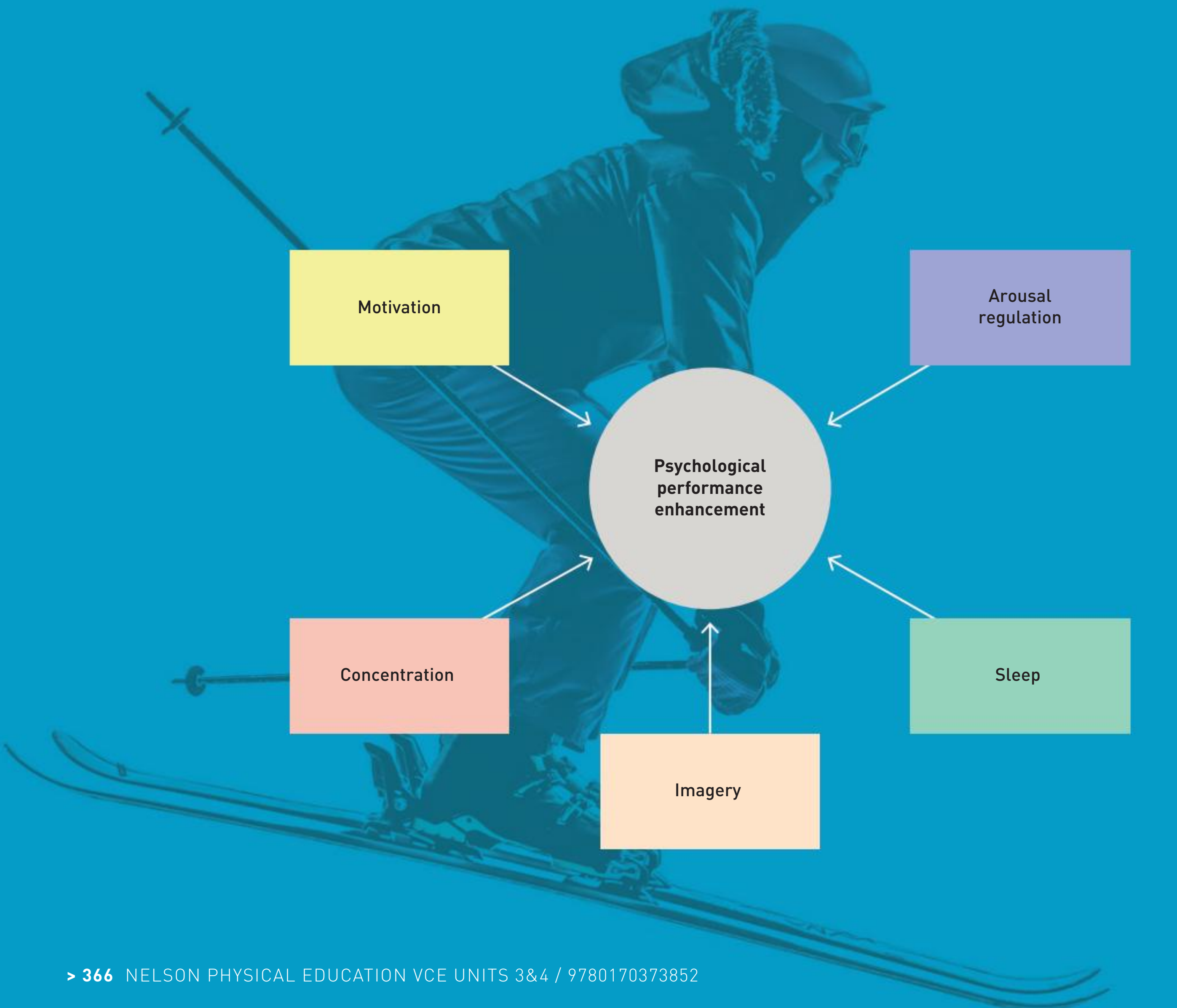
Key knowledge

» psychological strategies used to enhance performance and aid recovery including sleep, confidence and motivation, optimal arousal, mental imagery and concentration

Key skills

» evaluate a range of psychological strategies which affect performance and recovery

Source: Extracts from VCE Physical Education Study Design (2017–2021), reproduced by permission, © VCAA.



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TRAINING YOUR BRAIN

The main objective of any sport is to win. However, to be a champion athlete or team requires consistency at a high level. Being able to train your brain to be mentally proficient helps minimise fluctuations in performance.

Successful performance in most sports requires four major mental qualities:

» concentration – the ability to maintain focus
» confidence – belief in one's abilities
» control – the ability to maintain emotional control regardless of distraction
» commitment – the ability to continue working to agreed goals.

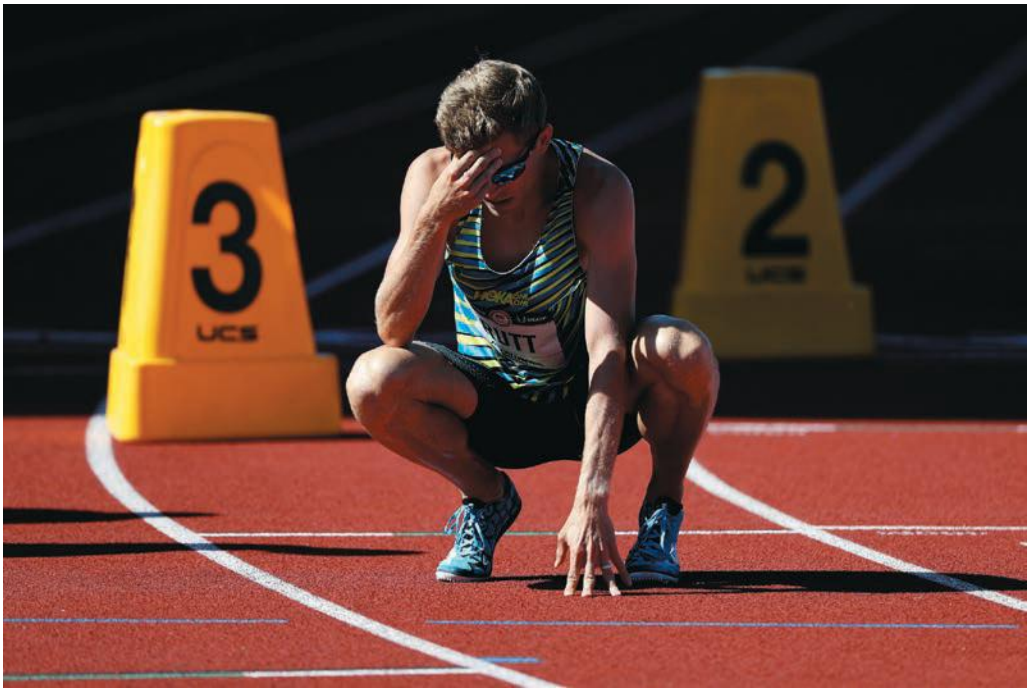
The strategies and techniques discussed in this chapter allow athletes to develop the four Cs.

Sports psychology is the scientific study of people's behaviour while participating in sport and physical activities, and the application of related knowledge. Sports psychologists can be divided into three main speciality groups:

» social–psychological psychologists, who link social interactions with personalities to determine behaviour
» psychophysiological psychologists, who consider physiological processes of the brain and their influence on physical activity
» cognitive–behavioural psychologists, who determine how an individual's thoughts affect their behaviour.

PSYCHOLOGICAL SKILLS TRAINING

Strategies developed by sports psychologists to assist athletes can be used by both athletes and coaches. This chapter focuses on **psychological skills training (PST)** and deals mainly with the cognitive–behavioural aspects of sports psychology. Psychological skills are like physical skills: they can be taught, learnt and practised.



Getty Images/Patrick Smith

Performance at the highest level requires the world's greatest athletes to control their anxiety levels and develop their focus, confidence and resilience. Being able to achieve this under so much pressure requires a great deal of work developing the athletes' psychological skills.

Performance can be radically improved by employing PST. Have you ever wondered why on some days you perform with ease and make few mistakes, while on other days, mistake after mistake occurs? When there is very little difference in your physical state or training, this difference must come from variations in your mental state. Psychological skills need to be practised during training, competition and recovery.

At elite levels often there is little difference between the skill and fitness levels of athletes. This means the difference between winning and losing can be the athletes' mental state.

PST can help athletes make adjustments to their actions, thoughts, feelings and physical sensations to help them achieve their goals.

PST can be used to:

- help build confidence
- enhance motivation
- manage stress and anxiety (by maintaining optimal arousal)
- use imagery and visualisation
- focus concentration and attention.

Every PST program tends to be different, to best match a participant's individual needs. PST programs can focus on one or more principles, depending on which areas need improvement. These principles might include goal-setting, **arousal**, mental rehearsal, confidence building and concentration. Programs tend to have three common stages: the education phase, the acquisition phase and the practice phase.

The education phase

The education phase is short (1–2 hours). It involves assessing the level of mental skills practice currently being used by an athlete, and explaining the importance of developing psychological skills. It typically involves discussion on how skills such as arousal regulation and **imagery** are currently being used by elite athletes to maximise their performance levels, and demonstrating that these do work and are effective.

The acquisition phase

This phase involves more sessions than the education phase, and focuses on how the psychological skills are to be learnt by the individual. For example, an athlete prone to unregulated arousal states might be taught how to replace negative statements with positive ones. The next step would involve being taught how to use these positive coping strategies in real-life, competitive settings. This phase is very individualised. For example, if an athlete 'freezes' and suffers from increased muscle tension during competition, physically based relaxation techniques such as progressive relaxation would be taught.

The practice phase

It is best if psychological skills become automatic via **overlearning**. That is, athletes make these skills an integral part of their training and practise them to replicate real game scenarios. In the previous example, an athlete could enter the practice phase after they become confident and versed at using relaxation techniques. Their trainer would then guide them through a series of progressive relaxation techniques, which should become self-guided and simulate real game settings.

During this phase it is vital to keep a diary to record the frequency and perceived effectiveness of the psychological skills used in practice and competition. This will provide feedback for future improvements and training.

PSYCHOLOGICAL STRATEGIES TO ENHANCE PERFORMANCE

The following strategies have been shown to enhance the likelihood of successful performance:

» Use mental rehearsal before competition.
» Develop detailed competition plans that include various potential situations and coping strategies.
» Practise routines to react to and cope with a variety of challenging circumstances and distractions before and during performance.
» Focus your concentration on the upcoming performance, rather than the past, and block out negative or irrelevant thoughts.
» Regularly practise the same skill under different levels of arousal and anxiety levels and in a variety of circumstances and conditions.
» To enhance self-confidence, practise specific plans to deal with challenges during performance.

The first three strategies relate to concentration, mental rehearsal and imagery. The last three relate to the development of arousal regulation, motivational techniques and developing confidence.

MOTIVATIONAL TECHNIQUES

Motivation is a complex area because so many factors can influence a person's level of motivation at any given time. Within the motivational techniques section of this chapter, we will describe types of motivation, forms of motivation and reinforcement, assessing motivation, **goal setting** and building confidence.

Player motivation

Adults typically place a greater emphasis on accomplishment and competition than children do. Research shows that children are motivated to participate in sport to have fun, improve skills, belong to a group, be successful and gain recognition, get fitter and find excitement. Some adults play sport because they are paid to do so, while some are there for the health and fitness benefits. Others are more interested in the social aspects of their involvement. The coach needs to be aware of what the players are hoping to gain from their involvement.

There are **extrinsic motivating factors**, such as prize money, certificates, chocolate frogs, progress charts and trophies, or **intrinsic motivating factors**, such as being satisfied with one's performance or simply enjoying the competition.

Coaches cannot control the motivation levels of their athletes. However, they can help athletes work towards desirable goals, and so control their motivation to compete. A focus on effort levels and personal achievement (such as achieving a personal best) is more motivating than a focus purely on winning, which depends on other, uncontrollable factors.

Continual improvement in the performance of an athlete is an indication that aspects of the coaching regime are succeeding. Motivated performers tend to:

» attend practice/training sessions, be punctual, successfully complete assigned tasks, encourage team mates and be involved in club activities outside the training environment

FYI

Research generally shows that men are more motivated by competition and winning (win-oriented), whereas women are more motivated by improving performance (goal-oriented). Elite athletes generally score high on both win and goal orientations, compared to less skilled athletes.

- regularly meet expected targets during training and competition
- outwardly show motivated behaviour
- perform at their best without needing rewards.

Coaches must be consistent in their methods used to motivate players. Inconsistency can lead to motivational problems in athletes.

Forms of motivation and reinforcement

There are two methods of developing motivated behaviours. **Positive motivation** provides positive reinforcement after the individual has displayed the desired behaviour. Examples include positive acknowledgement of good play ('that's terrific', 'well done'), badges, jellybeans, performance information and positive feedback. Striving for a personal best (PB) is a positive reinforcer that all athletes can achieve.

Negative motivation is imposed after undesirable behaviour. Examples include making the athlete perform sit-ups or star jumps as punishment for an incorrect move during training, disapproving comments or rebukes, and demotion in grade.

The same **reinforcer** or method of motivation should not be used continually. Players need variation and an element of surprise for motivating behaviours to remain effective.

Tips for scheduling reinforcements effectively

- During the earlier stages of learning, provide frequent, continuous, positive and immediate reinforcement. In the later stages, less frequent, intermittent reinforcement is more desirable.
- Appropriate behaviour should be rewarded.
- Reward successful steps towards achieving the desired response.
- Reward the execution rather than just the outcome.
- Reinforce effort even when the learner is not succeeding, if they are trying their best.
- Reward good sportsmanship and desirable social skills.
- Provide specific feedback about the correctness of the learner's results.
- Provide motivational feedback to inspire continued or greater effort.
- Use verbal feedback ('well done') and non-verbal feedback (hand clapping and smiles) when the athlete performs something well.

Source: Weinberg & Gould, 2015

While positive motivation should be applied most regularly, particularly with young performers, negative motivation should be used if a performance is inadequate or incorrect. This provides a contrast between the coach's positive and negative motivations, and maintains the power and impact of the positive reinforcers. Negative motivators should never be applied more than positive reinforcers. In fact, the Australian Coaching Council recommends that coaches should provide ten times more positive reinforcers than negative.

CHAPTER CHECK-UP

1 Describe intrinsic motivation.
2 Explain how extrinsic motivation varies from intrinsic motivation.
3 Discuss whether professional athletes are more likely to be motivated intrinsically or extrinsically, and explain why.
4 Give examples of positive and negative motivation you have received from a coach.

INVESTIGATION

Search online for a Sport Motivation Scale (SMS). This consists of seven subscales that measure three types of intrinsic motivation, three types of extrinsic motivation and amotivation.

Weblink

Goal setting

Goal setting is another example of a motivational technique. Goal setting occurs when athletes set down clear targets, priorities and expectations. Athletes are more committed when they have a goal. Goal setting can affect many aspects of performance during training and competition, and can increase work output by up to 40–50 per cent.

Goal setting improves performance by:

- focusing attention on important elements of the skill(s) being performed
- activating and organising an athlete's efforts
- encouraging perseverance
- promoting the development of new learning strategies
- refining movements and **set plays**

Goal setting contributes towards a positive psychological state. Goals need to be set for both training and competitions.

TABLE 16.1 Types of sporting goals

	Focus	Features	Example
Outcome goals	End results, times, finishing place, ranking or medals	Can be difficult to achieve because they are linked to factors the athlete cannot control, such as performance of others	Finishing in the top five in a triathlon
Performance goals	Comparison of past and present performance, independent of other competitors	Lead to less anxiety and greater self-confidence because the athlete has control over their behaviour; will lead to improvement, if realistic	Improving the first-serve percentage in tennis from 40 to 50 per cent
Process goals	Actions (such as physical movement and game strategies) that athletes must perform during a competition to reach peak performance	Effective at improving performance levels because they positively influence other factors such as self-efficacy and confidence	Executing a defensive set play when a batter bunts the ball (makes a small, 1- to 2-metre hit) in baseball

Athletes have greatest control over their performance goals, so it is best to set these first to achieve greater success. It is important that several performance and process goals accompany every outcome goal that is set; achieving these short-term goals enables the long-term goal to be realised.

Long-term goals aim at a broad target and are often set at the start of a season, whereas short-term goals continually provide a manageable focus point for an athlete, acting as the stepping stones for achieving long-term goals. Table 16.2 describes the guidelines for goal setting. A simple way to remember these guidelines is to use the acronym SMARTER.

TABLE 16.2 Guidelines for goal setting

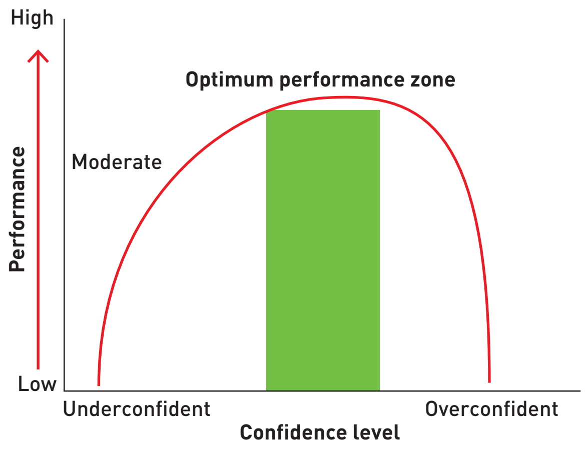
SMARTER	Description	Example (tennis)
Specific	Goals need to be specific and as clear as possible to focus attention	To use a kick serve effectively
Measurable	Progress should be evaluated against a standard of previous performance	To land the serve within the service court on 7 out of 10 attempts during training (twice a week). Make 20 serves per side each training session.
Accepted	Goals should be accepted by all parties involved in preparing the athlete (coach, family, etc.)	'OK, we're all agreed.'
Realistic	Goals should extend the athlete but be achievable within their ability	70% success rate is realistic for this player.
Time phased	Goals should include a specific date for completion	19 March
Exciting	The athlete needs to be challenged and inspired	Set up a mini tournament with your friends.
Recorded	Goals should be written down	Recorded in training diary

BUILDING CONFIDENCE

Another key motivational technique is building confidence. Self-confidence is an individual's belief that they will be successful. Confident players believe in themselves and their ability (both physical and mental) to reach their potential. Self-confident people exhibit positive emotions. They remain calm and focused under pressure, and are more likely to remain on task for long periods of time and work to achieve their goals. Confident people are more likely to take calculated chances during their games and adopt a 'never-give-up' attitude.

Confidence levels and performance attainment closely reflect an inverted-U shape, as shown below. (This is commonly referred to as the inverted-U hypothesis or graph.) It is therefore important that athletes reach the optimum confidence zone, where they are neither underconfident nor overconfident. There is generally a close association between confidence and level of arousal; if you are in the optimum zone for arousal, you are probably feeling confident. Sometimes, however, lacking confidence can result in high levels of arousal, caused by anxiety. Conversely, low levels of arousal can sometimes arise from being overconfident. For example, if you are going to play against a team that has not won a game all season, you may be overconfident and feel quite flat (low level of arousal) because you have not pumped yourself up for a tough competition.

Confidence levels fluctuate for all athletes – confidence is a state of mind. Athletes should avoid being hard on themselves if their confidence is low.



The inverted-U, illustrating the confidence–performance relationship

Source: Weinberg & Gould, 2015

TABLE 16.2 Confidence level characteristics

	Underconfident	Optimum performance zone	Overconfident
Thoughts	negative, defeat or failure, doubt	positive thoughts of success	excessively positive
Feelings	tense, dread, fear, not wanting to take part	excited, anticipation, calm, elated, prepared	calm, blasé
Focus	on others, on less relevant factors (coach, umpire, conditions)	on self, on the task	lacking focus on the task/s to be performed, distracted
Behaviour	lack of effort, likely to give up, unwilling to take risks (rather play it safe), blame others or conditions for outcome	give maximum effort and commitment, willing to take chances, positive reaction to setbacks, open to learning, take responsibility for outcomes	may lack maximum effort, appear arrogant, not push themselves and take the win/performance for granted, may ignore advice from others

Improving confidence

Success is critical in enhancing confidence. This starts at training, where it is important for skills to be executed with some degree of success. As skills are mastered, the attention should shift to game play and strategies, which should be linked to the mastery of psychological skills. When all of these are practised (preferably under game-simulated conditions) and athletes experience success, it is likely that confidence levels will rise.

Athletes use the following strategies to improve their confidence levels:

» Athletes need to act and think positively, even when experiencing adverse competition conditions.
» They should focus on the next segment of play and act as confidently as they do when things are going their way.
» Using positive self-talk that is instructional and motivational and includes cue words helps to maintain high confidence levels and guards against performance deterioration.
» Positive images are also important.
» Confidence levels remain high if athletes feel that they are adequately trained.
» Specific conditioning ensures that athletes are confident about their chances of meeting the physical demands of a contest, and this impacts positively.
» The ability to follow game plans or routines ensures that confidence levels remain high. Knowing what to expect (having practised many physical and mental scenarios) and how to respond removes uncertainty and ensures optimal performance levels.
» Athletes need to accept periods of low confidence and simply focus on improving performance, rather than becoming anxious about this.
» Limiting their focus to their own performance, rather than that of teammates or opponents.
» Focusing on small, immediate milestones – day-to-day successes and improvements in performance along the way – and not measuring success only by the bigger picture.
» Acknowledging the things that are going well rather than just working on areas for improvement.

CHAPTER CHECK-UP

1. How does goal setting bring about performance improvements?
2. Why is it often preferable to aim for process goals rather than outcome goals?
3. Give an example demonstrating how several clearly stated process goals might eventually bring about an outcome goal for a basketball player.
4. Apply the SMARTER principles and write a goal for a netball player.
5. Describe how a junior coach could increase children's confidence.

SLEEP AND PERFORMANCE

Although common sense tells us that a lack of sleep will result in poor sporting performances, it's not always clear exactly why this is the case. While many of the outcomes associated with insufficient sleep are physiological, they are closely linked to a person's psychological state. A lack of sleep (also known as sleep debt) can result in:

» decreased ability to metabolise glucose, which is essential for energy production
» increased levels of stress hormones such as cortisol
» decreased activity of human growth hormone essential for tissue repair, which can lead to injury
» decreased aerobic endurance
» increased perceived exertion
» increased feeling of tiredness
» increased moodiness
» reduced brain function and ability to make decisions.

Shutterstock.com/Aleutie

Lack of sleep can result in poor performance

Within a matter of days, the outcomes associated with sleep debt can cause significant declines in an athlete's performance, which can have devastating effects on their psychological state. Even changing your sleep pattern for as little as two days, or sleeping for longer on weekends, can significantly upset your body clock. Cramming for exams at the last minute can be detrimental to performance because the sleep deprivation can cause reduced brain function, among many other factors.

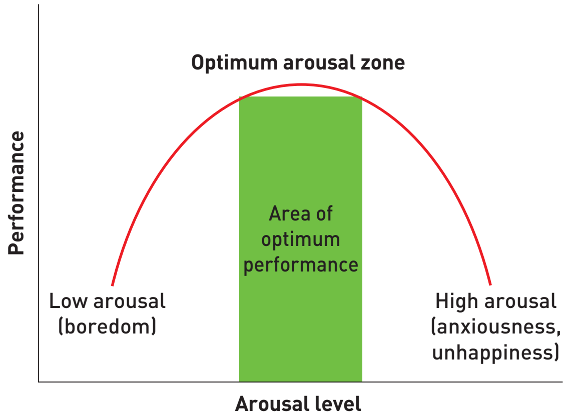
To maximise your chances of quality sleep, you need to rest in a quiet, dark, cool place on a comfortable bed. It is often very difficult to obtain quality sleep during competitions when you are travelling and sleeping in a strange bed, so it is advisable to arrive at the accommodation a few days prior to competition, rather than the day before.

