TOPIC 5
How does training affect performance?

OVERVIEW
5.1 Energy systems
5.2 Types of training and training methods
5.3 Principles of training
5.4 Physiological adaptations in response to training
5.5 Topic review

OUTCOMES
In this topic students will:
• explain the relationship between physiology and movement potential (H7)
• explain how a variety of training approaches and other interventions enhance performance and safety in physical activity (H8)
• design and implement training plans to improve performance (H10)
• devise methods of gathering, interpreting and communicating information about health and physical activity concepts (H16)
• select appropriate options and formulate strategies based on a critical analysis of the factors that affect performance and safe participation. (H17)
5.1 Energy systems

The human body requires a continuous supply of energy both to meet the needs of its systems and organs and to power muscular contraction for movement. However, unlike the car which carries its energy supply in a fuel tank, body energy is stored in the chemical bonds that join atoms and is released only as needed. This is a very efficient method of storing fuel because of its light weight and because it occupies only a small amount of space in the body. The fuel required by a runner to complete a marathon would weigh at least as much as the runner. Yet food weighing only a fraction of this is ingested prior to a race. The transformation of food (chemical energy) to energy that the muscles can use (mechanical energy) is the role of energy systems.

Energy provided by food is measured in kilojoules (kJ). Foods have different amounts of energy. Carbohydrate and protein supply 16 and 17 kilojoules of energy per gram respectively, whereas fat yields 38 kilojoules per gram. Hence, foods with relatively high levels of fat yield a larger number of kilojoules and, subsequently a lot more energy.

When food is digested, it breaks down to sugars, amino acids and fatty acids, substances that become available as a usable form of energy. From these, ATP or adenosine triphosphate is produced and represents the most important substance in energy production. ATP is a high energy compound that stores and transfers energy to body cells, allowing them to perform their specialised functions, such as muscle contraction. Large amounts of fuel in the form of carbohydrates (glucose or sugars), fats and protein (amino acids) lie in storage in the body, waiting to be used. ATP can be likened to a spark plug in an engine. It enables the release of energy from these substances where it can be used for muscular contraction and essential body processes such as digestion, blood circulation and tissue building. Some of these functions are illustrated in figure 5.2.

The ATP compound consists of a large molecule called adenosine (A) and three smaller molecules called phosphates (P). Each of the phosphates is held together by high energy bonds. The chemical structure of ATP is shown in figure 5.3.
When the last (terminal) phosphate is detached, energy stored in bonds between the phosphates becomes available and this is transferred to the cells. This process is like flicking on a light switch. The light will not work until the current flows and provides energy to light the globe. In the muscle cells, the energy from ATP allows the fibres to contract and make movement possible. This is represented in figure 5.4.

However, ATP now has only two phosphates attached. In this state it is referred to as ADP (adenosine diphosphate) and is powerless to provide energy. It is represented in figure 5.5.

Unlike food that has had the nutrition extracted for use by the cells, used ATP does not become a waste product that is discharged from the body. Rather, it has the ability to be quickly rebuilt or resynthesised, allowing us to continue to function while still using the limited amount we have. Resynthesis is the process of restoring ATP to its former state. Your body would struggle to carry all the ATP needed to supply energy for a day. In fact, it has been estimated that the body turns over ATP to the equivalent of 75 per cent of its weight during a 24-hour period (see figure 5.6) and much more if the person exercises intensely. Having energy stored in bonds and being available on demand is an extremely efficient way of packaging because it avoids the need to carry it around in bulk. It is similar to saving work onto a flash drive. As digital text, it is lighter and easier to transport than the printed, bulkier hard copy.

ATP needs to be continually rebuilt to enable an energy flow. Under normal conditions such as sitting, lying or reading, only sufficient ATP is produced to enable basic functions to be sustained. The body uses fats and glucose almost entirely as sources of fuel while at rest, sufficient ATP being produced through metabolism of these fuels using the third energy pathway or aerobic system (see figure 5.7). However, if intense physical demands such as cycling, swimming or running are placed on the body, the systems respond by producing much higher levels of ATP to ensure that our immediate energy needs are met.
The three systems that make ATP available are:

- the *alactacid* system (commonly called the ATP/PC system)
- the *lactic acid* system (glycolytic system)
- the *aerobic* system (oxygen system).

The alactacid and lactic acid systems are both called *anaerobic* pathways because they do not require oxygen for the resynthesis of ATP. Lactic acid is a by-product of the incomplete breakdown of carbohydrate in the absence of oxygen. However, the *aerobic* system is oxygen dependent; that is, ATP produced using this system relies on the availability of sufficient oxygen in the cells.

The systems are commonly called energy pathways because they each supply ATP but use different processes to do so. Each system has a way of resynthesising (rebuilding) the partly destroyed ATP molecule. How well each system resynthesises ATP determines its efficiency in energy production.