ACHIEVING OPTIMAL AROUSAL

Arousal is the amount of readiness or activation a person experiences when faced with a task. Athletes need an optimal level of arousal to experience success. The relationship between arousal and performance is seen on the following page. Like the graph on page 372, this is an inverted-U graph.

As you can see, a zone of optimal performance exists at a moderate level of arousal. Sometimes called 'flow' or 'the zone', this is usually experienced as a joyful experience where the athlete performs in the moment. Keeping within this zone ensures the performer has sufficient arousal to give a high-quality performance, while not being overstressed and off-task.

The zone of optimal performance is in a different place and is a different shape (height and width) for different people. Some people may operate most effectively at a level of arousal that would leave other people lacking motivation or interest. It is likely that someone who performs well in low-level competition might experience difficulties in high-level competition. Alternatively, someone who performs only moderately at a low level of competition might perform better under more pressure.



The relationship between arousal and performance – notice the optimum arousal 'zone'

Low levels of arousal

- Performance likely to be poor
- Person shows low levels of arousal when they lack motivation or are bored, tired or not directly involved in the action of a team game
- Muscles feel heavy and lethargic
- Concentration drops
- Enthusiasm decreases
- Apathy rises

High levels of arousal

- Performance suffers
- Person appears and feels tense, highly excited or anxious
- Muscles become tense
- Movements become jerky
- Coordination drops
- Mistakes increase

Athletes must take responsibility for controlling their own arousal levels, particularly in a team situation. If some members are already in their optimum zone, paying attention to a coach's motivating half-time talk may move them to a state of being over-aroused. Similarly, if some team members need to be relaxed, applying relaxation techniques to the entire team may move others to a state of **demotivation**.

Getty Images/Matthias Kern

How can the stresses that arise in competition be controlled?

FYI

'Champions aren't made in gyms. Champions are made from something they have deep inside them – a desire, a dream, a vision.' – Muhammad Ali, American boxer

Many factors can cause an athlete to feel anxious and stressed. These factors can be classified as player or performance factors, time and outside influences. Examples include:

» not feeling prepared due to inadequate preparation and training
» teammates not performing well or lacking dedication
» team conflict
» opponents behaving poorly
» losing games that should have been won
» poor decision-making by the coach
» poor officiating
» criticism by other players or the press
» not having enough time for a social life.

Sport competition anxiety test

This test measures an athlete's tendency to experience anxiety during competition. It is a measure of competitive trait anxiety. The test is based on 10 questions, each using a three-point scale (often, sometimes and hardly ever) to describe how individuals feel when competing in sports and games. Each respondent is scored from 10 (low competitive anxiety) to 30 (high competitive anxiety).

Sport competition anxiety test calculator

Read each statement below, decide whether you rarely/sometimes/often feel this way when competing in your sport. Then select your response. At the end, select the Analyse button to see your test result.

Question	It affects me
Competing against others is socially enjoyable.	often
Before I compete I feel uneasy.	often
Before I compete I worry about not performing well.	sometimes
I am a good sportsman when I compete.	often
When I compete, I worry about making mistakes.	sometimes
Before I compete I am calm.	sometimes
Setting a goal is important when competing.	often
Before I compete I get a queasy feeling in my stomach.	often
Just before competing, I notice that my heart beats faster than usual.	often
I like to compete in games that demand a lot of physical energy.	sometimes
Before I compete I feel relaxed.	sometimes
Before I compete I feel nervous.	often
Team sports are more exciting than individual sports.	often
I get nervous wanting to start the game.	often
Before I compete I usually get uptight.	sometimes

Analyse

Your SCAT score is 25 You have a high level of anxiety

Reset

Source: Mackenzie, 2001

DATA ANALYSIS

1. Based on the data provided above, suggest three strategies that a person could implement to reduce their level of anxiety.
2. Find a SCAT test calculator online, or link directly via http://vcepe34.nelsonnet.com.au.
3. Complete the SCAT test, then suggest three strategies you could implement to reduce any tension you might be feeling before a big game or a School Assessed Coursework (SAC) task.

Weblink

Arousal regulation

Athletes need to recognise the relationship between how they feel and how they perform. They should think about how they felt when they were **in the zone** and their performances were outstanding, compared to feelings linked with poor performances. Depending on a performer's level of arousal, they may need to employ arousal reduction or arousal promotion techniques.

Arousal reduction techniques

Progressive muscle relaxation (PMR)

PMR focuses on the difference between tension and relaxation. This relaxation technique is commonly used by athletes. To be effective, PMR should be practised for 20–30 minutes daily. The technique involves progressively tensing and relaxing major muscle groups, usually working from head to toe, until all muscles are relaxed. Each muscle group is contracted slowly and held 'tight' for 5–10 seconds and then slowly released, working all the way down the body in the following order: forehead → face → neck → upper arms → forearms → fingers → chest → stomach → buttocks → thighs → calves → toes.

When athletes tense muscles and then 'let go' of that physical tension, this in turn decreases mental tension. Athletes use this technique (during practice or recovery, or even during time-out, changes of end, time on the bench or stoppages in play) to bring them back into the zone and to improve subsequent performance. Some people practise these skills before going to work, while others do so before going to sleep. Having a suitable, comfortable location in which to practise PMR is essential. Learning to identify the muscle groups and how to tense and relax these muscles takes time. Muscles should be tensed for between 4 and 8 seconds, and controlled, deep, slow breathing should be used during PMR.

Meditation

Meditation has been used in Eastern practices for more than 2000 years. It can have a powerful impact on mind, body and soul. Meditation involves exercising an individual's attention. This gives the mind a rest and allows a temporary shutdown of cognitive processes such as decision-making. Athletes use many types of meditation.

Concentration is the most important factor to ensure meditation is successful. Concentration must be highly developed to control the natural tendency of the brain to flow from one idea to the next, and to eliminate the random thoughts that constantly appear. To aid concentration, some people focus their thoughts on one specific thing, such as their breathing, or a sound, or the shape of a bird. Other people like to chant a word or mantra during their meditation sessions. It is important to practise during a quiet time of day, and not immediately after being very active.

Alamy Stock Photo/imageBROKER

Meditation is a powerful arousal-reduction technique. When would it be appropriate to use this strategy?

Breathing control

Some athletes use breathing techniques to help them relax and **refocus** while preparing for the next action or part of a match. The annotated photo below shows one approach that is favoured by many athletes. This sequence assists athletes by blocking out distractions, providing a mental break from the activity, relaxing muscles and sticking to a game plan.

Alamy Stock Photo / PA Images

As you think about the next part of your performance:

1. **relax your neck, shoulder, chest and arm muscles**
2. **take a slow, deep breath and force your chest to rise and stomach to extend (don't hunch or raise your shoulders) until your lungs are filled**
3. **exhale slowly and feel your chest return to its resting position.**

4. **As you exhale, go through a prepared routine that is going to refocus your attention and future efforts.**

You might focus on:

- gaps in the softball field where you want to hit the ball
- where point-of-contact is being made in a tennis serve
- specific parts of the racecourse approaching key areas such as corners, bends and the pit lane.

Controlled breathing brings about arousal modification and enables refocusing of thoughts.

Biofeedback

Biofeedback is a physically based technique used to modify physiological or automatic body functions during training, and to carry this over into competition. Electronic instruments provide athletes with auditory or visual feedback on a range of physiological parameters such as heart rate, muscle tension and skin temperature. These either give a direct reading or emit sounds relative to the intensity of the stimulus.

For example, during training, a baseball pitcher might feel tension in their shoulder and neck muscles. Feedback from attached electrodes is provided via a loud beeping noise. The pitcher uses relaxation techniques to reduce the intensity of the noise as their muscles become more relaxed. A diary is kept, outlining which relaxation techniques are most effective at reducing tension, and these are practised and implemented during game situations to bring about effective pitches.

Biofeedback has also been used to improve the performance of rifle shooters. They are made aware of their heartbeat (via electronic signals or feedback) and after practice, are able to fire in between beats, leading to improved performance. Essentially, biofeedback enables athletes, after much training and experience, to become more attuned to their physiological functions and to control them more effectively.

Stress inoculation training (SIT)

As the name suggests, SIT **inoculates** athletes against the effects of stress. As athletes adapt, cope and work effectively when facing small amounts of stress, they build up immunity to stress. Coping comes in the form of developing positive thoughts, mental images and self-confidence statements.

Athletes are taken through an initial conceptualisation stage where awareness of positive and negative thoughts and coping strategies (such as positive self-talk and imagery) is developed. In the next stage they practise these coping strategies and, finally, they apply the coping skills in low-stress situations. As the levels of stress are increased, the athlete learns how to cope and adapt at each level, and carries this over from practice to performance.

INVESTIGATION

ANXIETY-BUSTING TECHNIQUES

METHOD

Students decide on a team game that the whole class can participate in, such as basketball, tennis, indoor hockey or netball. During this physical activity, potentially anxiety-producing factors (stressors) are introduced. These could include:

- a knock-out competition
- observation of the activity by the principal
- filming the activity for later viewing by the class or year level
- turnover or error penalties of extra points.

As the class completes the activity, try to incorporate some of the relaxation techniques discussed earlier.

DISCUSSION

Discuss these questions during breaks in the play or at the completion of the activity.

1. How did the stressors increase anxiety?
2. What types of 'anxiety-busting' techniques were tried?
3. How effective were the techniques at reducing students' anxiety and refocusing them on the performance?

Arousal promotion techniques

Elevated breathing rate

In the same way that breathing control can reduce tension and help focus energy, taking short, sharp breaths activates the central nervous system and increases its state of awareness. As athletes take more rapid breaths, they tend to focus on the performance ahead of them, using this as a centring technique to shut out all distractions. Quite often you will see tennis players, after losing a few games in a row, put their heads into their towels at the change of ends and take 15–20 quick, deep breaths. As they do this, they are focusing on their stroke play, game strategy and body mechanics (footwork, service action and so on).

Act energetically

Sometimes athletes feel lethargic or tired. This can occur in the last quarter of a netball game, for example, or even before the game commences. Acting energetically tends to increase arousal levels. You may have seen football teammates bumping into each other lightly, slapping each other and getting physical with each other in the change rooms, or before taking to the field. This is a way of getting themselves pumped up during their pre-game routine.

Positive talk and sounds: 'Talk it up!'

The mind is a powerful tool that controls how we think and perform. While talking (to yourself or others), the use of emotive words such as *tough*, *aggressive*, *hard-hitting*, *dependable*, *forceful*, *strong* and *commitment* has been found to increase arousal levels. Is it any wonder that coaches often use these words in their speeches? Some athletes also use 'cue words' to sharpen their focus – these might be phrases such as 'relax' or 'fast hands'.

Listening to upbeat, up-tempo music can also increase arousal levels. It is common to see athletes listening to music before a game, or even during breaks. Athletes participating in events that take several hours often use music to keep them up and in the optimum arousal zone. You may have seen high jumpers or pole vaulters listening to music during the lengthy wait between jumps. Some athletes even try to get the crowd to rev them up by clapping or cheering rhythmically.

PRACTICAL ACTIVITY

COUNTERING NEGATIVE THOUGHTS

Identify the negative thoughts you have before and during a game. For each negative thought, develop a positive thought that you can say to yourself to counter the negative thought when it occurs (see examples below). Record your thoughts in a similar table.

RESULTS

Negative thoughts	Positive thoughts
I don't play well in the wet.	I've played well in the wet before. I just need to keep it simple.
What if I miss the kick?	You have done this kick a million times in practice. Think how good it will be when you kick the goal!

DISCUSSION

Describe the body language athletes display when they are feeling negative. How is this different from the body language displayed by a highly motivated and confident athlete? Your comparison could be summarised in a table format.

Alamy Stock Photo/imageBROKER

Alamy Stock Photo/Juergen Hasenkopf

Serena Williams has had to learn how to overcome self-doubt

FYI

Many consider Serena Williams to be the greatest female tennis player of all time. After she won one of her 36 grand-slam titles, she said she often doubts herself, and that everyone does, but that thinking positive to overcome those doubts is what is important.

CHAPTER CHECK-UP

1 Elite athletes often talk about being 'in the zone'. Briefly explain what you think this means and describe the related performance characteristics.
2 Why is it important that arousal be considered on an individual basis rather than a team basis? Discuss briefly.
3 Summarise the steps used in progressive muscle relaxation and outline how this technique brings about improved performances.
4 'Biofeedback is too scientific in the way it allows athletes to monitor their response during performances.' Respond to this statement, briefly discussing the advantages and disadvantages of biofeedback.
5 Why is it important to record psychological skills (in a diary) as part of training and performance?
6 Briefly outline how stress inoculation training works.
7 Provide at least three examples of positive self-talk you have used, or could use, to increase arousal.
8 Provide at least two examples of music you would find energising or uplifting. Briefly discuss how the music would raise your arousal levels. How do these examples differ from music you might listen to in an effort to calm down?
9 Provide at least two examples of positive images that might elicit increased arousal before one of your performances.

MENTAL IMAGERY

Energising mental imagery

Energising **mental imagery** involves visualising something that is uplifting and energising to the athlete – the vision often involves them giving a strong performance. Examples include:

» a swimmer visualising himself moving sleekly through the water like a seal
» a surfer seeing herself cutting through the waves like a shark fin
» a footballer imagining that he is going to tackle opponents with the strength of a rhino
» a netballer seeing herself bounding over the court like a gazelle.

Develop effective routines

Having an effective routine allows you to focus on the key factors and prevent potential distractions, such as the size of the crowd, from entering your mind. Depending on the activity, a pre-competition workout typically takes place a couple of hours before the actual game, performance or competition. This allows athletes to become accustomed to the playing field and conditions, and gives them time to go through set plays and pre-game conditioning, including stretching. Following this, the players come out onto the field and perform warm-ups immediately before the game. As well as preparing themselves physiologically, they can practise some of the psychological techniques for enhancing performance. By doing this on the field, sometimes in front of thousands of spectators, they are less likely to be distracted by the audience at the outset of the game. Table 16.3 shows a sample pre-match routine.

TABLE 16.3 Example of a pre-match routine

The night before	The morning of the game	At the ground
» Eat a high-carbohydrate, medium-protein meal with plenty of fluid. » Go to the cinema or watch an absorbing movie. » Have an early night.	» Wake at usual time and have a normal breakfast. » Spend 15 minutes imagining goals for the game. » Relax. » Head off to the ground, arriving 30 minutes before team meeting.	» Attend team meeting, focusing on the key points highlighted by the coach. » Monitor weight to assess hydration. » Perform individual warm-up activities. » Walk onto the pitch to become acclimatised to the ground. Perform on-ground warm-up. » 15 minutes before the game, assess arousal level and regulate accordingly. » 5 minutes before the game, imagine performing successfully.

Some athletes attain optimum arousal and concentration levels by trying to imagine themselves performing skills before actually doing them. This is known as mental imagery, mental rehearsal or visualisation. Mental imagery is a form of simulation and is similar to other sensory experiences (seeing, feeling and hearing), but the experience occurs in the mind. This allows users to create, modify or strengthen pathways important to the coordination of muscles by training the powerful thought processes.

Imagery should involve as many senses as possible; effective imagery involves a lot more than simply 'seeing' how performances occur. Imagery can also be **kinaesthetic**, auditory and tactile. Kinaesthetic senses allow us to feel our body as it moves through different actions; sensory nerves in muscles, joints and tendons provide us with feedback. Even before you've hit a golf ball, you can sense if your body parts are moving correctly and you know whether the ball is likely to end up where you want it to go. Auditory senses are used to monitor the way the playing environment sounds. You can pick the different sounds from your opponent's racquet as they apply either topspin or slice to a shot, which helps you prepare accordingly. Tactile sense allows you to take in how the equipment you are using feels. A softball player feels the way their bat is positioned while preparing to hit (for example, for an outfield drive compared to a bunt) without even looking at their hand position or feeling the firmness or position of their grip.

It is beneficial to use as many senses as possible during the rehearsal stage. The more senses that are used, the more effective the imagery. Refer to Table 16.4 to see how a baseball player uses multiple senses during imagery.

Have you ever gone over a performance in your head before actually doing it? Next time you see a ski jumper, watch what they do before the actual jump. They often close their eyes and picture the various manoeuvres they are going to perform; you might even see them turning, twisting, bending and rotating body parts. They then produce the same sequence as they perform the jump.

Mental rehearsal can only work effectively if athletes are in a relaxed state. To use this technique, you should try to create clear and lifelike images in your mind. Recreate details exactly as they would appear in the performance itself; these details include yourself, the setting, spectators and so on. Most importantly, picture yourself succeeding. Try doing this for 5–10 minutes at a time. The more often you rehearse, the more likely it is that this technique will result in successful performance.

Before racing, world champion canoeist Leanne Guinea (see interview below) mentally rehearses her run, including movement around each upstream and downstream gate. This is an example of kinaesthetic imagery.

Imagery improves performance by:

» improving neural pathways between the brain and muscles and enhancing muscle activity
» providing a mental template of rehearsed sequences that can be used as is, or quickly adapted to suit variations in performance environments
» enabling athletes to practise and prepare for events and eventualities they are likely to encounter during competition
» working in conjunction with other psychological skills by preparing athletes for physical and psychological problems that don't normally occur, so that when they do occur, responses are appropriate, confident and effective
» slowing down complex skills so that key components can be isolated and correct movements felt
» identifying potential problems with technique
» allowing athletes to pre-experience the achievement of goals. This builds confidence that goals can be achieved, thus facilitating improved performance levels that might not otherwise have been reached.

TABLE 16.4 Use of the senses during imagery by a baseball player while batting

Kinaesthetic sense	Visual sense	Auditory sense	Tactile sense
Sensory impressions arising in the player's muscles and joints provide information about the movement of the body and its parts.	The player imagines seeing the ball leave the pitcher's hand and watching the release point and the rotation of the seams on the ball.	The player hears the sound of the ball hitting the bat.	The player notices how the bat feels in their hands when they grip the handle.

REAL WORLD FOCUS

Interview with Leanne Guinea

AP via AAP/Darko Bandic

Leanne Guinea, former Australian National Open Age C1 Champion and 2009 World Champion

Leanne, how do you use imagery before a big race?

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

Can you give us some specific examples of measurable long- and short-terms goals you set yourself leading up to the Worlds?

Each year I set a range of short-term goals including technical, physical, mental and performance goals, each with a specific strategy and a date by which I plan to achieve them. An example of one of my short-term physical goals for next season was to reach level 12.0 on the beep test and to achieve 17 chin-ups. One of

>

my long-term goals was to decrease the ratio of gates that I hit during a race run: down to one per 100 gates by next World Championships. I find these kind of goals effective as they are measurable in training and competition, and I can use benchmarks to assess my improvements for motivation.

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

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

Questions

1 Outline one arousal reduction strategy employed by Leanne Guinea.
2 Described one arousal promotion strategy used by the former world champion.
3 Describe the importance of using mental imagery for a C1 paddler.

LABORATORY

INVESTIGATING THE EFFECT OF MENTAL REHEARSAL

AIM

To investigate the effect of mental rehearsal on performance.

PROCEDURE

1 Have 10 free throws at the basketball ring. Record your result.
2 Move away from the area and mentally rehearse the free throw for the next 5–10 minutes. Picture yourself standing at the free-throw line, bouncing the ball before you shoot, bending your elbow and releasing the ball from your hand, seeing the ball's flight through the air and (importantly) the ball going through the hoop. Do this over and over in your mind, as if you were a spectator watching yourself.
3 Repeat the procedure and have another 10 free throws. This time, before you take each shot, use your rehearsal routine.

DISCUSSION

1 What was your success rate out of 10, without rehearsal and with rehearsal?
2 Rehearsal also acts to decrease anxiety. How can this be beneficial to athletes?
3 If you found that rehearsal had no effect on your success, why do you think this was the case?
4 Dozens of movements are associated with the basketball free throw. List five to 10 key movements that you focused on as part of your rehearsal.
5 When can mental rehearsal lead to poorer performance results?

Video

QUICKVID

Watch an interview with Associate Professor Michael Spittle about the psychological aspects of performance enhancement. Go to your student website via http://www.nelsonnet.com.au and use your login code. Then look at the resources for Chapter 16, page 384.

Simulation

Simulation is similar to imagery, in that it aims to train the brain to cope with circumstances that will occur during a game or competition. Simulation, however, is carried out by making the physical training environment as similar as possible to the game setting. This includes training in front of spectators, adjudicating or umpiring a competition, or playing full contact games. In essence, simulation is very similar to the principle of specificity.

Simulation is thought to be superior to imagery in training; the stimuli introduced are often more vivid because they exist in reality. However, simulation requires greater effort to set up and implement, and is less flexible in terms of the range of scenarios that performers can practise for. For maximum effect, simulation and imagery should be used together.

Visuo-motor behaviour rehearsal (VMBR)

VMBR is an extension of mental imagery and is linked to simulation. It combines the psychological aspect of generating a mental image with feedback from the performance of the physical skill. VMBR involves three phases:

» an initial optimal arousal phase for entering a psychological zone conducive for mental imagery
» visualising performance through various imagery techniques
» performing the actual skill under game or simulated conditions.

By repeating this process (with the intended skill) during training, it is hoped that real-time feedback results in mentally coordinating the visualisation and imagery component with actual performance. When this happens, minor changes in the skill and/or the imagery process can occur, and performance levels improve. Before VMBR can begin, imagery techniques must be learnt and understood within the context of performance; otherwise, the process can be detrimental. If the individual is concentrating too heavily on mental imagery techniques (due to unfamiliarity with procedure), less attention can be devoted to the actual activity.

CHAPTER CHECK-UP

1 It is thought that the more senses used during imagery, the better performance improvements can be. Briefly discuss why this might be the case.
2 Provide an example of mental rehearsal (using as many senses as possible) to prepare for a basketball free throw and a tennis serve.
3 Imagery allows athletes to consider situations that they might never encounter while training, but might one day face while competing. Briefly discuss the advantages of doing this.
4 What are the key differences between mental rehearsal and simulation or visuo-motor behaviour rehearsal (VMBR)?
5 Why is it imperative that athletes be confident in their use of imagery before they try simulation and VMBR?
6 Summarise how imagery and related psychological techniques can bring about improved performances.

CONCENTRATION

One of the best definitions of concentration contains three parts, as shown below. (These points are summarised in Table 16.5 on page 388.)

1 Focusing on relevant environmental cues

This is also known as selective attention and enables players to block out irrelevant cues such as spectators and other noise.

2 Maintaining attention focus over time

This involves maintaining focus over extended periods of time and not allowing concentration lapses to occur.

3 Having awareness of the situation

This is the ability to size up the game situation, opponents and other environmental factors and bring about the most appropriate response. For example, elite athletes are able to 'do the right thing at the right time' during games, even under pressure-packed conditions. The key skill relates to being able to focus your attention on specific tasks and situations so that your body can work in synchrony.

Source: Solso & MacLin, 2008

You can see that the words 'concentration' and 'attention' are used interchangeably, and this commonly occurs in the field of psychology. Nideffer (1976) described attention in sport in terms of width and direction. Width describes how narrow or broad the attention is, and direction describes either an internal or external focus. With this model, there can be four possible types of attention:

1 Broad internal focus

This is used to focus on thoughts and feelings (for example, a fast bowler preparing to run in to the wicket to bowl).

2 Broad external focus

This is used to focus outwards on an opponent's actions (for example, watching an opponent try to make a fast break in a cycling race).

3 Narrow internal focus

This is used to focus thoughts and mentally rehearse upcoming movements (for example, a springboard diver).

4 Narrow external focus

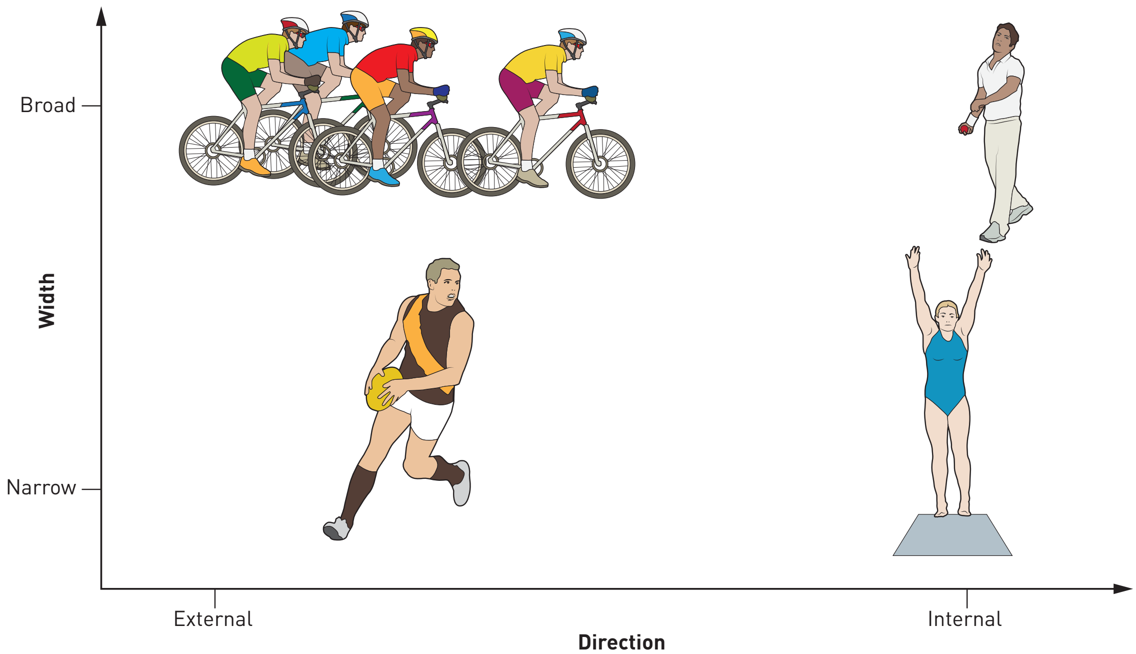
This is used to focus on very few external cues (for example, a footballer focusing on the ball while waiting to take an unopposed chest mark).

QUICKVID

Weblink

Go to http://vcepe34.nelsonnet.com.au to learn more about Nideffer's model of attentional styles.

In any situation, an athlete's attention needs to shift to meet the demands of the environment. Many factors can lead to an athlete experiencing inappropriate attention focus, and their performance can deteriorate as a consequence. This might occur because they focus on past performance errors and aren't able to 'let things go'. It is easy to remember:

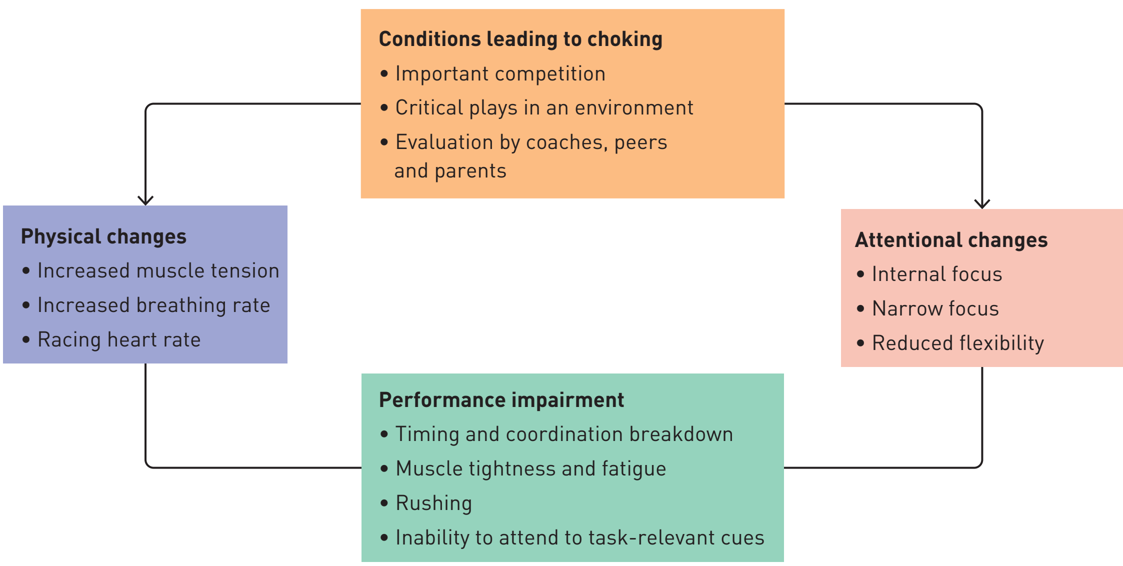


Four types of attention mode: broad, narrow, external, internal

'The last time I did this, I made this mistake', or to think: 'I hope that doesn't happen again'. Sometimes distractions are caused by **future-oriented thinking**. This is typically expressed by 'what if' thoughts: 'What if I get injured?' or 'What if I fail?' or 'What will the rest of my team think if …?' By focusing on the negatives, concentration drops and performance follows suit.

Choking

Choking can also cause concentration to falter. This occurs when athletes sense a build-up of pressure or when there is a lot depending on the outcome of the next phase of play. Increased pressure often results in the focus of attention shifting to become internal and narrow; the



The choking process

Adapted from: Weinberg & Gould, 2015

performer's ability to shift this focus decreases. Impaired timing and coordination, fatigue, muscle tension, negative self-talk, decreased selective attention, and poor judgement and decision-making usually accompany choking (see page 387).

Improving concentration

Simulation training provides an ideal way of practising real game scenarios. Athletes practise shutting out irrelevant cues and sharpening their selective attention. They learn to use 'cue' or 'trigger' words that trigger specific responses during competition. Such cue words should be either instructional ('follow through', 'move your feet', 'follow the wide serve in') or motivational ('keep chasing every ball', 'don't worry – relax'). As well as helping to maintain focus, cue words should ensure that appropriate responses occur at key times.

Routines act as templates and facilitate almost automatic behaviour that isn't affected by outside distractions or loss of concentration. Routines bring structure to performance processes and emotional states while ensuring attention is focused on present, task-related cues. Related to this is the need to adhere to game plans wherever practical, and ensure that process goals are met.

Overlearning skills is another practice that assists in maintaining concentration levels at their highest. This ensures that athletes are at an **autonomous stage** and frees up their attention to concentrate on aspects other than the skills or movements required to bring about successful performance. Overlearning applies to physical and motor skills and to psychological skills as well.

A pre-performance routine in tennis forehand could be as follows:

» Determine the body positioning and footwork required.
» Decide which part of the court the shot will be played into.
» Decide on the type of forehand to be played (slice, spin, flat).
» Adjust grip on racquet to enable the shot to be played.
» Take a deep breath.
» See and feel the ball travelling to the point you expect.
» Watch the ball travel over the net after making contact with your racquet.

TABLE 16.5 Components of concentration

Focus on environment	Staying focused	Situational awareness
» Also known as selective attention » Enables players to block out irrelevant distractions, such as spectators	» Maintaining focus over an extended period of time » Not allowing concentration lapses to occur	» Being able to quickly evaluate the game situation, opponents and other environmental factors » Being able to make the correct decision under pressure

LABORATORY

CONCENTRATION

Quiet-eye (QE) training is a systematic pre-performance routine used by players to improve accuracy. This concentration practice has been shown to improve basketball free-throw accuracy in a number of research studies.

AIM

To examine the effect of the following quiet-eye training on free-throw accuracy

METHOD

1 Have each member of your class complete a pre-test, shooting for goal from the free-throw line 20 times. As each person finishes, record their score.
2 Rank players from the highest score to the lowest score and divide the list of names into two groups: high-scoring and low-scoring.
3 Randomly assign half of the students to a control group. This group has free practice for 15 minutes.
4 The other half of the students are the experimental condition group. They use a QE routine (see instructions below) to practise shooting from the free-throw line for 15 minutes.
5 All students should have a 5-minute break before the post-test trial.
6 All students complete a post-test by having another 20 shots from the free-throw line. Record the pre-test and post-test results in a table like the one below. Graph the results for each condition and group, showing raw scores and percentage change separately.

INSTRUCTIONS FOR QE ROUTINE

1 Take stance, focus your gaze at the basketball rim and repeat 'Nothing but net' three times, while bouncing the ball.
2 Maintain QE for 1.5 seconds by focusing on a specific location of the rim (for example, a point at the back) and say, 'Sight focus'.
3 Shoot quickly, using a fluid action. Shift your gaze only after the ball is released.

RESULTS

Skill level	Control condition group			Experimental condition group		
High-scoring names	Pre-test score	Post-test score	% change	Pre-test score	Post-test score	% change
Low-scoring names						

Scaffold

DISCUSSION

1 Which group (control or experimental condition) showed the most improvement between the pre- and post-test? Discuss why you think this was the case. Also compare results for the high- and low-scoring groups relative to their condition.
2 What are the limitations of your research?
3 What conclusions can you draw from your data?

INVESTIGATION

Visit the Australian Institute of Sport website via http://vcepe34.nelsonnet.com.au to find out more about research undertaken in the area of sports psychology. This site provides current research findings and links to worldwide psychological research findings.

Weblink

CHAPTER SUMMARY

- Like physical skills, psychological skills can be taught, learnt and practised. Performance can be radically improved by employing psychological skills training (PST).
- PST programs can focus on one or more principles, depending on which areas need improvement. These principles might include goal setting, arousal, mental rehearsal, confidence building and concentration.
- It is desirable that psychological skills become automatic via overlearning, that athletes make these skills an integral part of their training, and that skills are practised to replicate real game scenarios.
- Goal setting has been shown to increase work output by up to 40 or 50 per cent. Goals need to be set for both training and competitions.
- There are three types of sporting goals: outcome goals (related to end results), performance goals (present compared with previous) and process goals (related to actions).
- Short-term goals provide a more manageable focus point for athletes and act as the stepping stones for achieving long-term goals, as well as bringing about improved performances.
- The acronym SMARTER is an effective way of goal setting. It stands for specific, measurable, accepted, realistic, time phased, exciting and recorded.
- The relationship between arousal and performance is shown by the inverted-U hypothesis (or graph). It is possible to experience situations of under-arousal, optimal arousal (also referred to as being in 'the zone') and over-arousal.
- Arousal reduction techniques include controlled breathing, progressive muscle relaxation, biofeedback, stress inoculation training (SIT), listening to calming music and using routines.
- Arousal promotion techniques include rapid breathing, acting energetically and positively, using positive talk and energising imagery, and participating in pre-game workouts or preparation.
- Athletes can attain optimum arousal and concentration levels by trying to imagine themselves performing skills before actually doing them. This is known as mental rehearsal, mental imagery or visualisation.
- Effective imagery involves much more than simply 'seeing' how a performance should be executed. It calls on as many senses as possible during the rehearsal stage: typically, these are visual, kinaesthetic, auditory and tactile.
- Imagery improves performance by improving neural pathways between the brain and muscles, providing a mental template of rehearsed sequences, enabling athletes to prepare for a range of events and eventualities, working in conjunction with other psychological skills, and allowing athletes to pre-experience the achievement of goals that build confidence.
- Simulation and visuo-motor behaviour rehearsal (VMBR) are both carried out by making the physical training environment as similar as possible to the game setting. Thoughts are actually taken through to the physical application stage.
- Concentration or attention typically involves three parts: focusing on relevant environmental cues, maintaining attention focus over time, and having awareness of the situation.
- The four possible types of attention are broad internal focus (on thoughts and feelings), broad external focus (on opponent's actions), narrow internal focus (to mentally rehearse upcoming movements) and narrow external focus (to focus on very few external cues)
- Factors that can lead to an inappropriate attention focus and deteriorating performance include environmental distractions, thinking about past performances, future-oriented thinking, fatigue, muscle tension, negative self-talk,

poor handling of game pressures and not sticking to game plans.

- Cue words, selective attention training, routines, overlearning and maximum confidence levels all help to ensure that concentration levels remain optimal.
- Confidence levels and performance attainment closely reflect the inverted-U shape demonstrated by the arousal theory. It is possible to lack confidence, be over-confident or be in the optimum zone.
- Confidence levels remain high if athletes feel that they are adequately trained, both physically and psychologically. Knowing what to expect by having practised many physical and mental scenarios, and how to respond to them, removes uncertainty and ensures optimal performance levels.

CHAPTER REVIEW

Multiple-choice questions

1 Which of the following situations would be beneficial when an athlete is experiencing anxiety?
   - A progressive muscle relaxation
   - B increasing the respiratory rate
   - C acting energetic
   - D yawning

2 PST refers to which of the following?
   - A pressure stress training
   - B performance skills training
   - C psychological skills training
   - D performance sequential transfer

Short-answer questions

3 The diagram at the top of page 387 shows the four basic types of attention or concentration.
   - a Create a similar 'graph' for either basketball, netball or soccer.
   - b Provide examples from your chosen sport to clearly show how the attention focus should change depending on what is happening in the game.

4
   - a What causes 'choking' in athletes?
   - b Provide examples of times you have either witnessed or experienced an athlete choking.
   - c Discuss at least three psychological techniques you might suggest to deal with choking.

5 Provide at least three examples of how future-oriented thinking has caused your performance levels to drop. Discuss this with reference to confidence levels as well.

6 Cue words are often used in conjunction with positive self-talk.
   - a Provide at least two examples of cue words and two examples of positive self-talk.
   - b Briefly outline how each practice is thought to bring about improved performance levels.

7 a What is the relationship between physiological training and psychological training?

   b Briefly discuss any similarities between arousal and confidence.

   c Provide examples where athletes might be overconfident, and discuss the effects this might have on their performance.

8 a How can game plans potentially improve both concentration and confidence?

   b Provide an example of a game plan you could use while playing your favourite sport.

9 Reflect on the last time your performance deteriorated due to pressures and anxiety.

   a List the factors that caused you to feel pressured and raised your anxiety levels.

   b Discuss the way you felt, both physically and mentally, while experiencing this pressure.

   c Discuss several arousal regulation techniques that you could have used, and the effects these would have had on your performance.

   d Why is it recommended that psychological skills training occurs routinely as part of every training session?

GLOSSARY

1-repetition maximum (1RM)
the maximum weight that can be lifted in one maximal exertion

abduction
moving a body part away from the midline of the body

acceleration
the change in speed with respect to time, often measured in metres per second per second (m/s/s or m/s^2)

acidosis
an abnormal increase in acidity

acromial process
the bony protrusion felt on the top of the shoulders

active recovery
exercising at a low intensity in order to allow muscles to recover from high-intensity activity

acute response
an immediate change (increase or decrease) in the respiratory, cardiovascular and/or muscular system in response to exercise

adduction
bringing a body part towards the midline of the body

adenosine diphosphate (ADP)
a chemical compound made up of adenosine and two phosphate molecules

adenosine triphosphate (ATP)
a chemical compound made up of adenosine and three phosphate molecules; energy released by the breakdown of ATP enables cellular function and muscular movement

adipose tissue
the anatomical term for loose connective tissue, or 'fat'

aerobic glycolysis
the breaking down of glycogen with sufficient oxygen (while working aerobically), resulting in the release of 'clean energy' or ATP and carbon dioxide, water and heat

aerobic training zone
training performed at 70–85 per cent of maximum heart rate, also known as the continuous training zone

affordances
opportunities for action

agility
the ability to change body position quickly and accurately, and to maintain balance, while moving at speed

anabolic effect
the building of proteins and muscle tissue

anaerobic
in the absence of oxygen

anaerobic capacity
the total amount of work done by the anaerobic energy systems to produce ATP

anaerobic glycolysis
the breaking down of glycogen with insufficient oxygen, resulting in the production of lactic acid, lactate and hydrogen ions, contributing to fatigue

anaerobic power
the rate of anaerobic ATP production

angle of release
the angle at which a body or object is projected into the air in relation to the horizontal

angular acceleration
the rate of change of angular velocity

angular displacement
the difference between the initial and final angular position of a rotating body

angular distance
the total of all angular changes of a rotating body

angular momentum
the quantity of angular motion of an object

angular motion
movement of a body part around an axis of rotation

angular speed
the angular distance travelled divided by the time taken to cover the distance

angular velocity
the rate of change of angular displacement over time

anthropometry
the study of the measurements and proportions of the human body

arousal
a person's level of readiness or activation when faced with performance

arteriovenous oxygen difference (a-vO_2 diff)
the difference in oxygen concentration in the arterioles compared to the venules; a measure of how much oxygen the muscles are extracting from the blood

atrophy
wasting away of muscle tissue

auditory learner
a person who prefers receiving instructions verbally

autonomous stage
the highest stage of learning, where actions become automatic and seem to require little thought

balance
the ability to control equilibrium while stationary or moving

ballistic stretching
moving a joint through its range of motion with controlled momentum, but with greater force than dynamic stretching

beep test
alternative name for the 20-metre shuttle run test, a multi-stage maximal fitness test

behavioural
involving action and doing

biofeedback
feedback regarding automatic body functions such as heart rate, blood pressure and body temperature, used to bring about mental adaptation

biomechanics
the science of studying living things from a mechanical perspective

blocked practice
repetitively practising a skill for a period of time before practising another skill

bradycardia
decreased heart rate

carbohydrate loading
the practice of increasing carbohydrate stores within the muscles and body by increasing carbohydrate intake and tapering training in the time (up to 10 days) leading up to major competition

cardiac output (Q)
the amount of blood pumped out of the heart in one minute

catabolic effect
the destructive metabolism (breakdown) of muscle tissue and other compounds in the body

catecholamine
an amine (for example, adrenaline) derived from the amino acid tyrosine, that acts as a hormone or neurotransmitter

central fatigue
fatigue that occurs when muscular function is decreased as a result of central nervous system (CNS) impairment

central governor mechanism
a function of the brain that regulates physical activity so that intensity cannot cause damage to the heart muscles

centre of gravity
the point at which the whole weight of an object can be considered to act

choking
a situation where performance deteriorates as a result of a heightened sense of pressure or importance being placed on an upcoming event or action

chronic adaptations
long-term changes that occur with training

closed motor skill
a skill where the performer has greatest control over their environment

concentric muscle action
when a muscle shortens as force is developed

consensus
overall agreement

constraints
boundaries that shape a learner's self-organising movement patterns, cognitions and decision-making processes

continuous motor skill
skill that has no obvious beginning or end point

cool-down
an easy exercise performed after an intense activity to allow the body to transition to a resting state

coordination
the ability to use the body's senses to execute motor skills smoothly and accurately

correlates
a mutual or complementary relationship between two or more factors, such as a cause and an effect, or a test result and an estimated rating

demotivation
the reversal of a state of being motivated and aroused

diastole
the relaxation phase of the heartbeat

diastolic blood pressure
pressure in the arteries when the heart relaxes and ventricles fill with blood

diffusion
the movement of molecules from an area of higher concentration to one of lower concentration

discrete motor skill
a skill that has a distinct beginning and end

displacement
a change in the position of a body

distance
the path travelled by a body from point A to point B

distributed practice
practice that is spread out over frequent short sessions

DOMS
delayed-onset muscle soreness: the muscle soreness felt the day(s) after using muscles in ways they are not accustomed to

dynamic flexibility
the ability to move a joint quickly through its range of motion with little resistance

dynamic stretching
moving a joint through its range of motion with controlled momentum

eccentric force
a force applied at a perpendicular distance from the centre of gravity of an object

eccentric muscle action
when a muscle lengthens as force is developed

electromyography
in motion analysis, records the electrical activity within a muscle just before contraction

EPOC
excess post-exercise oxygen consumption; another term for oxygen debt

equilibrium
when all forces and torques are balanced

extension
increasing the angle of the joint

extrinsic motivating factors
factors external to the athlete

fine motor skill
a skill that involves the recruitment of smaller muscles for precise movements

fitness test battery
a group of tests selected to assess particular fitness components relevant to one sport/profile

flexibility training
stretching when the body has warmed up; can be static, dynamic/ballistic, or PNF stretching

flexion
decreasing the angle of the joint

force
a push or a pull acting on an object

force arm
the distance from the axis to the force

friction
a force that acts in the opposite direction to motion when two surfaces are in contact with one another

future-oriented thinking
thinking ahead about what you are going to do and what might happen

general motion
motion involving translation and rotation at the same time

gluconeogenesis
the production of glucose, mostly in the liver, from amino acids, fats, lactate and other non-carbohydrate substances

glycaemic index (GI)
an index that ranks foods on a scale of 0 to 100, according to how much they raise blood sugar over a two-hour period, compared to pure glucose

glycogen sparing
a long-term adaptation (resulting from aerobic training) that allows fats to be used more readily and earlier during performances; this results in less use of the lactic acid system and allows glycogen to be used much later in performances

glycolysis
the breakdown of glycogen, either aerobically (with oxygen) or anaerobically (without oxygen)

goal setting
the process of setting short-term plans aimed at achieving larger long-term outcomes

gold standard tests
acknowledged as the best test to directly measure a specific fitness component