### 5.1.1 Alactacid system (ATP/PC)

As mentioned, residual supplies of ATP in the body are very limited. In fact, we have sufficient for only one explosive muscular contraction, for example, a standing long jump or sprint start lasting one to two seconds. An explosive movement causes the ATP molecule to ‘split’, providing energy for muscular contraction. Further muscular work relies on *creatine phosphate (CP)* breaking down to creatine and phosphate, and releasing energy in the process. CP is an energy-rich compound that serves as an alternative energy source for
muscular contraction. The energy is used to drive free phosphate back to ADP so it can once again become a triple phosphate. Once reformed, ATP can break down again — and so the process goes on. The problem, however, is that CP supplies are exhausted within 10–12 seconds and take two minutes to be restored. The sequence is shown in figure 5.9.

**FIGURE 5.9** The breakdown and resynthesis of adenosine triphosphate

Adenosine triphosphate consists of adenosine (A) and three phosphates (P).

The phosphates are held together by high energy bonds.

ATP ‘splitting’ occurs when the end phosphate is detached, providing energy for muscular contraction and heat.

Having lost a phosphate, ATP is now reduced to ADP (adenosine diphosphate).

Creatine phosphate (CP) consists of creatine and phosphate. It becomes available to help in the process of resynthesis — that is, reforming ATP which has been partly destroyed.

Like ATP, creatine and phosphate are also held together by high energy bonds.

The bond between creatine and phosphate breaks down, releasing energy.

The energy released drives the free phosphate (Pi) back to join ATP.

ATP is reconstituted — that is, brought back to its original form.

The terminal bond between the end phosphate breaks down, releasing energy and heat, and so the process continues until CP supplies are exhausted.

**Source of fuel**

We have about 90 grams (about the same weight as a large egg) of ATP in our body. This is sufficient to power the muscles required in one explosive movement such as a jump, start or throw. That equates to one to two seconds of hard work. Following that, we rely on the 120 grams of reserve fuel, CP, stored in our cells. Creatine phosphate, then, is the fuel of the ATP/PC system.
Efficiency of ATP production

The alactacid system functions to make ATP rapidly available. Moreover, this occurs whether or not oxygen is available. This rapid supply is enabled primarily by a concentration of CP within muscle cells that is approximately five times greater than that of ATP. However, the supply of ATP is very limited if the demand is high as a result of sustained, maximal or near maximal work. But the system is able to recover quickly. Hence, the importance of this system to short, explosive movements in activities such as weight-lifting, discus throwing and starts in athletics is paramount.

![Figure 5.10](image)

Duration of the system

In the alactacid system, ATP supplies are exhausted after two seconds of hard work and CP supplies are exhausted in a further 10 to 15 seconds. However, at rest, CP supplies are almost fully restored within two minutes.

Cause of fatigue

At maximal or near maximal effort, fatigue is caused by the inability of the system to continually resynthesise ADP from CP because CP supplies are quickly exhausted. This is why we are unable to run at maximal effort for distances longer than 100 metres. It is particularly evident in an all-out sprint over 150 metres, where the winner will not be the athlete that accelerates most to the finish, but the one who slows down the least in the final metres of the race.

By-products of energy production

While there are no fatiguing by-products of this system, heat is produced during the process of muscular contraction.
Rate of recovery
The ATP/PC system recovers quickly from exercise. Within two minutes, most of the ATP and CP supplies have been fully restored, with 50 per cent of creatine phosphate replenishment occurring in the first 30 seconds of rest recovery. This is why high jumpers, weight lifters and discus throwers can ‘back up’ almost immediately after their first and second attempts.

SNAPSHOT
Creatine loading
Creatine is a rapidly available, energy-producing substance used by the body during high intensity activity. It is used to bind phosphate to form creatine phosphate, which is essential to regenerate ADP to ATP and provide energy for muscular contraction. As creatine is a natural substance and found in meat and fish, it is classified as a food supplement, not a pharmaceutical. As such, it has gained vogue among athletes keen to improve performances in strength, power and sprint events. It is a legal food supplement and was first used in the 1992 Olympics.

Most studies have found creatine to be effective in boosting performance when taken in conjunction with high carbohydrate diets. Creatine supplementation of 20 grams per day over five to seven days each week has been reported to improve sprint performances from one to five per cent and up to 15 per cent on repeated sprint type activities. Other studies report no performance-enhancing effect.

Most research on creatine is inconclusive, particularly where supplementation continues over a period of time. It appears to contribute to weight increases, elevated heart rate and dehydration, which causes cramping in hot, humid conditions. It has also been reported to contribute to stress fractures attributable to escalation in the strength of muscular contractions.

Inquiry
Creatine loading
Discuss the ethics of using a substance such as creatine to boost energy stores. Even if legal, could it represent a gateway to other performance-enhancing drugs that are illegal? Explain your viewpoint.

Application
Experiencing the alactacid system
Have three students run a 150 metre distance at full effort. Place markers indicating the start to the 75 metre distance (section 1) and the 75 metre mark to the finish (section 2). Time the runners for each of the sections.
How did the times compare over each of the sections? Using your knowledge about resynthesis of ATP, discuss reasons for the results with the class.