Golgi tendon organ
a nerve ending that is found in the tendon near the muscle that is sensitive to both tension (contraction) and passive stretch of the skeletal muscle

goniometry
motion analysis measurement of joint angles

gross motor skill
a skill that involves the recruitment of larger muscle groups

haemoglobin
oxygen-carrying compound found in red blood cells

handgrip dynamometer
an instrument used to measure strength

heart rate (HR)
the number of times the heart beats in one minute

homogeneity
similarity between all the parts (scores)

hyperthermia
unusually high body temperature; elevated core temperature

hypertonic sports drinks
drinks that contain a lesser proportion of water, and a greater proportion of sugar, than the fluids in the human body

hypertrophy
growth and increase in the size of muscle cells

hypoglycaemia
a condition created when blood glucose levels are significantly reduced, often during extended endurance activities calling upon glycogen reserves in the liver

hypokinetic disease
a disease associated with a lack of physical activity, such as heart disease, lower back pain, obesity and type 2 diabetes

imagery
use of thoughts and images seen through the mind's eye

impulse
the product of a force and the time period over which it is applied, which is equal to the change in momentum of an object

inertia
the tendency of an object to resist change in its state of motion

informed consent
agreement by a performer to continue with testing after being made aware of the risks involved with the test

inoculate
to expose the body to certain situations, so that it develops an immunity to that situation and is able to shut it out

intensity
the level of exertion being applied to an activity

interplay
a situation where all three energy systems contribute to ATP production, with one system being the major ATP producer at any time

inter-rater agreement
the degree of agreement among raters

interval distance
the distance of each repetition, usually in metres

in the zone
when performance becomes automatic, full of flow and unaffected by outside distractions; typically occurs during times of optimal arousal and confidence

intrinsic feedback
feedback from the performer's own senses; the internal information received by an athlete based on the outcome of a particular movement or series of actions

intrinsic motivating factors
factors that come from within the individual

isokinetic muscle action
when muscle lengthens or shortens at maximal tension and constant velocity over the full range of motion; the speed of the contraction is controlled

isometric muscle action
when muscle length remains constant as force is developed; a static contraction

kinaesthetic
related to sensory impressions arising in the muscle and joints that provide information about the position and movement of the body and its parts

kinaesthetic learner
a person who prefers to learn by experiencing ('doing') the task

lactate inflection point (LIP)
the exercise intensity beyond which lactate production exceeds removal, sometimes referred to as the lactate threshold

lever
a simple machine consisting of a rigid bar that can be made to rotate around an axis

ligaments
connective tissues that connect bone to bone

linear motion
movement of the body where all parts move in the same direction at the same time along a line

line of gravity
a theoretical line that passes through the centre of gravity in the direction that gravity acts

load
the amount of weight to be lifted

macrocycle
an annual plan that works towards peaking for a major competition

mass
the amount of matter that makes up an object

massed practice
practice that is bunched together; longer sessions, but less often

maximal test
a test that is performed to exhaustion

mechanical advantage
the ratio of the force arm to the resistance arm

mental imagery
picturing or visualising events in the mind

mesocycle
a developmental period; usually refers to a specific block of training within the macrocycle

microcycle
part of a mesocycle, usually about 7–10 days. Microcycles contain more specific exercise training sessions, based on the overall purpose of the mesocycle

mitochondria
parts of a cell; the sites of aerobic respiration in muscles

moment of inertia
the resistance of an object to changes in its angular motion

momentum
the motion possessed by a moving body

motivation
the intensity and direction of effort

motor unit
a motor neuron and the muscle fibres it stimulates

myocardium
heart muscle

myofibrils
parts of muscle fibres that contain the two protein filaments, actin and myosin

myoglobin
oxygen-carrying pigment found within muscle cells

myopathy
a disease of muscle tissue

multi-joint exercises
exercises where two or more joints are involved, such as a squat

negative motivation
when negative or punishing consequences are imposed after undesirable behaviour

novice (weight training)
a person with less than 6 months' experience

onset of blood lactate (OBLA)
when lactate levels reach 4 mmol/L and begin to rise rapidly

overlearning
repeated practice of skills, both physical and psychological, so that they become automatic

overload
a planned increase in training stimulus to cause a positive long-term adaptation

overtraining
to train excessively, usually resulting in injury and stress

oxidation
the breakdown of fats or glycogen to CO_2 and H_2O with ATP production in the presence of oxygen

oxygen debt
a deficit of oxygen resulting from intense exercise

oxygen deficit
temporary shortage of oxygen in cells, typically at the start of exercise where oxygen demands are greater than the body's ability to supply the necessary levels

passive recovery
a recovery that typically involves complete rest or exercise at a slow walking pace

peaking
the manipulation of training to ensure a performer is at their optimal physiological state before a competition

perceived competence
a psychological construct based on self-evaluation of one's effectiveness or capability in a specific context

percentiles
the 100 equal groups into which a population can be divided in order to rank them

periodisation
the planned variation in training methods, volume and intensity designed to bring about optimal performance at a specified time

peripheral fatigue
fatigue that occurs when muscle function is disrupted at the muscle site(s) as a result of impaired internal muscle processes

phosphocreatine (PC)
a chemical fuel (also called creatine phosphate or CP) consisting of a bound phosphate and creatine molecule stored in muscles and split rapidly to rebuild ATP during explosive activities

plateau
to reach a period or level where no change is observed; also a period of no change

plyometrics
explosive movements completed at maximal intensity, usually lasting a couple of seconds

PNF (proprioceptive neuromuscular facilitation) stretching
a stretch in which a muscle is gently moved through its range of motion until the first sign of discomfort, then contracted isometrically for 6 seconds before being relaxed slightly and then gently stretched again

positive motivation
when positive, reinforcing events occur after desirable behaviour

projectile
an airborne body that is only affected by the forces of gravity and air resistance

projectile motion
the movement of an object through the air

proprioception
sensory information relayed from within the muscle

protocols
rules or procedures

psychological skills training (PST)
rehearsal or practice of a variety of psychological techniques

pulmonary
of, or relating to the lungs

$PWC_{170/\,130}$
physical work capacity

qualitative analysis
description of the quality of human movement without the use of numbers

quantitative analysis
analysis of human movement involving the use of numbers

radial or carotid pulse
site for measuring heart rate by feeling each beat as blood is pumped through the arteries; located in the wrist or neck region

random practice
varied sequencing of different motor skills in the same training session

reaction time
the time from the presentation of a stimulus to the onset of a response

recovery method
either active or passive recovery

refocus
to gain renewed attention or concentration

reinforcer
method of motivation, which can be positive or negative

reliability
the ability of a test to produce consistent and repeatable results

repetitions
the number of times a work interval is repeated in a sequence

resistance arm
the distance from the axis to the resistance

respiratory rate (RR)
the number of breaths taken in one minute

rest interval
the relief time between work periods

rotation
moving a body part inwards or outwards around its longitudinal axis

sarcomere
the smallest contractile unit of skeletal muscles

sarcoplasmic reticulum
specialised areas of cardiac muscle that act as storage and release areas for calcium

serial motor skill
the combination of several discrete skills performed in a sequence

set
a series of repetitions performed without a rest

set play
a series of pre-practised movement patterns that follow a set sequence, typically used by sporting teams

simulation
when real-life situations are practised or experienced

single-joint exercises
exercises where only one joint is involved, such as a biceps curl and the elbow joint

specificity
the principle that exercising a certain part of the body primarily develops that part

speed
distance divided by change in time

split routines
when different body parts are trained on different days

stability
the ability of a body to resist a change in its current state of equilibrium

static flexibility
the ability to reach and hold a point in a joint's range of motion

static stretching
a stretch held in a challenging position for a period of time, usually with the aim of improving flexibility

steady state
when the body is able to supply sufficient oxygen to meet the oxygen demands

stroke volume (SV)
the amount of blood ejected by the left ventricle per beat

summation of momentum
the sequential and coordinated movement of each body segment to produce maximum velocity

synergist
a muscle that helps another muscle to accomplish a movement

systole
contraction phase of the heartbeat

systolic blood pressure
pressure in the arteries following contraction of ventricles as blood is pumped out of the heart

tapering
the reduction in training volume before competition

tendons
connective tissues that attach muscle to bone

tension
force developed in the muscle when it contracts

thermoregulation
the ability to keep body temperature within certain boundaries, even when the surrounding temperature is very different

tidal volume (TV)
how much air is inspired or expired in one breath

torque
the turning effect caused by applying an eccentric force

training frequency
the number of times per week a training session is repeated

training intensity
the measure of how hard an individual is training. There are many different methods that can be used to measure intensity. One of the more common methods is heart rate

training volume
the amount of time spent training, that is, minutes per session or hours per week. However, it can also be reported in terms of distance covered

unloading
a deliberate reduction in training volume to allow greater recovery

validity
the degree to which a test measures what it is intended to evaluate

vasoconstriction
a decrease in the diameter of a blood vessel, resulting in a decrease in blood flow to the area supplied by the blood vessel

vasodilation
an increase in the diameter of the blood vessel, resulting in an increase in blood flow to the area supplied by the blood vessel

velocity
displacement divided by the change in time; e.g. the speed at which a weight is lifted

venous pooling
accumulation of blood in one part of the body

venous return
the flow of blood back to the heart

ventilation (V)
how much air is breathed in or out in one minute

ventilatory threshold
the point where ventilation increases at a non-linear rate

visual learner
a person who prefers to learn by watching demonstrations of the task they are about to perform

VO_2 maximum (VO_2 max)
the maximum amount of oxygen that can be taken up, transported and utilised per minute

weight
the measure of gravitational force acting on a body

work intensity
the required exertion level of a work interval (either RPE or % max HR)

work interval
the period of time work is undertaken before a break

work-to-rest ratio
the work interval divided by the rest interval, expressed as a ratio

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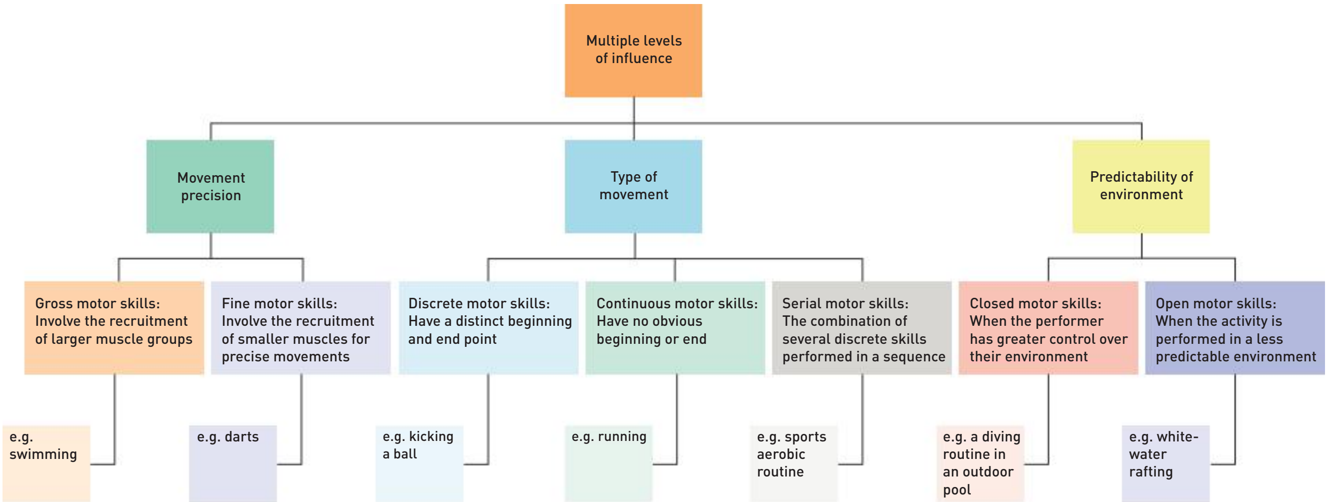
ANSWERS

CHAPTER 1: CHARACTERISTICS OF SKILLS & STAGES OF LEARNING

Chapter check-up p. 8

1 Five motor skills in hockey, for example, could be dribbling the ball, hitting the ball, pushing the ball, trapping the ball and weaving around opposition.

3



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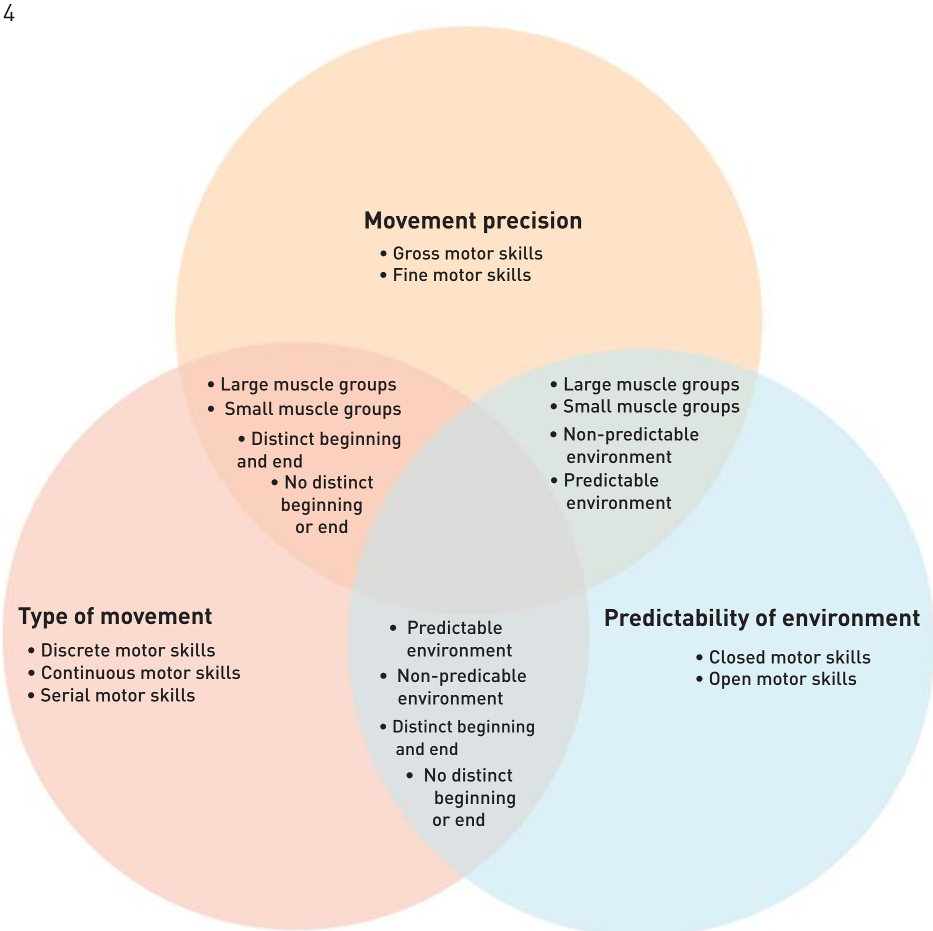


Chapter check-up p. 11

1 A continuum implies that there is no clear point at which a person moves from one stage to the next. It may be easier to classify someone as being in either the associative or autonomous stage than to determine the exact time that they moved from one stage to the next. A continuum allows us to recognise that different stages of development exist without the need to identify the exact moment each stage is reached.

2 A person in the beginner or cognitive stage of development is trying to grasp the basic concepts of the skill they are trying to learn. They will know they are doing something wrong, but will be unaware of how to remedy the situation.

Someone in the associative stage will make fewer errors than the person in the cognitive stage of development. They will be able to remedy some, but not all, of their errors. Their focus will be shifting from how to perform the skill onto external stimulus, such as the effects of spin on a ball.

3 The distinction for someone in the autonomous stage is that the performance of the skill will be largely subconscious. Their focus will almost entirely be on external cues and tactics. They are able to remedy the majority of errors.

4

COGNITIVE	ASSOCIATIVE	AUTONOMOUS
* Understanding the skill * Focus is on movement production * Large improvements in performance * Lack the ability to error detect and correct	* Refining the movement pattern * Ability to focus more on external stimuli such as the spin on a ball * Improving error detection and correction ability	* Automatic performance * Performer has developed anticipation * They can detect and correct their own errors

CHAPTER REVIEW P. 20

Multiple-choice questions

1 B

2 C

3 B

Short-answer questions

4 Knowledge of results allows beginners to align internal feedback to the desired outcome of the task.

5 Blocked practice is practising the same skill continuously without a break, such as a basketball player practising 50 free throws in a row. Random practice is the varied sequencing of different skills without a set pattern. A basketball example would be a player taking 50 practice shots from varying positions on the court, without forming a pattern.

6 When a skill has several components, it may be appropriate to break the task into segments, provided that each segment is not too dependent on the previous segment. For example, a tennis serve would be easier to break into component parts but a cartwheel in gymnastics would be difficult to break into segments.

7 Answers will vary

CHAPTER 2: IMPROVING SKILLS

Real world application p. 22

1 We know from research that young people with better-developed motor skills may find it easier to be active and engage in more physical activity (PA) than those with less-developed motor skills.

2 There is a significant difference between the time spent in vigorous physical activity by sex. More boys than girls are classified in the highest level of motor skill performance and time spent in vigorous physical activity.

3 Locomotor skills form some of the most common physical activities such as walking, dancing and jogging. Object control skills are common to participation in many sports, so while many people are active, far fewer participate in regular organised sport possibly because they don't have the skills to enjoy participation and have success.

4 Physical Education teachers not only need to focus on the development of fundamental movement skills to ensure students' success in sporting contexts, they also need to recognise the importance of including in PE programs lifestyle physical activities that are far more likely to be what students will participate in as adults.

Chapter check-up p. 24

1 Teachers, coaches, dance instructors, athletic trainers, sports medicine practitioners, physical therapists, fitness instructors.

2 Purposes include

» diagnosis of strengths and weaknesses of players or teams.

» obtaining a final result or rank in competition

» identifying talent or team selection

» predicting future performance results.

3 They generally involve some measurement of performance (e.g. quantitative data about a baseballer's pitching would include a statistical breakdown of total pitches, strikes, balls, locations of pitch, radar measurement of ball speed). Most quantitative assessments in sports science relate to biomechanics and exercise physiology. They are generally laboratory-based, making them too expensive for everyday use in teaching and coaching. Assessment is still subject to qualitative factors and therefore doesn't guarantee validity.

4 Accessing the measures, equipment and expertise to collect, manage and analyse the data into something quick and user-friendly is rarely feasible in an everyday context for teachers and coaches.

Practical activity p. 24

The fielder needs to get their body behind the line of the ball, get down low, where possible use part of their body to act as a further barrier beyond their hands to prevent the ball going past them. For example, if the fielder leans forwards, a ball that kicks up above the fielder's hands might hit their chest and still be in front of them. The fielder also needs to look at the ball as they scoop it up into their hands.

Chapter check-up p. 29

1 Characteristics of skilled performance include:
- » perform consistently at a very high level
- » coordinated
- » balanced
- » flexible
- » fit
- » efficient in time and energy
- » strong kinaesthetic sense
- » good anticipation
- » efficient technique
- » sound mental approach.

2 Variables that could be observed:
- » global dynamics of a team
- » whether the team is completing set plays according to the game plan
- » patterns of play of opponents
- » behaviour of opponent coach
- » situational variables.

3 Factors to keep consistent include procedures, conditions, equipment, environment and tester.

4 At any stage a coach can intervene via:
- » adaption of training exercises in practice
- » visual strategies (digital footage, digital clips of elite performance)
- » meetings (with individuals or the team)
- » written reports to provide feedback based on video footage.

5 Answers will vary. Sample answer: If a young softball player doesn't have the grip strength and trunk power to hold a heavy bat, they will not be able to swing the bat quickly in a smooth horizontal pathway around their body. To compensate for their lack of strength and power they tend to drop their hips, keep the bat head too low, and swing the bat through in a more diagonal fashion from low to high causing them to either not contact the ball, miss hit or hit the ball into the air as a fly ball.

CHAPTER REVIEW P. 41

Multiple-choice questions

1 B

2 C

Short-answer questions

3 a A young person who is unable to competently throw, kick or catch is unlikely to participate in physical activities and sports that require these skills. We know from research that young people with better-developed motor skills may find it easier to be active and engage in more physical activity (PA) than those with less-developed motor skills.

b The fundamental movement skills (FMS) lay the foundations for the development and mastery of more complex sport specific skills that determine the level of performance a person can achieve when playing sport.

c Because many Australian children are not proficient in many of the basic motor skills, they have little success performing the more complex sport-specific skills that feature heavily within secondary school physical education and sport programs.

4 a Qualitative movement can be analysed for many purposes including:
- » diagnosis of strengths and weaknesses of players or teams
- » to obtain a final result or rank in competition
- » for talent identification or team selection
- » to predict future performance results.

b Answers will vary. Sample answer: a tennis player could have their serve and forehand techniquse qualitatively analysed to determine whether they are using a smooth swing and displaying many of the basic components of the skills.

5 A coach needs cross-disciplinary knowledge to determine what factors are causing a problem. For example, a coach teaching a child to throw needs knowledge of biomechanics, to apply the concepts of levers and force summation; of motor development, to ensure the instruction is developmentally appropriate for the child (using a ball they can grip in a small hand); of how a child learns skills; and how to apply that knowledge.

6 a Refer to the diagram at the bottom of page 25.

b 1: Determine the specific purpose of the analysis.
2: Decide which player to observe, and the specific skill(s) to focus on.
3: Decide number and timing of observations.

c See Table 2.2 on page 27.

7 a By using checklists, rating scales, and by establishing criteria/rubrics.

b Answers will vary.

c **Validity** refers to the test's capacity to measure what it is intended to. **Reliability** refers to the ability of a test to reproduce similar results when conducted in identical/similar conditions, contexts and situations.

CHAPTER 2 continued

8 a Error correction is the intervention to enhance performance made by coaches/teachers based on their interpretation of the observed data. Error correction can be an organised training process and a set of processes coaches can use to communicate information to the players. Weakness are identified and strategies to address weaknesses are developed using either direct or constraints-based coaching or instructional approaches.

b Refer to the flow chart on page 29.

c Sample answer: to select an incorrect golf club for the distance to the green, so the ball did not travel far enough.

9 a The constraints-based approach to coaching takes into account the interaction of individual, environmental and task constraints. How these constraints are modified affect the execution of the goal-related task and ultimately affect learning the skill. In a constraints-based model, the interaction between the individual and their environment affects their perceptions and actions; this interaction is circular.

b The decisions made about the timing, progressions, and how the task will be performed are controlled more by the coach in direct approaches. The coach in a constraints-based model creates a learning environment to shift some control of these decisions to the players.

c Sample answer: Affordances are opportunities for action, defined relative to the action capabilities of the individual. A centre player in netball will only pass the ball to a wing attack as hard as they know it can be thrown, and that the wing attack is able to catch it.

10 Cultural factors include: education, politics, religion, social organisations, technology, values, attitudes, race, climate, housing, child-rearing practices, geographic location.

Social factors include: family structure, role and status in society, time, available resources, access to equipment, access to coaches, discrimination, personality, self-belief (perceived competence), self-motivation, active role models, parental encouragement.

CHAPTER 3: KINETIC CONCEPTS OF HUMAN MOVEMENT

Chapter check-up p. 46

1 A biomechanist uses qualitative and quantitative information to develop and refine movement in sport and physical activity.

2

QUALITATIVE	QUANTITATIVE
Observation	Data such as times, distances, joint angles and forces
Uses tools such as video footage Description of movement pattern	Uses tools such as opteoelectronic motion sensors, goniometers, force platforms, light gates, digitised video footage
Feedback is instantaneous	Feedback to athletes is quick, but calculations and analysis often need to be done in a laboratory
Commonly used by coaches at junior levels	Generally used for elite athletes

3 A Little Athletics coach would be able to provide feedback on their athletes' performance from a biomechanical perspective. This type of information helps refine movement patterns and race strategies in order to increase the efficiency of the movement and optimise the performance outcome.

4 Answers will vary.

Chapter check-up p. 52

1 Mass and velocity

2 The baseball has much greater momentum due to the velocity at which it is travelling. The mass of a baseball and a volleyball are very similar, so the most important factor in determining momentum in this example is the velocity at which the ball is travelling.

3 Player A's momentum = 90 kg × 6 m/s = 540 kg m/s

Player B's momentum = 80 kg × 7 m/s = 560 kg m/s

Player B has the greater momentum. Momentum can be increased by an increase in velocity – the player will need to move faster.

4 Similar to: the total momentum of two objects involved in a collision will be the same, before and after the collision occurs.

5 Suitable example: When a footballer applies a hip and shoulder to a stationary opposition player, the momentum the footballer possesses is transferred partially to the opposing player. The opposing player's momentum increases through an increase in velocity (they move) and some is retained by the player applying the bump, but they slow down and their momentum is decreased – therefore the overall momentum of the collision is conserved.

6 Summation of momentum allows for the larger, slower moving body parts, such as the legs, hips and torso, to begin the movement. The resultant momentum (Mxv) is transferred to the smaller and lighter body parts (shoulder, arm, wrist), which results in a faster velocity (mxV) and an overall faster release velocity of the ball.

Chapter check-up p. 54

1 A glove increases the time over which the force is applied, effectively reducing the impact of the force on the hand.

2 This position involves bending the knees and hips on landing. It increases the time over which the force from the ground can be distributed and reduces the impact of the force, reducing the risk of injury.

3 Teaching points include:

Extend your arms to the ball and cup your hands.
Bend your elbows as you catch the ball.
Bend your knees as you bring the ball down to your body.

Chapter check-up p. 57

1 Forces will either produce movement or change movement.

2 A body will remain at rest or continue in a state of constant motion unless acted upon by an external force. For example, a golf ball placed on the tee will stay there until hit by the club.

A force applied to an object will produce a change in motion (acceleration) in the direction of the applied force that is directly proportional to the size of the force. For example, a football kicked with greater force will travel further than a ball kicked with less force.

For every action there is an equal and opposite reaction. For example, in rifle shooting, the rifle applies a force to the bullet, in firing, and the bullet applies an equal and opposite force on the rifle, which is often seen as the recoil of the rifle on the shoulder of the shooter.

3 Newton's second law, $F = ma$, says that the force is proportional to the acceleration and the acceleration is inversely proportional to the mass. A greater mass will result in lower acceleration for the same applied force, so the medicine ball will have less acceleration than the basketball.

4 Examples include:

Football players use 'grippo' to increase the friction between their hands and the ball to increase ball control, and assist in marking the ball, particularly in the wet.

Surfers wax their board to increase the friction between the board and their feet to assist in maintaining their balance while riding a wave.

A swimmer will wear a swim hat and tight-fitting bathers and may 'shave down' to reduce the friction between their body and the water. The reduction in friction reduces the drag, allowing them to move through the water more quickly.

Speed skaters sharpen their skates and wear tight-fitting Lycra suits to reduce friction between the ice and their skates, and between their body and the air. This reduction in friction reduces drag.

5 Examples include:

A tennis ball bouncing on the ground: the ball exerts a force on the ground (action) and the ground exerts a force back on to the ball (reaction), which can be seen in the deformation of the ball.

A 400-m runner: the foot strikes the ground (action) and the ground pushes back against the foot (reaction).

Swimming: the hand pushes the water backwards (action) and the water pushes the swimmer forwards (reaction).

6 Rolling friction: the friction present between a rolling object and a flat surface.

Sliding friction: the friction between two moving surfaces.

Flat tyres on bikes increase the rolling friction, which means a greater force is required to overcome the friction and propel the bike forwards.

Chapter check-up p. 61

1 Greatest moment of inertia: layout

Fastest rotation: tuck

2 First law: a diver will continue to rotate after leaving a diving platform unless another external torque acts on the body.

Second law: the greater the torque applied to the pedal on a bike, the quicker the wheels will rotate and the faster the cyclist will travel.

Third law: when a bat is swung forcefully, rotation of the upper body results. If the batter's feet are not planted firmly, then the lower body will rotate in the opposite direction.

3 Change the distribution of the mass or change the length of the club. A longer club will have a greater moment of inertia, but if able to be swung will result in increased angular velocity of the club head and ultimately an increase in the linear velocity of the ball. A shorter club will be easier to swing and can rotate at a higher angular velocity, but may not generate the same club head speeds.

4 As the moment of inertia decreases (when the gymnast moves into the tuck position), the angular velocity increases.

As the moment of inertia increases (in the layout position), the angular velocity decreases. The moment of inertia remains constant throughout the whole movement, as it is conserved.

CHAPTER REVIEW P. 63

Multiple-choice questions

1 D

2 C

3 C

4 D

Short-answer questions

5 From the most to the least:

- » a horse and jockey racing down the straight (most)
- » a tennis ball served by an elite player
- » a netball centre walking back to position
- » a football handballed to another player (least).

6 a They can increase their velocity to a maximum as quickly as possible and then try to maintain that speed in order to reach the base as quickly as possible, without having to worry about decelerating as they approach the base.

b Momentum, or Newton's first law of motion

7 The radius of rotation and the mass distribution would give the club a high moment of inertia, which would make it difficult for a child to swing.

8 Refer to the movement sequence diagrams on page 53.

Summation of momentum: the elite athlete will be able to impart a greater release velocity due to an increased ability to summate the momentum from the larger, slower body parts to the faster, lighter body parts.

Impulse: by increasing the time over which the force is applied to the shot, the elite athlete is able to increase the impulse, which results in an increased change in momentum of the shot and ultimately a greater velocity – meaning it will travel further.

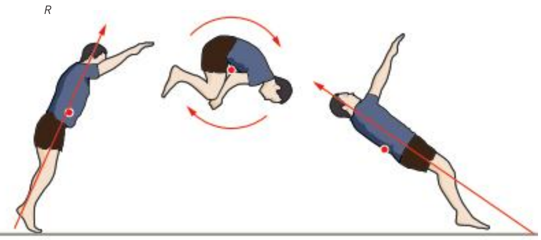
9 Suitable example: when a footballer applies a hip and shoulder to a stationary opposition player, the momentum the footballer possesses is transferred partially to the opposition player. Their momentum increases through an increase in velocity (they move) and some is retained by the player applying the bump, but they slow down and their momentum is decreased – therefore the overall momentum of the collision is conserved.

10 a Tumbling: teach the children to tuck tightly so that the moment of inertia is reduced and the rate of rotation will be increased.

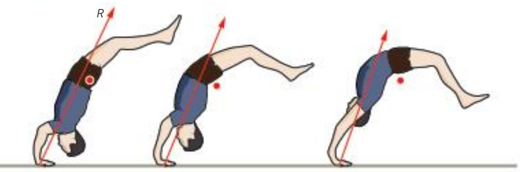
b Landing: teach children to bend knees and hips so that the time over which the force is absorbed is increased, reducing the risk of injury.

11 a

b



c



12 These surfaces increase the time over which the ground reaction force can be absorbed by the body. A pole vaulter experiences a greater force than a long jumper due to the height from which they land, therefore thicker mats are used in pole vaulting compared to the sand used in the long jump.

CHAPTER 4: KINEMATIC CONCEPTS OF HUMAN MOVEMENT

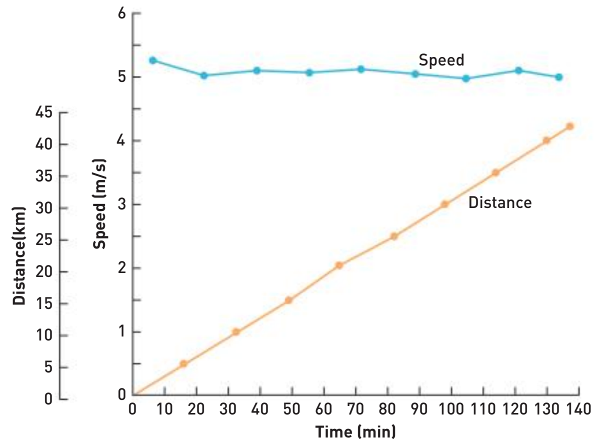
Data analysis p. 68

1 42.195 km/137 min 42 s = 42 195 m/8262 s = 5.11 m/s

2 The athlete maintained a relatively consistent pace throughout the race. The average split speeds remained above 5 m/s.

3 42.195 km/137 min 42 s = 42.195 km/2.295 h = 18.4 km/h

4 Distance–time would be linear, showing that speed had little variation throughout the race. Speed–time would almost be a straight line for the same reason (see graph below).



5 42.195 km in 3 hours and 45 minutes
speed = distance/time = 42.195/(3 + 45/60) = 11.25 km/h

Data analysis p. 70

1 The race distance and displacement are both 100 m as it is run in a straight line, finishing 100 m from where the race started.

2 12.35 m/s or 44.44 km/h. It took 7.1 seconds or 70 m into the race to hit his top speed.

3

DISTANCE (M)	CUM. TIME (s)	SPLIT TIME (s)	SPEED (m/s)	SPEED (km/h)
10	1.89	1.89	5.29	19.05
20	2.88	0.99	10.10	36.36
30	3.78	0.90	11.11	40.00
40	4.64	0.86	11.63	41.86
50	5.47	0.83	12.05	43.37
60	6.29	0.82	12.20	43.90
70	7.10	0.81	12.35	44.44
80	7.92	0.82	12.20	43.90
90	8.75	0.83	12.05	43.37
100	9.58	0.83	12.05	43.37

4 11.10 m/s or 39.96 km/h. The average looks at the total time to cover the distance, and takes into account periods of acceleration and deceleration.

5 Constant velocity: no change in speed. Bolt's speed is relatively constant from the 50-metre mark of the race (12.05–12.35 m/s). Being able to maintain maximum velocity is beneficial to race performance.

6 0–10 metres. The gradient of the graph can be used to determine acceleration.

7 12.35 m/s – 12.05 m/s = 0.3 m/s

The fact that Bolt can maintain close to his maximum speed for the second half of the race reflects his overall performance when compared to others in the race.

8 Positive acceleration from 0 m–70 m

Negative acceleration from 70 m–90 m

Zero acceleration from 90 m–100 m

9 Accelerate quickly over the first half of the race; maintain maximum speed for as long as possible.

Chapter check-up p. 70

1 In an Olympic triathlon the total **distance** of the swim is 1.5 km, the bike leg is 40 km and the run distance is 10 km. However, depending on where the start and end of each leg is, athletes may have zero **displacement**. A swim leg that commences on the beach, with swimmers swimming out to a buoy 750 m away and back to the beach, would result in a total displacement of 0 m. The same holds for the bike and run leg if athletes ride or run a circuit that starts and finishes at the same point.

2 **Velocity** is used in describing a headwind or a tailwind because the direction as well as the size (speed of the wind) is important. A tailwind will assist a runner and a headwind will disadvantage a runner.

3

LAP	TIME (s)	DISTANCE (m)	AVERAGE SPEED (m/s)
1	54	400	7.4
2	52	400	7.7
Total time	106 s (1 min 46 s)	800 m	7.5 m/s

4 As a diver leaves the 10-metre platform, the distance they cover will increase at an increasing rate; that is, their velocity will increase, from zero when they leave the platform to a maximum when they hit the water, and then decrease again as they move through the water. Until they enter the water, their acceleration will be constant throughout – at 9.8 m/s^2, which is due to gravity. It is the acceleration which causes the increase in velocity as the diver descends from the platform.

5 Given zero initial velocity,

$v = a \times t = 9.8 \times 3 = 29.4$ m/s

Chapter check-up p. 76

1 Suitable examples:

» 100-metre sprint: general motion
» Double somersault: angular motion
» Glide (ice-skating): linear motion

2 Refer to the small diagrams on page 73.

3 If the gymnast does not land perpendicular to the mat so that the force from the ground goes through the centre of gravity, an eccentric force will cause the body to 'spin', that is, rotate in a forward direction, causing the gymnast to step forward and not 'stick' the landing.

4 Full layout: axis of rotation = the bar, angular distance = 360 degrees

Dismount: axis of rotation = centre of gravity, angular distance = 540 degrees

5 A full-size bat will be too heavy for a junior player to swing. Because the distance from the axis of rotation to the point of the applied force is increased, a greater force is required to initiate the rotation of the bat (i.e. to swing the bat).

Angular acceleration is caused by torque, and if the player cannot generate enough torque the bat will be swung more slowly, resulting in a decrease in the linear velocity of the ball being hit, which means it will not travel as far.

Chapter check-up p. 83

1 Factors include:

» angle of projection: the angle at which the projectile is projected into the air
» speed of release: the speed at which the projectile is projected into the air
» height of release: the difference between the height of release and landing height of a projectile.

2 Situations include:

» long jump. The angle of release is between 18° and 27° to achieve maximum horizontal distance.

» blocking in volleyball. The angle of release is almost 90° to maximise vertical displacement, so the player can gain as much height as possible over the net.
» line drive in softball. The angle of release is close to 0° to maximise the horizontal displacement of the ball.

3 45° is the optimal angle of projection when the projectile is released and lands at the same height. This does not happen very often in sport. When a ball is thrown in cricket, for example, the release height will vary from the landing height depending whether the ball hits the stumps or is caught by the keeper. These factors will determine the angle at which the fielder will release the ball to maximise the accuracy of the throw. 45° will not always be the optimal angle of release for a cricket ball. Other sports where 45° is not the optimal angle of release can be found on page 80.

4 Increasing the angle of release will change the projectile path of the ball. An angle of release greater than 45° will result in a flight path with greater vertical displacement, which will clear the defenders and could still result in a successful shot as the ball can go through the basket on the downward phase of the flight.

5 In both forms of diving, maximising the vertical displacement of the body gives the diver more time to complete the dive. The springboard diver will generate greater height off the board by jumping almost vertically (increased angle of projection). This also generates a greater release velocity, and both will increase the flight time of the dive. From the platform, divers don't need to increase their vertical displacement as much as springboard divers, and will jump up and out with an angle of projection of less than 90°, decreasing to approximately 45° depending on the dive being performed.

6 For any given angle of release, the higher the speed of release, the greater the horizontal distance the projectile will travel.

CHAPTER REVIEW P. 87

Multiple-choice questions

1 D

2 A (linear velocity = radius of rotation × angular velocity, 55 × 0.90 = 49.5 m/s)

3 B

Short-answer questions

4 Suitable answers include:
» running. The angular motion of the hip, knee and ankle result in linear motion of the body.
» cycling. The angular motion of the hip, knee and ankle result in linear motion of the body and the bike.
» wheelchair racing. The angular motion of the shoulder, elbow and wrist result in the linear motion of the body and the chair.

5 a 2200 metres
b 200 metres
c 3 m/s
d 0.3 m/s

6 100-metre freestyle vs 1500-metre freestyle

Displacement 100 metres (swimmers complete two laps of the pool)

0 metres (swimmers start and finish at the same end)

Velocity: Velocity = displacement/time, approx. 2.3 m/s = 0 velocity

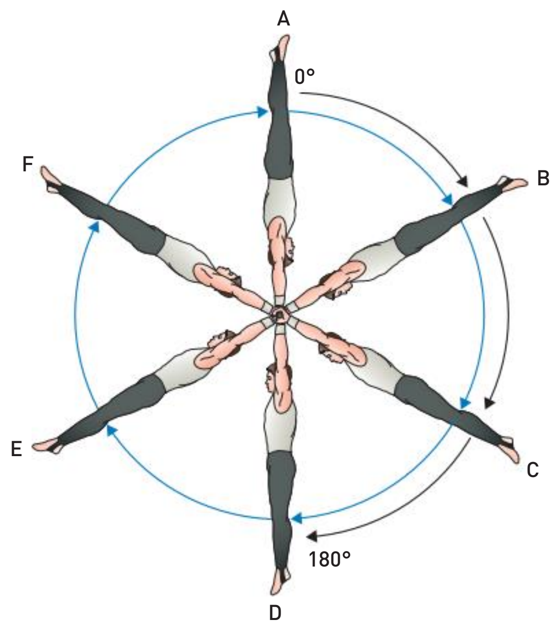
Acceleration: Acceleration = Velocity/time, approx. 0.1m/s^2 = 0 acceleration

Looking at the displacement, velocity and acceleration of the whole 1500-metre event provides no relevant data for a coach or athlete to use. It would be better to look at the distance, and speed and acceleration over different periods of the race, rather than averages calculated for the whole race.

7 Drop punt: The ball is held point down and the foot impacts with the ball on the bottom point. This is an eccentric force that causes the ball to spin backwards, end over end.

Torpedo punt: The ball is held on an angle across the body, the foot impacts with the ball on the long surface of the ball, imparting an eccentric force that causes the ball to spin in a spiral motion.

8 a



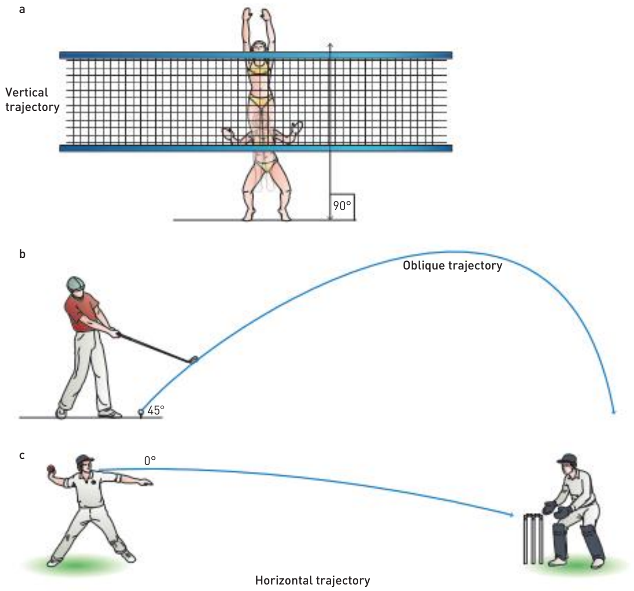
b 120°
c 180°
d 400°/s

9 Triple jump: take-off and landing heights are the same, so optimal angle should be 45°. However, similar to long jump, this would result in a decrease in take-off velocity. To optimise horizontal displacement, take-off angle would be similar to long jump, at 18–27°.

Discus: height of release is greater than landing height, so the optimal angle of release is less than 45°.

Javelin: height of release is greater than landing height, so the optimal angle of release is less than 45°.

10



CHAPTER 5: BIOMECHANICAL PRINCIPLES OF EQUILIBRIUM

Chapter check-up p. 90

1 Static equilibrium: when the sum of all vertical forces, horizontal forces and the sum of all torques acting on a body or object equal zero.

Suitable examples include:

» a gymnast holding a stationary V-sit
» a platform diver holding a handstand to initiate a dive.

2 Dynamic equilibrium: when the object is moving with a constant velocity, without changing speed or direction.

Suitable examples:

» a windsurfer
» a cyclist balancing around a tight corner
» a jockey riding a horse

3 The shot-put is released when the muscles contract to extend the elbow and shoulder joints.

Chapter check-up p. 97 (top)

1

SPORT/ACTIVITY & EQUIPMENT	EFFECT ON STABILITY	EFFECT ON PERFORMANCE
Golf – shoes 	Increase	Greater friction between the body and the ground increasing stability during swing
Bobsleigh skeleton – sled 	Decrease	Decreased friction between the sled and the ice, easy to disrupt the stability of the sled to travel faster down the track
Gymnastics – mag chalk 	Increase	Increased friction between the hands and the equipment, providing greater stability during movement
Mountain bike riding – tyres 	Increase	Increased friction between tyres and ground, increasing the stability of the rider as they navigate through the turns on the course

Chapter check-up p. 97 (bottom)

1 Equilibrium: when all forces and torques are balanced.

Balance: the state of equilibrium and the ability to control it.

Stability: the ability of a body to resist a change in its current state of equilibrium.

2 Examples include:

» football boots, spikes in running, waxing a surfboard, batter's gloves (baseball/softball).

3 Factors affecting stability:

» body mass
» friction between the body and the surface or surfaces contacted
» base of support
» position of the centre of gravity.

4 Bending their knees lowers the athlete's centre of gravity and increases their stability.

5 Balance is the ability to control equilibrium. A gymnast needs to move from one skill to another, often in quick succession, and may need to place their body in a position which will not resist a change in equilibrium, meaning they have also low stability.

Chapter check-up p. 105

1 The muscle provides the resistance in this anatomical lever. The force is the weight of the dumbbell, and the axis is the elbow joint.

2 It is an example of a third-class lever system. Sliding the hand down the paddle increases the mechanical advantage of the lever system.

3 The length of the resistance arm increases from each position (wall, bench and ground), resulting in a decrease in the mechanical advantage of the lever system. This means that more effort (force) is required to move the resistance (body weight).

4 Modified equipment is smaller (shorter lever length) for children, meaning that it is easier to control.

CHAPTER REVIEW P. 106

Multiple-choice questions

1 D

2 C

Short-answer questions

3 The coach could suggest using a crouch start, with one foot in front of the other to increase the base of support and therefore increasing stability of the student. To allow for an increase in acceleration, the student should move their line of gravity to the front of the base of support, which will allow an easier disruption of stability when the starting pistol sounds, and a faster acceleration out of the blocks.

4 Patrick will find it hard to swing the clubs as they will be too long for him. He will not be able to generate the force required to rotate the longer clubs, and will have difficulty swinging the clubs successfully.

5

STANDING SPRINT START	CROUCHED SPRINT START
Centre of gravity higher Line of gravity through centre of gravity, inside base of support Base of support wider	Centre of gravity lowered Line of gravity toward front edge of base of support Base of support narrow

The crouch start will result in the athlete having less stability, which would be beneficial in moving forward quickly at the sound of the starter's pistol.

6 Bend their knees: lower the centre of gravity.

Feet shoulder width apart: Increase base of support.

Extend arms: Keep line of gravity over base of support by reducing rotation.

7 Extending the arms above the head increases the lever length and increases the force required to move the resistance through the range of motion (into a sitting position), making it a more difficult exercise to perform.

CHAPTER 6: THE THREE ENERGY SYSTEMS WORKING TOGETHER TO PRODUCE ATP

Chapter check-up p. 110

1 Foods not appearing in the picture that are high in:

CARBOHYDRATES	FATS	PROTEINS
Muffins Honey Rice cakes Corn Peas Sugar and syrups Pretzels Sweet potato Fruit juice	Butter Ice cream (contains milk fat) Avocados Palm oil Coconut oil Peanut butter Toasted muesli Veal Cakes, sweets, doughnuts	Low-fat Greek yoghurt Lean beef Protein bars Whey Quinoa Soy beans Tofu Cottage cheese

2 Recommended carbohydrate intake would exceed levels in a balanced diet in the following sporting situations:

» athletes who undertake large amounts of aerobic training, such as swimmers, marathon/ triathlon competitors, etc., who need to refuel throughout the training session/day

» athletes consuming larger amounts of carbohydrates than recommended intake because they are carbohydrate loading for endurance competitions in several days' time

» sportspeople who undertake more than one training session per day (morning and afternoon).

3 a The 20-km athlete would consume more low GI foods to ensure constant and slow release during the event. It would take an elite 20-km runner upwards of 1 hour and 10 mins to complete the activity. Carbohydrate loading would not offer a big advantage as a balanced diet should provide adequate amounts of energy. It is likely the 20-km athlete will try to increase hydration levels and stored water in cells prior to the event.

b It is likely that rugby players would consume higher amounts of protein to assist muscle repair due to the contact nature of the game. The 20-km runner would have higher loss of carbohydrates to fuel their activity and hence consume larger amounts post-event than the rugby players.

4

CARBOHYDRATES	FATS	PROTEINS
Complex carbohydrates can be found in cereals/ grains (bread, rice, pasta, oats, barley, millet, buckwheat, rye) and some root vegetables, such as potatoes and parsnips. A healthy vegetarian diet should contain plenty of these complex starchy carbs as they are beneficial for health, weight and energy levels. Less refined complex carbs, like whole wheat bread, whole wheat pasta and brown rice, are best of all because they contain essential dietary fibre and B vitamins.	Peanuts and other nuts Avocados Olive and other plant oils Soya beans	Nuts: hazels, brazils, almonds, cashews, walnuts, pine kernels, etc. Seeds: sesame, pumpkin, sunflower, linseeds Pulses: peas, beans, lentils, peanuts Grains/cereals: wheat (in bread, flour, pasta etc.), barley, rye, oats, millet, maize (sweetcorn), rice Soya products: tofu, tempeh, textured vegetable protein, vegie burgers, soya milk Dairy products: milk, cheese, yoghurt (butter and cream are very poor sources of protein) Free-range eggs

Chapter check-up p. 118

1 **Glycogen sparing** that accompanies aerobic training sees more lipids/fats being used earlier on in activities and less associated use of carbohydrates to resynthesise ATP. This means carbohydrates are more available later on in the activity as the predominant fuel source, which means higher intensities/running speeds can be maintained for longer and hence quicker times achieved.

2 Switching to fats can be delayed by improved aerobic capacity via training, consuming hypertonic/glucose drinks during the activity or reducing the running intensity.

Chapter check-up p. 133

1 This typically occurs when oxygen supply cannot keep up with demand and is associated with sudden increases in workload or performance intensity that might occur when:

- » surging away from a group of competitors in a triathlon, cycling event, marathon, etc.
- » performing over more difficult terrain (running uphill, running on sand, running in muddy areas, sprinting to the finish line).

2 This tends to happen when an active recovery is undertaken and oxygen consumption remains above resting levels for longer than it would if a passive recovery had been used. The extra oxygen is used to double the rate at which lactic acid is removed from muscle sites and also facilitates its conversion into glycogen.

3 Quite often an active recovery will make it impractical to consume foods required for rapid fuel restoration such as high GI foods. This might delay their consumption and contribution to rapidly restoring glycogen to pre-activity/exercise levels. Additionally, most active recoveries are performed at intensities that make it impossible for PC to be resynthesised.

4 This tends to occur because the ATP–PC system and anaerobic glycolysis/LA system have a finite capacity.

5 Athlete B would have a higher EPOC because they do not have the same ability to take up, transport and use oxygen as the endurance athlete. Additionally, Athlete B would have a smaller stroke volume, less blood, less mitochondria and lower percentage of slow twitch fibres – all meaning they would experience larger debts/EPOC at the end of the treadmill run.

Chapter check-up p. 135

1 Greater contribution from the anaerobic glycolysis or LA system compared to the first 200 metres

2 PC is depleted at the same rate in both 200-metre sections of the race, but the amount depleted during the first 200 metres is significantly greater than that depleted in the second 200 metres. More than 80% of PC is depleted in the first 200 metres of the race.

ATP is depleted at quicker rates than PC.

3 After significant activation/use of the anaerobic glycolysis system, intensities need to drop to allow any accumulated H^+ to be oxidised and this can then be reused again and again – the key is to remove large amounts of accumulated H^+ before re-engaging this system to contribute to additional ATP production.

4 At the 40-second stage, the elite runner is deriving most ATP from the anaerobic glycolysis system, with all PC depleted and the aerobic energy system now the second most important system, contributing around 40% of the ATP at this stage. At the same stage, the club-level runner (running at slower pace) would still have anaerobic glycolysis as the major ATP producer, but their aerobic energy system is contributing less than the elite performer at the same stage (slower supply of oxygen to working muscles compared to the elite runner).

5 At the halfway stage (200 m), most ATP is being produced by the anaerobic glycolysis system, with the next highest amount coming from the PC system and the least amount (about 20%) coming from the aerobic energy system. At the end of the race the anaerobic energy system is still the major ATP producer, but the aerobic energy system takes over as the second most significant system, with the PC system contributing very small amounts, if any, at this stage of the race.

6 Lactate first appears in the muscles and signals imminent fatigue resulting from acidosis and effects on glycolytic enzymes. It is then shunted to muscles with lower lactate concentrations and is picked up in blood measurements. By this later stage it is often difficult to counteract the fatiguing effect on performance.

Chapter check-up p. 137

1 No oxygen is required/available.

- » Rapid splitting of PC to produce energy is much quicker than any of the food fuels.
- » PC stored at muscles is more readily available than glycogen stored at the muscles.

2 Fuels utilised by the anaerobic glycolysis system take longer to be broken down than PC and so the rate at which ATP can be resynthesised is also slower.

3 The anaerobic glycolysis system calls upon glycogen as a fuel, which does not require a passive recovery to be resynthesised so it can be used again. As long as glycogen/glucose is present and available to working muscles, the anaerobic glycolysis system can utilise this and contribute to energy production.

4 All three systems would be contributing to ATP production, with PC being depleted slower than during a 100-metre sprint because the intensity would not be maximal from the outset of the race. It is likely the anaerobic glycolysis system would be contributing most to ATP production at this stage, with the aerobic system staring to really 'crank up' due to increased functioning of the cardiovascular and respiratory systems. It must

be recognised, however, that the aerobic system needs 75 seconds when working maximally to take over from the two anaerobic energy systems as the major ATP producer. Approximate contributions at the 40-second stage would be:

- ATP-PC energy system – 5%
- Anaerobic glycolysis energy system – 55%
- Aerobic energy system – 40%

5 The runner would not be working maximally for the duration of his/her event. The cyclist would be able to take up and transport greater amounts of oxygen due to increased work rates from the cardiovascular and respiratory systems. Differences would also occur because the cyclist would be using fewer muscles than the runner, who is totally weight-bearing on the running surface.

6 Even though the athlete is sprinting, PC has not had a chance to rebuild itself and hence has no contribution to the final burst of effort/sprint. The anaerobic glycolysis/LA system would increase its contribution when compared to the previous distances when less effort was required but this would only result in a maximum of 3 moles of ATP production. Because the event has been going for between 3 and 3.5 minutes, the aerobic system has had sufficient time to take over as the major supplier of ATP and will continue to do so even in the final sprint to the finish line because it is capable of procuring 36 moles of ATP.

Chapter check-up p. 139

1 Short-interval training develops the ATP-PC system. Intermediate-interval training develops the anaerobic glycolysis system.

2 In most cases this would restrict repeated use of the ATP-PC system due to insufficient recovery time to restore PC to pre-exercise levels. This would typically be done where game demands called upon this type of recovery and where improvement in lactate tolerance and delayed LIP are essential to being successful. The decreased rest period would increasingly activate the aerobic energy system as well.

3 An active recovery will facilitate H^+ removal but will not adequately allow PC to be resynthesised.

4 By improving their anaerobic capacity/lactate tolerance, endurance athletes will better be able to surge/increase work-rate and sustain this before fatiguing and needing to slow down; in particular this is of significant benefit at the end of endurance events when they can sprint to the finish line at higher speeds and sustain this for longer than their opponents.

CHAPTER REVIEW P. 141

Multiple-choice questions

1 C

2 B

3 D

4 D

Short-answer questions

5 Fats take much longer than carbohydrates to break down and so the rate at which they produce energy is slower. Carbohydrates do not require the same amount of oxygen as fats to produce energy, so more is available to working muscles.

6 a Three advantages an athlete gains by being able to increase their LIP include the ability to:

- work at a higher intensity before starting to accumulate fatiguing H^+ ions
- activate the aerobic system at an earlier stage of performance and delay 'anaerobic' related fatigue mechanisms
- 'save energy' for later on i.e. to work aerobically while competitors work anaerobically
- produce more energy/ATP per gram of fuel.

b There will be a greater contribution from the aerobic energy system.

c Intermittent training/intermediate-interval training will cause the anaerobic glycolysis system to become more powerful. This will see an increase in glycogen stores and glycolytic enzymes and most likely delay the point at which H^+ ions will rapidly accumulate.

7 a By training – increase muscle size/hypertrophy and thus provide a bigger storage site for PC; or by diet manipulation – creatine supplementation.

b This will allow the PC system to work as the major ATP producer for longer before the anaerobic glycolysis/LA system takes over as the major ATP producer and the associated sharp rise in metabolic by-products (especially H^+).

8 ATP is resynthesised via the three energy systems and the way all three systems work together to provide energy is known as the energy system interplay. Discussion must clearly demonstrate that all three systems are working to varying degrees based on intensity, duration and ability to refuel.

9 Because the event does not start out at maximal intensity the ATP–PC system would last about 15–20 seconds before ATP is predominantly produced by the anaerobic glycolysis system. At the same time the aerobic system is increasing its contribution and takes over as the predominant ATP producer around the three-minute mark, and continues to be the predominant energy producer throughout the event. When the runners surge, or work at higher intensities such as running uphill, there is increased contribution from the anaerobic glycolysis system but this still produces one-twentieth as much energy as the aerobic energy system. There are no opportunities to replenish PC throughout the race so its contribution to ATP production remains negligible from about the 20–30 second stage of the race.

CHAPTER 7: ACUTE RESPONSES TO EXERCISE

Chapter check-up p. 146

1 The two factors are increase in tidal volume and increase in respiratory rate. The changes are both involuntary, however, they can be controlled by a voluntary action, such as when instructed to 'take a deep breath and hold'.

2 Ventilation is the product of respiratory rate (RR) and tidal volume (TV). As RR and TV increase, so does ventilation.

3 At rest the need for oxygen is low, but as exercise begins, the body's need for oxygen increases significantly. The body responds in a number of ways in order to meet this need. The individual will breathe more often and more deeply (increased respiratory rate and increased tidal volume). These increases result in the rapid rise in ventilation as V = RR × TV. The levelling off represents a period of time where the oxygen demand is being met with supply (steady state) and no further increase in ventilation is required. The recovery section of the graph represents the gradual return of RR and TV to pre-exercise levels, as the demand for oxygen has now decreased.

4 During submaximal exercise, the respiratory system will increase ventilation by increasing both TV and RR linearly, with respect to oxygen consumption, until a steady state is reached. At this point there will be no further increase in ventilation. During maximal exercise, ventilation will continue to increase until exercise ceases. The increase in ventilation is a result of increases in RR only. The rate of increase is linear up to the ventilator threshold, at which point ventilation increases faster than oxygen consumption.

5 When the body begins to exercise, the demand for oxygen by the working muscles increases. To meet these demands the body will increase the respiratory rate and tidal volume to increase ventilation (volume of air taken in per minute).

Chapter check-up p.152

1 Cardiac output (Q) = stroke volume (SV) × heart rate (HR). Any increase in SV, HR or both will result in an increase in cardiac output.

2 Resistance exercises cause compression of the blood vessels by the muscles, causing an increase in blood pressure. Blood pressure can also increase due to the Valsalva response elicited in heavy resistance training, where air is forcefully expired against a closed airway.

3 Increases in ventilation and diffusion mean that more oxygen is available in the blood. Increases in cardiac output mean more blood is pumped out with each beat and delivered to the working muscles. The increase in venous return means that more blood is available to be ejected with each beat. Increases in cardiac output and a-vO_2 difference lead to an increase in oxygen consumption.

4 During exercise blood is redirected to the working muscles. This means more blood is delivered to the muscles and the muscles can extract greater amounts of oxygen to be used for energy production, causing an increase in a-vO_2 difference.

Chapter check-up p. 156

1 Skeletal capillaries will dilate (open up) to increase the blood flow to the muscles with minimal increase in blood flow viscosity; this will also increase the surface area to allow for more sites for diffusion to occur. This results in an increase in blood flow to the working muscles and greater oxygen delivery.

2 100-metre sprinter: decreased ATP and CP stores; marathon runner: decreased glycogen and intramuscular fat stores

3 Fewer motor units are recruited for activities that require less force; more motor units are recruited for activities that require more force.

4 At rest and during submaximal exercise intensities, lactate is produced, but sufficient oxygen is available for it to be broken down and removed by the body. At high intensities, lactate is being produced faster than the body can clear it, so it accumulates.

5 At submaximal exercise intensities blood flow is directed to the working muscles and to the skin to aid in temperature control. At maximal exercise intensities the increased demand for oxygen means that more blood is directed to the muscles and less to the skin (2 per cent), which means that temperature increases and the risk of heat related injuries increases.

CHAPTER REVIEW P. 160

Multiple-choice questions

1 C

2 C

Short-answer questions

3 Sporting events that are of short duration and high intensity, such as high jump or long jump, will see a decrease in ATP and CP stores in the muscles. Events of extended duration and submaximal intensity, such as road cycling and 10 000-metre running, will see a decrease in muscle glycogen and fats.

4 All acute responses in the respiratory, cardiovascular and muscular systems work to increase the supply and use of oxygen to the working muscles and to remove waste products (CO_2, heat and water) so that energy can be produced aerobically to meet the demands of the exercise.

5 Increased blood flow to the skin and increased sweating. Practical strategies could include: ice vests, ice, hydration, shade, light coloured clothing, hats, fans, etc.

6 The heart can only pump out the amount of blood that fills the ventricles. Therefore if there is a decrease in venous return, less blood is returning to the heart

and therefore less blood is being pumped out with each contraction. Increases in cardiac output must be accompanied by an increase in venous return.

CHAPTER 8: ENERGY SYSTEM FATIGUE AND RECOVERY MECHANISMS

Real world application p. 168

1 There is more oxygen than H^+ ions available during low intensities, so these are broken down as soon as they are produced.

2 A small amount of lactate (approximately 20%) is converted back into glycogen, which can then be used to produce more ATP.

Chapter check-up p. 169

1 Accumulation of P_i and depletion of PC.

2 H^+ only accumulates when working above LIP (85% max HR) and jogging is below this intensity.

3 Depletion of PC results in the body switching to the anaerobic glycolysis system for most of the ATP production. This means carbohydrate (CHO) is used anaerobically to resynthesise ATP, which takes longer than PC to break down and hence a slower contraction rate/speed.

4 Lactate levels indicate whether or not someone is working in relation to their LIP. If they are predominantly training their aerobic system, they need to be training at or slightly below their LIP, but if they are hoping to increase their anaerobic capacity, they need to be training above their LIP.

5 Aerobic training allows athletes to work at higher intensities aerobically and hence delay accumulation of H^+ until higher intensities. Because this allows athletes to work at higher intensities, when they do surpass their LIP the amount of H^+ produced is subsequently higher before fatigue actually sets in.

Chapter check-up p. 174

1 Potassium is essential in transporting glucose into the muscle cell. If this decreases as a result of sweat, the muscle will increasingly use fats that contribute to slower resynthesis of ATP rather than carbohydrates.

2 a: PC; b: PC; c: CHO; d: PC; e: CHO; f: CHO

3 Fats take longer to break down than carbohydrates and also require more oxygen to be broken down, so less oxygen is available to working muscles.

4 H^+ interferes with the contractile mechanisms and glycolytic enzymes, which both result in weaker muscle contractions.

5 To avoid hyperthermia (increased core temperature), a competitor should be adequately hydrated before the event and should possibly have undergone carb loading (1 g CHO absorbs 3 g water). Lightweight clothing that is capable of allowing heat to escape would be ideal.

Chapter check-up p. 181

1 Answers should focus on athletes who perform explosive efforts lasting 3–10 seconds such as pole vaulters, long/triple jumpers, 100-m sprinters, etc.

2 Foam rollers compress blood vessels, promoting blood flow away from muscles and back to the heart, which increases the rate of H^+ removal.

3 Protein meals taken during recovery have the following associated benefits:

» increased rate of glycogen restoration
» improved rebuild of RBCs
» production of new hormones
» rebuilding enzymes.

4 Less fats would be utilised if carb loading was undertaken; low GI foods consumed 1 to 2 hours before race starts; glucose is replenished during the race via drinks and gels.

5 Passive recovery is required.

6 Intermediate interval training would have high levels of accumulated H^+ so the recommended recovery would consist of active recovery exercises. Long interval training would have negligible amounts of accumulated H^+ so the recommended recovery would be passive, with a focus on hydration.

CHAPTER REVIEW P. 183

Multiple-choice questions

1 B

2 B

3 D

Short-answer questions

4 a Elevated body temperature will cause blood to be redistributed away from working muscles and to skin to assist in cooling. (Wear ice vests, use cold towels, etc. during breaks in play.)

Dehydration will cause plasma levels to drop and increase blood viscosity, which will cause the blood to pump harder and also take oxygen and fuels away from working muscles. (Consume hypotonic drinks whenever possible during breaks in play.)

Accumulation of H^+ will interfere with contractile mechanisms at the microscopic level and restrict action of glycolytic enzymes. These will cause muscles to contract less forcefully and increase use of fats as a fuel source, which will both lead to a slowing down/reduced force production. (Active recoveries should be performed during the match as well as any massage while not in play to promote blood flow.)

Note: given the duration of the match, it is unlikely that fuel depletion will be significant; that is, carbohydrates will remain the major fuel used in ATP resynthesis.

b The hockey player should eat high-GI foods (preferably with protein) in the first 45 minutes of recovery. Ideally, this should include an isotonic drink because this hydrates and refuels the same time. Foods high in fibre should be avoided because of their slow absorption rate and potential for gastric upsets.

5 a Accumulation of H^+ can be delayed by increasing LIP via aerobic training or working within the aerobic training zone (below 85% max HR).

b An active recovery will result in H^+ being broken down and removed twice as fast as a passive recovery. This occurs because of increased oxygen during EPOC/oxygen debt.

6 Proteins co-ingested with carbohydrates during recovery increase the rate at which carbohydrates are reabsorbed into the body and contribute to glycogen restoration. Additionally, the proteins are important in rebuilding red blood cells that carry oxygen; building enzymes which are responsible for maintaining processes at their optimal speed and also production of hormones that also control many functions related to thermoregulation.

7 a High sweat rates that are not countered by adequate rehydration will result in loss of plasma, leading to a thickening of the blood and a slower transportation of oxygen to working muscles, coupled with a higher heart rate, which takes oxygen away from working muscles.

b Symptoms of dehydration include increased errors, slower movements, dry/sticky mouth, thirst, dry skin, headache, dizziness or light-headedness.

c Electrolytes serve a number of important functions. Sodium is important for regulating blood volume and maintaining muscle and nerve function. Potassium is the major cation inside cells and is hugely important for regulating heartbeat and muscle function. Magnesium helps maintain normal nerve and muscle function, boosts the immune system, maintains stable heart rate and stabilises blood sugar. Electrolytic drinks also have the ability to increase water retention in the cells/body.

8 Your answer must address what the main fatigue factor is in your chosen sport/activity and any suggestions around preventing it, or delaying it during performance as well as how to best recover when it has occurred.

9 a Lactate levels are measured during training to calculate the intensity that equates to LIP (this then becomes the top of the aerobic training zone). Lactate levels are also measured to reflect how the body is responding to exercise and might also be used to calculate the greatest amount the athlete can tolerate and still keep performing/training.

b Increasing LIP allows Helena to work at higher intensities aerobically. This means she can work harder without accumulating H^+.

10 a The 1500-metre race would have predominantly called upon Peta's aerobic energy system, but there may have been some accumulated H^+ remaining after it had been run. To remove these by-products it is important that Peta performs an active recovery. This will double the rate at which they are removed. This active recovery should be done for 10 to 15 minutes. At the same time, Peta should rehydrate via a hypotonic sports drink. Replacement of glycogen would not be a major consideration given the duration of the events she has competed in, and will compete in.

b The 800-metre is run at a faster pace than the 1500-metre race so the demand for oxygen is higher at different stages. The oxygen deficit is correspondingly higher as oxygen supply is unable to keep up.

11 a An active recovery involves the same activity being performed at a reduced intensity; a passive recovery involves either total rest, or performing a very low-intensity activity such as slow walking.

i Passive, to replenish PC

ii Passive, as no H^+ is accumulated

iii Active, to promote H^+ oxidation and increase blood flow to facilitate removal of wastes.

b General fatigue usually involves a large number of body parts and may also result in psychological fatigue, which is often commented on as 'exhaustion'. The athlete should be assisted via an oxygen mask and IV hydration (this can replace fuels and water).

12 a Marie could either have higher aerobic capacity or be taking creatine supplements, which both hasten PC replenishment.

b Sarah would increasingly be producing ATP via her anaerobic glycolysis system due to lesser PC replenishment. Because Marie is using her PC system more with each sprint, she will be the one accumulating more P_i.

c The goal shooter predominantly uses her PC system and H^+ is not a metabolic by-product associated with use of this system.

d Proteins are useful in repairing/rebuilding muscles, rebuilding red blood cells, enzymes and hormones; and when proteins are co-ingested with carbohydrates, this results in faster replenishment of glycogen. Carbohydrates are consumed to replace those used in producing energy for muscular contractions.

CHAPTER 9: FITNESS COMPONENTS USED IN SPORTS AND ACTIVITIES

Chapter check-up p. 195

1 Static flexibility is about moving a joint to a given point in the joint's range of motion while dynamic flexibility is a joint's ability to move through the range of motion quickly with little resistance.

2 A suitable order, from most limiting to least limiting, is:

- joint structure
- soft tissue structures
- temperature
- age
- gender.

Justification: joint structure cannot be altered, soft tissues can be trained, temperature can be increased but does not affect flexibility as much as soft tissue, and age and gender, although they cannot be changed, do not significantly limit flexibility.

3 Flexibility training can increase performance and reduces the risk of injury by increasing the dynamic flexibility of the body. Even in sports where static flexibility is not required, such as batting in softball, performance would be improved through increased range of motion in the shoulder joint.

4 The following examples support the statement. Jockeys are generally short, slight and carry little excess body weight. Gymnasts are often petite, muscular and have low body fat levels. Rowers are often tall with long limbs (arms and legs).

Chapter check-up p. 203

1 Muscular actions can be compared as follows:

- isometric action – muscle length remains the same as force is developed
- isoinertial action – muscle lengthens or shortens as force is developed
- isokinetic action – maximal tension developed in the muscle while lengthening or shortening at a constant velocity over the full range of motion.

2 Any three of: fibre diameter, contraction time, relaxation time, PC stores, glycolytic enzyme activity, myosin-ATPase activity. These characteristics are those that enable muscles to contract more forcefully and produce greater strength.

3 Fast-twitch fibres are highly fatiguable and have low mitochondrial density, capillary density and myoglobin content, making them less suitable to endurance activities that rely on energy from the aerobic system. They have less triglyceride stores and less oxidative enzymes, which reduce the fibres' ability to produce ATP aerobically.

4 Pennate fibre arrangements are designed to produce force, so the quadriceps and plantar flexors would be more suited to developing force. These muscles produce forceful actions, for example a barbell squat.

5 Older adults who have a decline in strength limit their ability to live independently if they are unable to perform daily tasks such as getting out of bed, in and out of chairs, bathing etc. Other tasks that require strength include doing the shopping, pushing trolleys and lifting bags. Strong postural muscles are also important for maintaining mobility and active transport modes.

Chapter check-up p. 211

1 For example: football (both Australian Rules and soccer) requires decisions to be made in relation to the correct response to a stimulus, which may be the ball, an opposition player or environmental factors such as wind, where the whole body must change direction or speed or both.

2 Tennis requires fast changes in direction of the body in response to the return shot from an opponent.

3 Health-related components are important to maintaining optimal functioning, whereas skill-related components affect performance. It is important to be healthy and have optimal functioning of the body systems before specific skill-related components are improved.

4 The ACSM's definition has the additional criterion that the movement must be accurate as well as fast. An athlete's ability to change velocity or direction accurately in response to a stimulus may not result in the desired performance outcome if they do it inaccurately.

CHAPTER REVIEW P. 213

Multiple-choice questions

1 B

2 C

3 C

4 A

Short-answer questions

5 Any three of:

- efficiency and strength of the heart muscle – the more efficient the heart in delivering blood to the muscles, the greater the aerobic capacity
- health of the blood vessels – elasticity and vessels that are free from obstructions such as plaque allow uninterrupted and increased blood flow to working muscles to increase oxygen delivery
- haemoglobin levels – increased oxygen-carrying capacity of the blood increases the oxygen available for aerobic respiration
- efficiency of the respiratory system – increased efficiency of the lungs means less oxygen is required for breathing, so more is available for aerobic energy production
- extraction capabilities of the muscle – the more oxygen that can be taken up by the muscles, the more will be available for aerobic energy production.

6 Anaerobic capacity is the amount of energy that can be produced by the anaerobic systems and anaerobic power is how quickly (rate) the energy can be produced.

CHAPTER 9 continued

7 Muscular **strength** refers to the ability of the muscles to generate a maximal force in one effort – such as in lifting a heavy weight. **Power** refers to the ability to exert a force rapidly – such as when throwing a discus. Muscular **endurance** requires the repeated (submaximal) effort of the muscle to perform the action. Unlike strength (which produces great force) or power (which produces force quickly), the ability of a muscle to perform the same action repetitively is needed in events such as cycling or running.

8 For example: in alpine skiing, balance is required to stay upright while moving down the mountain at high speeds. Skiers increase their balance by bending their knees, lowering their centre of gravity and keeping their body weight over the skis so that the line of gravity falls within the base of support. Friction between the skis and snow can be reduced by waxing the skis.

Extended-response questions

9 Answers will vary. The following points should be part of the argument constructed:

- genetic predisposition of muscle fibre types
- the ability of fibre types to be trained
- characteristics of fibre types
- the mental and physical capabilities needed to perform at the elite level.

10 Answers will vary, but must include a definition of strength and power; the understanding that strength and power are specific to a muscle or muscle group; and that power is not only how forceful an action is but how quickly the action can be performed.

CHAPTER 10: ACTIVITY ANALYSIS IN SPORTS

Real world application p. 219

1 Biometrics is defined as the measurement of unique physical and behavioural characteristics, providing accurate capture of physiological data.

2 Scientific performance management begins with a wearable GPS device worn by the player. The device captures all the movements of the body; for example, the distance the player travelled and the different speeds at which they ran. The scientific data gathered from these devices is used to help train and coach players.

3 Catapult technology has helped the Jacksonville Jaguars through live monitoring of their practice games. The data captured is uploaded and spreadsheets are created based on that data, providing objective feedback. Specific data comes from GPS and heart-rate data, so athletes can be trained according to the demands that will be placed on them in practice and in games.

4 A thin electronic patch; these are strategically placed around the body to gather accurate data. Examples include ECG data, heart rates and muscle activity.

5 The Athletes Services Model provides a series of tests to understand athletes' physical strengths, nutrition habits and areas of opportunity, and how they can improve.

6 To monitor the amount of fluid the athlete is losing. That data is used to create personalised fuelling recommendations for the athlete.

7 Players will buy into wearable technology because it will optimise opportunity. It will help them to play better, play longer, and make more money. Wearable technology can build up a picture of an athlete's physiology, strengths and areas of opportunity.

Chapter check-up p. 221

1 Activity analysis data allows us to determine the relevant fitness components, energy systems, movement patterns, heart rates, work-to-rest ratios and skill frequencies, so that appropriate fitness tests can be selected to test these aspects.

2

ADVANTAGES	DISADVANTAGES
Immediate changes can be made to playing set-up or style of play in response to how the game is progressing	Subjective or opinion-based decisions (can be reduced with training and increased viewing experience)
Player fatigue can be easily observed and counteracted with use of the 'bench' for recovery	No way of showing players how they performed
	No way of comparing performances
Players are able to stay on the field and positions can be rotated to increase player efficiency	Limited observer memory
	The pace of the game is too fast to 'take everything in'
	Difficult to observe multiple players on the same team
	Large playing fields increase distance over which observations need to be made

3 Game data is closely analysed following performances to determine the individual players' playing styles and team set plays of opposing teams. It is also used to view the effectiveness of set plays made by your own team and how teammates work together to bring these about. It's a bit like a game of chess where you react in certain ways when your opponent makes a move, and you can predict what is likely to happen a few plays into the future. The video data is vital in being able to show players how they and opponents perform – this is much more powerful than simply speaking to players about set plays and other game tactics.

4 Observation should be supported by statistical data collection, because this enables coaches and players to discuss different playing aspects; it also provides data to be archived and referenced in future, rather than relying on memory.

5 The trade-off is that the more accurate a game analysis method is, the less practical it tends to be – and vice versa. For example: direct observation is very easy and practical to use because it doesn't require specialist equipment or training; is non-invasive to players and allows immediate changes to be made. Digital recording/filming is more accurate because it is objective, data can be stored, etc. but it is less practical because of costs, and the potential inability to view players both on and off the ball.

6 What a player does 'off the ball' is just as important as when they are 'on ball'. Off-ball behaviours are often analysed to improve a player's game sense or tactical abilities – the information is used by coaches to reveal and discuss set plays, opposing moves, etc. It is also important to know how a player is 'recovering' in between efforts contesting the ball in order to better tailor training and recovery sessions.

7 Because the analysis provides data of likely fatigue mechanisms, these can specifically be worked on during recovery. For example, a midfield player in hockey, soccer or Australian Rules football would typically cover more than 10 km per match. Recovery would focus on refuelling and rehydrating these players as quickly as possible. Their more static teammates such as forwards or backs would rely more heavily on their anaerobic energy systems, and recovery would look more at removing metabolic by-products than replenishing fuels.

Chapter check-up p. 228

1 Agility is a combination of speed and flexibility.

2 Sprints occur in zone 6 and averages are obtained by dividing the total distance sprinted by the number of sprints performed: first quarter 335.6/14 = 24 m, fourth quarter 37.9/3 = 13 m.

3 The anaerobic energy systems (ATP–PC and anaerobic glycolysis/LA systems) are called upon more in the first quarter than the fourth quarter due to greater frequency of high-intensity efforts. Fatigue would thus be linked to fuel (PC) depletion and accumulation of P_i and H^+ (metabolic by-products associated with the two anaerobic energy systems). In the fourth quarter there is greater reliance on the aerobic energy system but only half the distance is covered compared to the first quarter. Even though drinks are run out to players, dehydration would be a consideration as the match progresses.

It is evident from the lower number of high-intensity efforts in the fourth quarter that greater contribution from the aerobic energy system is occurring than in the first quarter. This also means that the anaerobic energy systems (ATP–PC and anaerobic glycolysis/LA systems) are called upon more in the first quarter than the fourth quarter.

5

SKILL	AGONIST	ANTAGONIST
Serve/spike	Deltoid	Pectorals
Dig	Pectorals Forearm flexors	Deltoid Forearm extensors
Set	Triceps	Biceps
Leap sideways	Hip abductors	Hip adductors
Leap forwards	Quadriceps	Hamstrings

Chapter check-up p. 232

1 This would provide a more specific analysis, allowing for the design of far more specific training sessions working at targeted intensity levels as identified from the activity analysis.

2 It is critical that the game intensities identified in the activity analysis are replicated during training sessions (with similar work periods followed by similar rest periods) to best develop the associated energy systems and fitness components, according to the principle of specificity.

3 Live GPS data allows coaching staff or an individual to act immediately on the information provided. Typical GPS data can provide speed, distance, heart rate, body load information and intensity graphs, as well as generally tracking workloads. This player tracking option provides unprecedented insights into performance and game demands, which better informs decision-making, as the user of the device can objectively manipulate volume and intensity training loads for optimum game-day performance.

CHAPTER REVIEW P. 234

Multiple-choice questions

1 A

2 C

3 D

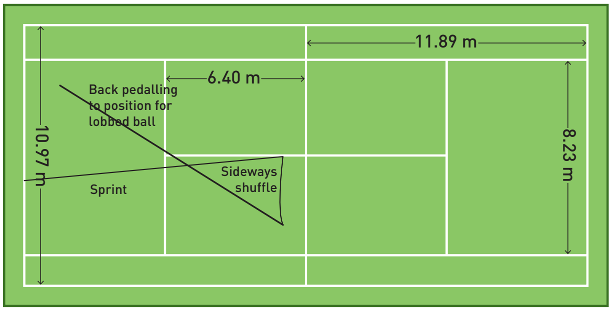
Short-answer questions

4 Training will allow them to become more efficient at watching and recording at the same time. It will also provide analysts with clear instructions on what they are observing and how this needs to be recorded, thus reducing subjective and opinion-based decisions.

5 A critique is an assessment or evaluation based on information available. Responses need to state that both provide data on intensities, but cheaper heart-rate monitors don't store information and only provide immediate read-outs. GPS can store information, provide second-by-second read-outs as well as providing information on acceleration (three planes maximum). Another advantage of GPS is that it provides contextual

information – i.e. it shows where players have moved throughout the match/competition. The downside of GPS analysis is the cost and expertise required to interpret the data.

6 a The different movements should be keyed/drawn differently – i.e. sprint should be different from sideways shuffle and back pedalling.



b Answers will vary.

c Answers will vary.

d 5–10 m and muscular power or agility.

7 Answers will vary.

CHAPTER 11: ASSESSMENT OF FITNESS

Chapter check-up p. 241

1 Important considerations before fitness testing include:

- » The intended outcome of any testing should be clear to both the participant and the person conducting the testing.
- » Is it culturally acceptable to be conducting testing?
- » Consideration needs to be given to participants in mixed-gender group fitness assessment.
- » Sensitivity of the participants needs to be considered.
- » How will results be compared?
- » Confidentiality needs to be considered.
- » Safety is paramount.
- » What are the financial costs of testing?
- » Is it maximal or submaximal testing?

2 So that participants are clear on the intended outcome. This may help to alleviate some of the stress associated with fitness testing.

3 It is vital to establish the fitness components, energy systems and muscle groups used in an activity before testing so that testing can be more specific to the demands of the activity.

4 It would be more reliable for a 50-metre sprint test. Any error caused by hand-held timing such as the reaction time of starting the timing will be a smaller percentage of the total time in the 50-metre sprint test.

5 Negative consequences of fitness testing include:

- » risk of injury
- » psychological trauma caused by results
- » reinforcement of low self-efficacy for participants achieving 'poor' results.

6 Purposes of fitness testing include:

- » determining fitness component strengths and weaknesses to better tailor a training program
- » Establishing a baseline to determine the effectiveness of a training program via pre- and post-testing.

In addition:

- » A participant may be more conscientious about completing a training program if they know post-testing will occur.
- » Test results could be used to help establish team positions.
- » Future potential of participants can be established.
- » Testing can help to establish potential health risks such as cardiovascular disease.
- » Test results can be used as part of employment selection criteria such as for the Victoria Police.

Chapter check-up p. 247

1 Potential risks include:

- » episodes of transient light-headedness
- » fainting
- » abnormal blood pressure
- » chest discomfort
- » nausea.

2 Because they would consider that the benefits of testing outweigh any potential risks.

3 To ensure that they have had time to understand all the information that is conveyed to them, and have been allowed sufficient time and opportunity to clarify anything that they are unsure of.

4 If the informed consent flow chart is not followed then a sporting club risks:

- » players being injured as they may not fully understand the test they are about to perform and cannot therefore withdraw from the test for medical or other reasons
- » players may not perform to the best of their abilities, as they may not fully comprehend the aim of the test and therefore may not see the value in performing the test
- » being negligent in their duty of care and suffering financial loss if a performer becomes injured during testing.

Chapter check-up p. 248

1 **Validity** refers to whether a test is measuring what it claims to be testing. **Reliability** refers to the test producing repeatable results under the same testing conditions.

2 Considerations (not in order):

- » Tests should be conducted at the same time of day.
- » The same warm-up should be conducted before the test.
- » Testing should be completed in the same order; this should include prioritising ATP–PC-dominated tests, such as the vertical jump test, to minimise fatigue.

- » Environmental conditions such as temperature, humidity, indoors or outdoors, etc. should be similar whenever possible.
- » Nutrition and hydration levels should be similar; these should be part of a performer's daily routine.
- » The performer should be well-rested prior to testing.
- » The same equipment, clothing and footwear should be used.
- » The same test should be used for the specific fitness component.
- » The performer's health status should be unchanged.
- » The performer's activity levels prior to testing should be similar, if not the same.

3 The aim of this question is to engage reasoning and debate to justify your choice. As long as your justification is sound, the answer will be acceptable. However, it would be easier to justify the value of completing the tests in the same order, commencing with those reliant on the ATP–PC system in order to avoid fatigue.

4 The goal of any testing regime is to ensure specificity. The Harvard step test is not specific to any mainstream sport. Accuracy is another important consideration. The Harvard step test does not have a high correlation compared to other field tests such as the 20-metre shuttle run test. The Harvard step test may also prove difficult to administer to a large group, given the requirement for each person to have access to a step of a given height. Compare this to other field tests of aerobic capacity, such as the 20-metre SRT or the Cooper's 12-minute run, which may prove easier to administer.

Chapter check-up p. 251

1

TEST	LABORATORY/ FIELD	MAXIMAL/ SUBMAXIMAL	DIRECT/ INDIRECT
VO_2 rowing ergometer	Laboratory	Maximal	Direct
20-metre shuttle run	Field	Maximal	Indirect
Cooper's 12-minute run	Field	Maximal	Indirect
1.6-kilometre run	Field	Maximal	Indirect
PWC_{130}	Field	Submaximal	Indirect
Yo-Yo intermittent recovery test	Field	Maximal	Indirect

2 For someone recovering from a serious health condition.

3 **Norm-referenced** results are based on the results from a given group. Performers then compare their test results to this group to see how they measure up. **Criterion-referenced** results are based on a predetermined target that is considered desirable. An example is waist circumference, where it is desirable for men to have a measurement under 94 centimetres, and women under 80 centimetres.

4 It is always important to ensure that the reference group is similar to the performer undertaking the test. For example, it would be inappropriate to compare a 12-year-old girl's vertical jump result to that of an elite adult female athlete.

Laboratory activity p. 261

1

ATHLETE	BEST POSSIBLE SCORE	TOTAL SCORE	TOTAL DECREMENT	PERCENTAGE DECREMENT
2	7 × 8 = 56	40	56 – 40 = 16	16/56 × 100 = 28.5%
3	6 × 8 = 48	38	48 – 38 = 10	10/48 × 100 = 21%

2 Both athletes rated average according to the ratings on page 261. Athlete 3's decrement is lower than Athlete 2's, suggesting that Athlete 3 has performed better on the raw data.

CHAPTER REVIEW P. 283

Multiple-choice questions

1 C

2 C

3 C

Short-answer questions

4 a–d Student choice of sport – so answers will vary.

5 a Aerobic capacity

b The 20-metre shuttle run test may be preferred when an easy-to-administer test that is both valid and accurate is required to assess aerobic capacity. It also has an inbuilt warm-up. The Yo-Yo Intermittent Recovery test may be chosen when a field test that more closely resembles the intermittent demands of sport (such as soccer) is required. Note: the Yo-Yo Intermittent Recovery test is popular in Europe and the UK.

c It may be appropriate to conduct a pre-activity screening followed by the informed consent process. The main concern would be to ensure the sedentary person is not placed in a situation that may place their health at risk.

CHAPTER 11 continued

d Towards the end of both tests the anaerobic systems, particularly the LA system, would increase their contribution. This is particularly obvious in the 20-metre shuttle run test; as the intensity increases through the levels, and particularly when the performer reaches an intensity above their LIP, there will be a greater contribution from the LA system, leading to the formation of fatiguing by-products such as H^+ ions leading to fatigue.

6 Normative data is derived from the collection of data. There has been a void in data collection for both the 10-metre and 20-metre sprint tests. Another factor is the reliability and accuracy of data collected. Most schools and sporting clubs use hand-held timing devices, so the accuracy of any data collected would be questionable, deterring people from establishing norms based on this type of data.

7 a Initially, sufficient data would need to be collected to establish a distribution curve. This may take several seasons, and would depend on the size of the team being tested. It would also be important to ensure that the people in the group being tested are approximately the same age, gender, etc.

b Without norms the test could still be very useful as a pre- and post-test comparison to establish whether the implemented fitness program is effective.

c The establishment of an alternative agility test would be based on specificity. It would be the opinion of the fitness advisor that the Illinois agility test is not specific enough to the demands of the sport in question. The fitness advisor has designed an agility test that more closely resembles the demands of the specific sport.

8 a Informed consent is the agreement of the performer to continue with the test after being made aware of its potential risks and benefits. This also includes the assurance of confidentiality.

b The process of informed consent involves:

- explanation of the test
- explanation of the potential risks, including time for the performer to ask questions
- explanation of the testing benefits, including time for questions
- assurance of confidentiality, including time for questions
- signature of the performer.

c Informed consent is important to protect the interests of both the performer and the testing organisation. From the performer's point of view, it involves them being made aware of the potential risks and benefits associated with the testing procedure. From the testing organisation's point of view, it is important for two reasons. First, there is an ethical obligation to ensure that the performer is fully aware of the risks and benefits of the test they are about to perform. Second, there is a duty of care owed to the performer.

CHAPTER 12: TRAINING PROGRAM PRINCIPLES

Chapter check-up p. 290

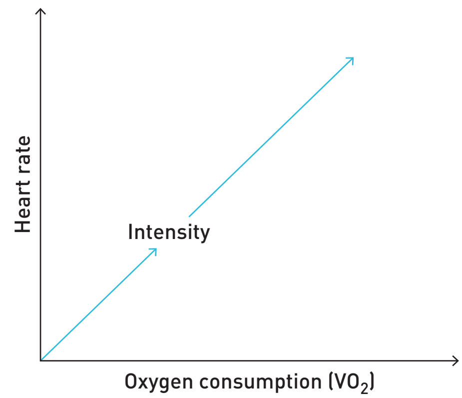
1 Two training sessions per week to maintain a fitness component; three or more training sessions per week to improve a fitness component.

2 Intensity can be measured via:

- percentage of maximum heart rate
- percentage of VO_2 max
- rate of perceived exertion
- accelerometers
- GPS tracking.

3 The delay, or lag, in registering heart rate, which makes it impractical for short or intermediate interval work.

4



Chapter check-up p. 294

1 Generally there is an inverse relationship between intensity and the length of a training session: the higher the intensity, the shorter the length of the training session.

2 Continuous, long-interval, fartlek, HIIT and circuit.

3 Unloading counters the effects of cumulative fatigue, which may hinder adaptations and lead to overtraining.

4 **Unloading** is the regular scheduled reduction in training volume in a training program. **Tapering** is the reduction in volume of a training program before competition to ensure the performer is at their peak.

5 A training plateau may occur when the performer becomes accustomed to a training workload.

6 All carbohydrate (CHO) loading should be accompanied by tapering to maximise glycogen stores. However, not all tapering needs to be accompanied by carbohydrate loading; for instance, anaerobic-oriented events would not require it. Because CHO loading stores excess water, this weight could be detrimental to an anaerobic performer such as a 100-metre sprinter.

Chapter check-up p. 296

1 The tailoring of a training program to mimic the demands of an activity.

2 Specificity ensures that chronic adaptations specific to the activity/sport are maximised.

3 Push-ups help to develop the pectoral, deltoid and triceps muscles. An example of push-up specificity to a sport would be in Australian Rules football tackling or a chest pass in netball.

Chapter check-up p. 297

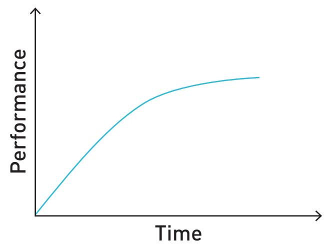
1 Reasons include that:

» performers are likely to have differing genetic dispositions such as percentage of slow- and fast-twitch fibers

» performers may have started the training program with differing fitness levels

» one performer may be closer to their genetic potential and therefore will have a slower rate of improvement.

2



3 Tailoring an off-season training program for an individual allows the program to focus on specific goals for that performer, such as improving on weaknesses. Tailoring allows injury, or post-season surgery, to be considered.

Chapter check-up p. 301

1 Alternatives could be training two sessions per week. Variety could also be introduced, such as bike riding instead of running.

2

BENEFITS	PROBLEMS
Mentally reinvigorates the performer	May compromise muscle group specificity
Improved performance through a different training stimulus	May compromise energy system specificity
Changing venue still maintains the integrity of the program	May compromise fitness component specificity

CHAPTER REVIEW P. 383

Multiple-choice questions

1 A

2 C

3 B

Short-answer questions

4 a James is overtraining and may end up injured.

b

	TUESDAY, THURSDAY, SATURDAY
Week 1	20-minute continuous jog with HR 135–140 bpm
Weeks 2, 3	20-minute continuous jog with HR 145–150 bpm
Weeks 4, 5	22-minute continuous jog with HR 145–150 bpm
Week 6	24-minute continuous jog with HR 145–150 bpm

c Depending on the program suggested in the previous answer, adding variety should help with staleness. This could include either a change of venue or a change of training method.

d James should definitively taper to ensure he is at his peak for the event. Tapering includes reducing the volume, but not intensity, of his training in the one to two weeks before the event. As James expects to complete the event in under an hour, there is no need to carbohydrate load; in fact this would add weight via water retention and slow him down.

5 a Variety can complement a training program when the goal of the program is not compromised. An example is changing the venue.

b When variety changes the goal of the training program, this may compromise the program goal. For example, a coach may introduce a different activity that compromises specificity.

c Variety may be used to freshen a performer mentally, to motivate them for future training sessions.

CHAPTER 13: FITNESS TRAINING METHODS

Chapter check-up p. 314

1 Developing aerobic capacity; lower injury risk; a foundation for more demanding aerobic training (e.g. interval, fartlek).

2 Benefits:

» Higher intensities can be maintained for the work phase of the program.

» Pacing can be developed.

» Specific energy systems can be targeted.

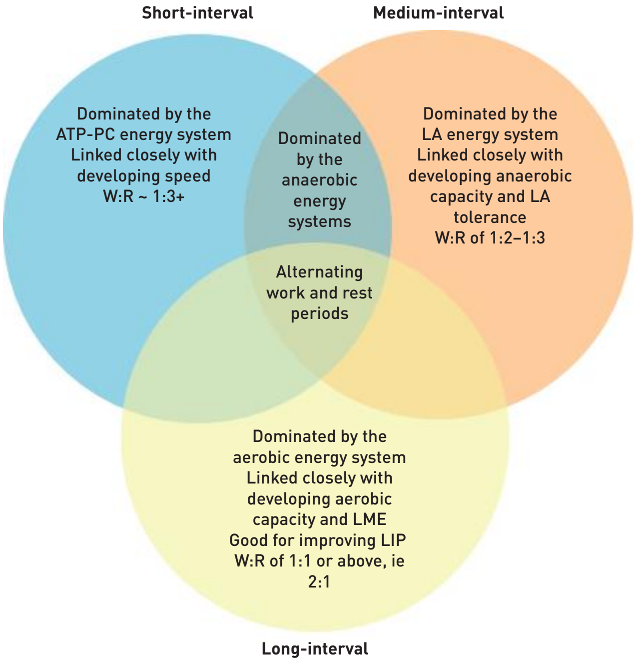
» Lactate tolerance can be developed with medium-interval training.

» Interval sessions can mimic the work-to-rest ratios of a game.

» Sessions are highly structured, so progress can be measured.

CHAPTER 13 continued

3



4 The simplest method of overloading fartlek is to add time to the total training session. Difficulties arise when overload is applied through increasing intensity. Given that fartlek is random, it may prove difficult to overload random bursts of speed in a structured manner to ensure the correct application of overload. Hill training is often used as a method of fartlek training, using the hills to provide the change in intensity. Again, it may prove difficult to find a suitable course that enables the appropriate addition of hills while maintaining the correct principles of overload.

Chapter check-up p. 322

1 Any time there is a rapid eccentric muscle contraction (e.g. bending quickly at the hips and knees before jumping), the stretch reflex initiates a rapid concentric muscle contraction as a protective mechanism.

2 Benefits include:

- » increases strength; allows for an increase in force production
- » can assist in enhancing speed and power
- » promotes weight loss and balance
- » improves body composition
- » helps prevent osteoporosis
- » improves psychological wellbeing
- » improves dynamic stability.

3 Plyometrics training utilises maximal intensity and so poses a greater potential for injury.

4 Risk-management strategies include:

- » Engage in a strength development program before commencing plyometrics.
- » Begin with a lower volume of exercises.
- » Start with less demanding exercises.
- » Ensure an adequate warm-up.
- » Ensure appropriate footwear and exercise surface.

CHAPTER REVIEW P. 324

Multiple-choice questions

1 B

2 A

3 C

Short-answer questions

4 70–85% of maximum heart rate or 60–75% of VO_2 max.

5 There is usually an element of repeated sprinting in team sports. Improving lactate tolerance will enable a performer to use their anaerobic glycolysis energy system for longer, enabling them to sprint faster.

6 A 'floating' recovery can be used in either long- or medium-interval training. At the end of a repetition, the participant slowly jogs (or cycles etc.) during the recovery period. This acts as an active recovery.

7 Both are aerobic training methods. Both are performed without rest. In continuous training, the participant usually maintains a relatively stable intensity in the aerobic training zone. In fartlek, the participant introduces random bursts of speed, which helps develop both speed and anaerobic capacity.

8

	EXAMPLE	GOAL	W:R RATIO	RECOVERY
Short-interval	9 x 60 metres in 10 seconds	Speed	1:5	50 seconds
Medium interval	5 x 400 metres in 60 seconds	Lactate tolerance	1:2	2 minutes
Long-interval	3 x 1 km in 4 minutes per rep	Aerobic capacity	1:1	4 minutes

9 a Upper-body plyometric exercises include clap push-ups and slamming a medicine ball into the ground.

Lower-body plyometric exercises include depth jumps, box jumps and bounding.

b Plyometrics training can enhance power and speed through improved neural adaptations.

CHAPTER 14: TRAINING PROGRAM DESIGN

Chapter check-up p. 328

1 Step 1: Conduct an activity analysis. This will help a performer and/or coach prioritise the training required, underpinned by the principle of specificity.

Step 2: Fitness testing. Once you have completed the activity analysis and analysed the data, you can assess your own fitness levels relevant to the game or activity.

Step 3: Determine which training methods you will employ. Training methods should be specifically tailored to the individual needs of the performer.

CHAPTER 14 continued

2 A training program is only as successful as the individual's ability to commit to it. For most, training time is limited, so the key is to maximise each session by making them as specific and relevant as possible. For some, time constraints may mean a training program is overly ambitious. This is where a periodised training program and timeline is crucial – this will give the performer a clear vision of the commitments and direction of training into the future.

3 Pre-training screening or questionnaires can identify any predisposition to injury or illness, preventing the loss of training time due to non-participation. A typical pre-training screening should encompass both medical and physical screening. (See chapter 13 for more detail).

Chapter check-up p. 335

1 Stage 1: The first stage of the warm-up should be graduated. See page 329 for more detail.

Stage 2: After the initial stage of the warm-up, it is important to transition seamlessly to the second stage: more specific movement-based activities at a gradually increased intensity. See page 329 for more detail.

2 Dynamic stretching can be introduced into stage 2 of the warm-up, further preparing the muscles, tendons and joints for the work that is to follow. See page 329 for more detail.

3 Resistance bands can be used for a stretch that challenges most major muscle groups. See above for more detail.

4 Using a foam roller increases blood flow; maximises effectiveness of stretching; eliminates painful trigger points in soft tissues; increases oxygen to muscles and accelerates removal of waste products after exercise.

5 The flow diagram should include the following components:

» the warm-up, including two clear stages
» the conditioning phase
» the cool-down.

6 A netball player could pass a ball, weave and then jump to catch a ball, land, and then cut and accelerate to pick up a ground ball. A high jumper could undertake some low-intensity bounds before building intensity and increasing the height jumped in preparation for the actual high jump event.

7 A cool-down aims to return the body to pre-exercise levels and, reverse the effects of fatigue, removing waste products. It also helps reduce the effects of delayed onset muscle soreness (DOMS).

Chapter check-up p. 339

1 Periodisation is the systematic planning of physical training. Based on scientific principles and methodologies, periodisation represents the best method of conditioning.

2 So that progress can be monitored. Physiological, psychological and sociological data gathered can be analysed, providing us with trend data. See pages 336–338 for more detail.

3 Possible methods include training diaries, digital activity trackers and apps. Mobile apps provide an easy and accessible way to record and analyse movement statistics in real time. See more detail on pages 337–338.

CHAPTER REVIEW P. 341

Multiple-choice questions

1 A

2 C

3 B

4 D

Short-answer questions

5 To improve a person's physiological capacity, and to facilitate chronic adaptations in the relevant fitness components, energy systems and muscle groups.

6 In order to ensure the most appropriate training methods are applied, an activity analysis must first be conducted.

7 Through undertaking an activity analysis, which should be as specific as possible. See Chapter 10 for more detail.

8 Fitness testing is the second step in the overall training program design. Fitness testing will identify strengths and weaknesses. The performer and/or coach can then strategically focus training on these areas.

9 The conditioning, or sports-specific, phase is the main part of an exercise training session. This is where the individual specifically targets the physiological requirements that have been identified as weaknesses, as well as maintaining those identified as strengths.

10 Record keeping allows you to:

» monitor your general performance and training load
» evaluate and adjust training loads where necessary
» review microcycles and macrocycles.

Recording training sessions ensures that we are not overtraining and running the risk of becoming injured, overtired or susceptible to illness.

CHAPTER 15: CHRONIC ADAPTATIONS TO TRAINING

Chapter check-up p. 351

1 An increase in left ventricle volume allows for increased stroke volume, which in turn increases cardiac output during maximal exercise intensity. At rest and during submaximal exercise the increased stroke volume and decreased heart rate result in no change to the cardiac output.

2 » Increased heart mass and volume, specifically left ventricle size/capacity
» Decreased resting heart rate
» Increased stroke volume

   » Increased cardiac output at maximal exercise levels
   » Increased capillarisation
   » Increased blood flow to working muscles
   » Decreased LDLs and increased HDLs
   » Increased haemoglobin
   » Increased blood volume
   » Decreased blood pressure

3 Increases in blood volume – this leads to increased oxygen-carrying capacity of the blood, which increases the amount of energy that can be derived from aerobic respiration.

4 When the heart and blood vessels increase their efficiency, less energy is needed to pump the blood around the body, so more is available at the working muscles for aerobic respiration.

5 LIP is increased with aerobic training because of the increase in oxygen availability. There is less reliance on the anaerobic systems to produce energy and more oxygen is then available for aerobic respiration. Oxygen is also available to break down the lactate that is produced so that the athlete can work at a higher intensity for longer before the lactate begins to accumulate.

Chapter check-up p. 353

1 Diffusion is the movement of a gas from an area of high concentration to one of low concentration. It occurs in both the lungs and the muscle. Diffusion occurs because oxygen levels are high in the lungs and carbon dioxide levels increase in the muscle and need to move to an area of low concentration.

2 Refer to page 352 of the text.

3 At submaximal workloads, VO_2 is lower in trained athletes because their cardiorespiratory systems are more efficient, meaning they don't need as much oxygen to meet the demands of the exercise.

4 Oxygen consumption is the product of stroke volume (SV), heart rate (HR) and arteriovenous difference (a-vO_2 diff).

   At submaximal intensities, HR decreases, SV increases and a-vO_2 diff increases. As a result, oxygen consumption at sub-max levels is lower for a trained individual because the cardiorespiratory systems are more efficient in delivering the required oxygen.

   At maximal levels, HR increases, SV plateaus and a-vO_2 diff increases resulting in an increase in oxygen consumption to meet the oxygen requirements of the exercise.

Chapter check-up p. 357

1 Mitochondria are the site of aerobic energy production in the muscle. Aerobic training causes an increase in size, number and surface area of the mitochondria.

2 Glycogen sparing allows athletes to conserve glycogen stores by increased utilisation of fats during submaximal exercise. When more oxygen is available, fats can be oxidised for energy in preference to glycogen. This allows the athlete to conserve glycogen for later in the event when they may need to surge/ sprint and require a fuel source that can be broken down without oxygen.

3 a-vO_2 diff can be considered both a cardiovascular and muscular adaptation because the volume of oxygen is measured in the blood vessels (the difference between oxygen in the arteries and veins) but is a result of the ability of the muscles to extract oxygen.

4 Oxygen is breathed in via the lungs, where it is diffused across the alveolar–capillary interface to enter the bloodstream. Haemoglobin carries the oxygen to the working muscles via the arteries, and diffusion occurs across the capillary–tissue interface so that oxygen can enter the muscle. Myoglobin carries the oxygen while in the muscle and delivers it to the mitochondria, where it is used in aerobic respiration to produce the ATP required for the activity.

Chapter check-up p. 363

1 Increased ATP and PC stores allow a greater percentage of the required energy to be derived from the ATP-PC system, which produces energy at a very fast rate. The athlete can then produce more powerful muscular contractions, allowing them to jump further.

2 The breakdown of ATP is the process by which energy is released. The resynthesis process is where ADP joins with P_i to make ATP. The increase in glycolytic enzymes allows for an increase in the rate at which glycogen can be broken down into ATP – increased rate of ATP production. The increase in ATPase speeds up the process of ATP breakdown and resynthesis, so the release of energy is more rapid.

3 » Neural factors – increased recruitment patterns, activation of CNS and excitement of motor neurons
   » Nutritional factors: protein intake affects growth and repair of muscle.
   » Hormonal factors: males have greater testosterone, resulting in greater muscle mass and therefore strength.
   » Physical activity: training increases the number and size of the muscle fibres, the contractile proteins and the size and strength of the connective tissue, resulting in strength gains.
   » Genetic factors: the proportion of slow- and fast-twitch fibres in the muscle affect strength (the more FT fibres, the greater the strength).
   » Environmental factors: physical and social environmental factors (opportunities for weight-bearing activities, social support, occupational tasks, etc.) affect strength development.

4 Neural adaptations occur before changes to muscle size (see page 361). The factors affecting increases due to neural adaptations are: increased recruitment of motor units, increased recruitment of fast-twitch fibres, increased firing rate of motor units and the increased coordination and synchronisation of motor unit firing rates.

5 Hypertrophy accounts for some increases in strength, as cross-sectional area is directly related to strength (see page 361). However, neural adaptations account for the initial increases in strength seen as a response to resistance training.

CHAPTER REVIEW P. 365

Multiple-choice questions

1 B

2 B

Short-answer questions

3 Fast-twitch fibres increase in size and number, have increased contractile proteins and have an increased size and strength of the connective tissue. These three changes lead to an overall increase in the size of the fibre, which is directly associated with increased strength (see graph on page 362).

4 Any three of:

- increased left ventricle size
- decreased resting heart rate
- increased stroke volume
- increased capillarisation
- increased blood volume
- increased lung volumes
- increased diffusion
- increased ventilation
- increased ventilator efficiency
- increased myoglobin
- increased mitochondria
- increased fuel stores
- increased a-vO_2 difference.

(See pages 344–357 for specific role of each adaptation in increasing aerobic capacity.)

5 An increase in mitochondrial density results in greater size and number of sites for aerobic production of ATP. This results in an athlete being able to produce more ATP aerobically and work at higher intensities aerobically before having to rely on an increased contribution from the anaerobic systems to meet the energy needs of the activity.

6 Aerobic-based training results in an increase in left ventricle volume while anaerobic training results in an increase in the left ventricular wall's thickness.

Extended-response question

7 Due to a decrease in anaerobic energy production and/or an increase in the body's ability to break down and remove the lactate that has been produced.

CHAPTER 16: PSYCHOLOGICAL STRATEGIES TO ENHANCE PERFORMANCE AND RECOVERY

Chapter check-up p. 370

1 Factors that come from within the individual, such as being satisfied with one's performance, e.g. shooting the ball in the basket, or simply enjoying the competition.

2 Extrinsic motivation refers to factors external to the athlete, such as prize money, certificates, chocolate frogs, progress charts and trophies.

3 To reach a professional level in any sport would require an enormous psychological commitment from the person. This sort of athlete would be more likely to be motivated by mostly intrinsic factors. Extrinsic factors are difficult to control. Some professionals have won thousands of dollars in prize money and although that would be rewarding, many athletes comment that they do not play to win money.

4 This is a personal reflection for each student. Answers should refer to the following:

Positive motivation: where reinforcing events have taken place after the individual has displayed desired behaviour. For example, positive acknowledgement of good play ('that's terrific', 'well done'), badges, jellybeans, performance information, positive feedback.

Negative motivation: where punishing consequences are imposed after undesirable behaviour. For example, making the athlete perform extra sit-ups or star jumps for an incorrect move during training; disapproving comments or rebuke; demotion in grade.

Chapter check-up p. 374

1 Goal setting improves performance by:

- focusing attention on important elements of the skill/s being performed
- activating and organising an athlete's efforts
- encouraging athlete perseverance
- promoting the development of new learning strategies
- refining movements and set plays
- contributing towards a positive psychological state.

2 The performer has direct control over process goals, whereas outcome goals are commonly linked to the performance of others (opponents, teammates, etc.). Process goals also assist promoting self-efficacy and self-confidence.

3 A basketball player may focus on improving their shooting action from the court and free-throw line. This might involve working to improve their own technique (bending knees, extending elbow, etc.) or shooting when clear as a result of a screen from a teammate that has been rehearsed during training. As a result of improved performance, the player reaches their outcome goal of being selected to represent the school in the A-Team.

CHAPTER 16 continued

4 SMARTER plan for netball:

S To shoot goals from 1–2 m away from the goal ring
M 20 shots at goal from 1 m; 20 shots at goal from 2 m
A Realistic and accepted
R 1 m = 80% success rate; 2 m = 75% success rate
T Within 6 weeks
E The 2 m shots will be challenging/exciting
R Performance records kept in training diary

5 As skills are mastered during training, a child's attention should shift to game plays and strategies and linked to this should be the mastery of psychological skills. When all of these are practised, hopefully under game-simulated conditions, and the child experiences success, it is likely that the child's confidence levels will rise.

Chapter check-up p. 381

1 'In the zone' is an expression used by sportspeople who experience optimal arousal and who are performing 'automatically' or instinctively. Characteristics include calmness, confidence, focus, freedom from inhibitions, and relaxation. Optimal performance is highly likely.

2 Teams are made up of individuals who might have shared goals but be at very different and individualised arousal levels. Some team members may be anxious about playing in a final; others might be overawed by the large crowd; some may have had sleepless nights and be under-aroused pre-match. It is imperative that each individual is offered advice and mental preparation according to their specific state and needs.

3 Progressive muscle relaxation involves progressively tightening/contracting and then relaxing major muscles (usually ordered from head to toe). Muscles are held 'tight' for 4–5 seconds and then slowly relaxed. This benefits performance because it has been associated with improved player focus and increased release of muscle tension. Both of these allow players to move with greater confidence and fluidity.

4 Advantages and disadvantages of biofeedback:

ADVANTAGES	DISADVANTAGES
Makes performers more aware of their own body/performance	Requires use of expensive recording equipment and trained specialists
Allows players to synchronise mental and physical performances	Large practice time required to be able to modify autonomous body functions
Improves ability to reach optimal arousal	Often only effective in 'closed' performance situations

5 As with any training, it is important to keep a record of all sessions. When monitoring a performer's progress, this record can then be referred to and adjustments made.

With PST, it is important that improved performance is linked to the PST undertaken, the performer's state of mind, arousal, and any other relevant factors.

6 Stress inoculation training aims to place a performer in situations where they are exposed to manageable stress. This might initially be imagined scenarios or situations they are likely to face when competing. They are taught effective coping strategies such as positive self-talk and relaxation techniques, and as they succeed in coping with the stress, they are taken through increasing levels until eventually they perform 'the real thing'.

7 Answers will vary. Examples are:

'I can do it'
'I'm going to succeed'
'This is my time'
'Keep going'
'It's OK'

8 Answers will vary. Examples are:

» Energising music elevates heart rate, brings positive images to mind, makes people want to go out and 'perform', makes people feel 'pumped' or 'psyched' and ready to go.
» Calming music slows heart rate and respiratory rate, allows inward reflection, creates a sense of 'slowing things down', and provides opportunities to relax and focus.

9 Answers will vary. Examples are:

» receiving a medal
» shooting the winning goal
» being lifted up by teammates
» spectators clapping
» coach congratulating you.

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1 Engaging as many senses as possible assists the athlete to imagine the performance in more detail to enhance success. For example, a baseball player might imagine how the bat feels in their hands (kinaesthetic), how the ball spins (visual), how their hands feel gripping the bat as they prepare to bat, etc.

2 Basketball examples:

» Feel the ball in your hand when imagining the grip.
» See yourself extend your arm and flick your wrist.
» Imagine the sound of the ball when it swishes through the net.

Tennis examples:

» Imagine the feel of scratching your back with the racquet head during the backswing of the serve.
» See the ball toss.
» Imagine the sound of a firm snap as the ball hits the strings.
» Feel your body reaching up to connect with the ball as high as possible.

3 It allows the athlete to prepare and rehearse a series of movements and strategies in response to specific scenarios. When these situations crop up during competition the athlete is less likely to panic and make an error.

4 Mental rehearsal usually simply involves imagining a successful performance under specific conditions. Simulation involves setting up very similar conditions to competition contexts: e.g. playing the noise of a large crowd while completing imagery during practice. VMBR includes three stages: getting yourself within an optimal zone, then visualising the successful performance, then performing the skill under game-like or simulated conditions (which combines imagery and simulation).

5 Simulation and VMBR are more complex. When athletes are confident at using imagery they can start to build in layers of distractions within scenarios of what could happen during game situations.

6 Imagery allows athletes to rehearse a range of skills and strategies and movements that need to be employed to perform successfully. It takes the pressure off athletes when these scenarios arise in the game because they can instinctively react rather than having to respond to a situation that is unfamiliar.

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Multiple-choice questions

1 A

2 C

Short-answer questions

3 a Answers will vary.

b Example: Basketball

» Broad internal = Focusing on own skill at free throw line

» Broad external = Keeping an eye on an opponent on the court

» Narrow internal = Sitting on the bench and picturing yourself 'faking' a move to open up a lay-up

» Narrow external = Watching the ball through the air as it is passed (unopposed) by a teammate

The focus shifts from internal to external depending on the level of 'closed' or 'open' surroundings in which players find themselves. Internal focus occurs when the player is unopposed and moving down-court, while opposition has set up a zone defence. External focus shifts when the player needs to respond to changing factors on the court.

4 a Choking often occurs when players are under pressure and their attention focus decreases and shifts to internal and narrow. This often leads to poor timing, bad decision-making, negative thoughts and self-talk and decreased selective attention.

b Many examples exist, and most usually occur when competition is close. For example:

» batsmen on the 'nervous nineties'
» golfers putting during a play-off
» tennis players in a tie-breaker during the fifth set
» football players kicking for goal after the siren.

c Strategies to avoid choking include:

» improving concentration/focus
» use of cue words
» performing set routines
» 'overlearning' skills/repeated practice
» rehearsed simulations
» focusing on positive aspects of performance
» positive self-talk
» relaxation techniques/practice

5 Future-oriented thinking can be detrimental to performers if they allow it to cause self-doubt and if it results in decreased confidence levels. Examples include:

» 'If I don't score this goal my team will be relegated and my mates will hate me.'
» 'If I serve a double fault now, she will break my serve and then she will be serving for the match.'

Sometimes future-oriented thinking can lead to over-confidence and decreased performance as well! For example:

» 'If we keep playing like this we are going to wipe the court with them.'
» 'We are three goals up – all we need to do is keep defending and we'll get into the final.'

This often sees players become complacent and stray from their game plan and sometimes provides opponents with an opportunity to get back into the game and sometimes win!

6 a Cue words:

» follow through on the backhand (tennis)
» front foot forward and bat close to pad (cricket)
» keep your eyes on the ball (table tennis)
» stay close to the line (athletics)
» kick off the wall (swimming)
» keep knees together (diving/gymnastics)

Positive self-talk:

» I've done this successfully a million times before
» keep pedalling hard all the way to the line
» stay calm
» I'm doing my best

b Cue words and positive self-talk both remind performers to keep to a rehearsed game plan/routine as well as allowing them to maintain concentration and selective attention.

7 a Physiological training refers to training that improves a performer's functioning. This can also include training from a psychological perspective.

b Arousal and confidence are very similar – in fact, they both present the same 'inverted-U' graphs in terms of optimal performance. Lack of confidence can be linked to under-arousal and overconfidence leads to over-arousal.

c Sporting examples of overconfidence adversely affecting performance are:

- A 400-metre runner, believing herself to be far ahead of her next opponent, decreases her speed in the last 20–30 metres of a race, only to be overtaken by another runner!
- A football team underestimates the capacity of their opponents and are overconfident about winning a match. They forget to keep to agreed team values/plays and don't play with their usual competitive sense. Their opponents kick a match-winning lead in the first quarter!
- An overconfident gymnast tries to perform a skill that he has never done before during a competition. He almost completes the third rotation, but fails to hold onto the bar and falls!

8 a Game plans improve concentration and confidence only if they have been rehearsed and successfully completed. The more they are rehearsed with resultant success, the more likely the performer is to believe that this will be the case in the actual game/competition. It provides a setting where actions/skills become 'automatic' and easy to repeat successfully.

b Many examples of game plans exist from most sports. Students should demonstrate how a prepared routine is brought about in a game: e.g., playing most shots to an opponent's backhand because it is not as strong as her forehand; or knowing an opponent cannot kick as well with his left foot and deliberately forcing him to use that side of his body; or the way a 1500-metre athlete has decided to run a race.

9 a Answers will vary.

b Answers will vary.

c The response should relate to either arousal reduction or arousal promotion techniques, and should describe how the techniques may have affected your performance. **Arousal reduction** techniques include controlled breathing, progressive muscle relaxation, biofeedback and stress-inoculation training (SIT), listening to calming music and using routines. **Arousal promotion** techniques include rapid breathing, acting energetically and positively, positive talk, energising imagery, and participating in pre-game workouts or preparation.

d PST allows psychological skills to be practised and developed until they become an ingrained characteristic of the athlete's performance. Psychological skills have to be practised regularly to be continually developed and improved.

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