Inquiry
Identifying alactacid dependent activities
1. Identify a range of sports or activities where the ATP/PC system is the predominant energy system.
2. Suggest how use of an interchange/substitution rule in some team sports could improve player performance on the field.
5.1.2 Lactic acid system

Following 10–12 seconds of maximal exercise, CP supplies are exhausted. ATP still needs to be produced to provide energy, assuming that the activity requires effort for longer than this, such as in a 400 metre race. Sufficient oxygen is not available even though the breathing rate has increased because of effort. This is because it takes some time for the blood to move from the lungs around the body and then to the working muscles where oxygen is in high demand.

The body needs to find a different fuel because CP supplies are at a low level. It does this by using the immediate sugar supplies circulating in the blood (blood sugar), as well as our sugar storage supplies in the muscle and liver. We refer to our blood sugar as glucose. It circulates freely in the bloodstream and its level is constantly regulated by the pancreas. When we accumulate too much, the body stores the excess in the liver and muscle. Stored glucose is called glycogen.

The process of using glycogen or glucose as fuel is called glycolysis. Glycogen is much more abundant than CP and can be used whether oxygen is available or not. In the case of the lactic acid system, oxygen is still not available because it takes a couple of minutes for the blood to transport oxygen from the lungs to the working muscles. For this reason, the lactic acid system is anaerobic (meaning the reaction occurs without oxygen) and, because glycogen is the only fuel, the degradation process is called anaerobic glycolysis. As sufficient oxygen is not available during intense exercise, lactic acid levels rise and continue to rise as intensity increases.

Lactic acid is produced because insufficient oxygen results in the partial breakdown of glucose, providing quick but limited ATP production, as well as the by-product, lactic acid.

Source of fuels

The only fuel that can be used by the lactic acid system is carbohydrate. This exists in two forms:
- as glucose in the blood
- in the storage form called glycogen.

Glycogen is broken down, producing ATP and energy for muscular contraction. This is illustrated in figure 5.12.

Efficiency of ATP production

The lactic acid system provides ATP quickly, but this requires large quantities of glucose. In other words, ATP is rapidly available but at considerable cost. For example, three moles of ATP is the most that can be manufactured from the breakdown of 180 grams of glycogen during anaerobic glycolysis. A mole is the gram-molecular weight of a substance. 1 mole (mol) = 1000 millimoles (mmol).

Duration of the system

The duration (work span) of the system depends on the intensity of the activity. Whereas a near maximal effort causes exhaustion in 30 seconds, an effort of 70–80 per cent will not cause exhaustion for three to four minutes and much longer for moderate intensity activity. Generally speaking, the lactic acid system

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**FIGURE 5.12** The lactic acid system uses glycogen to produce energy.

[Diagram of glycogen breakdown into ATP]
produces energy for high intensity activities lasting from 10 seconds to one minute or more depending on the effort involved. It is the dominant system for all maximal activity performed between 30 seconds and two minutes — for example, 200 metre sprint, 400 metre running, 800 metre running, 200 metre freestyle and gymnastic routines.

**Cause of fatigue**

Fatigue occurs when lactic acid levels build up within the muscle cells. Although it was previously thought that lactic acid impeded performance, recent research suggests that it can be beneficial. Researchers have shown that fatigue is not caused directly by lactic acid but rather by its rate of removal, and this varies from one person to another.

Lactic acid is produced whenever the body uses carbohydrate as fuel, and this occurs most of the time. Even at rest, some lactic acid is produced because some carbohydrate is being metabolised, even though the body’s predominant fuel source is fat. The speed of lactic acid production depends on exercise intensity. The faster you work, the more rapidly lactic acid accumulates. Excessively high levels of lactic acid prevent the muscle fibres from contracting and result in a rapid deterioration in performance.

However, while high lactic acid levels cause fatigue, tolerable levels can, in fact, enhance performance, because lactate is a fuel source. Finding the balance between the levels comes with training, together with the individual’s awareness of the presence of lactic acid accumulation. Lactic acid tolerance improves with training, as do removal rates. Even though production rates may be high during intense exercise, high removal rates may ensure that performance is not affected.

What, then, is the relationship between lactic acid and fatigue? When lactic acid is formed, it immediately separates into the lactate ion (lactate) and a hydrogen ion (H$^+$). Each substance has a different effect on the body’s ability to perform. The hydrogen ion is the acid part of lactic acid and impairs performance. In contrast, the lactate ion is a fast fuel, and is actually preferred by the muscle, even over glucose, because of its easy removal from the blood. Lactate is readily processed in the mitochondria or ‘food factories’ in the muscle cells and, while most is converted to carbon dioxide and water (65 per cent), some is converted to fuel. From here it is transported to other tissues such as the heart and brain and is used for energy. In fact, about 20 per cent of the liver’s glycogen supplies are produced from lactic acid.

The cause of fatigue in this system is predominantly the accumulation of lactic acid in quantities faster than it can be removed. However, other factors, such as the demanding nature of muscular effort, also need to be considered. High levels of lactic acid in isolation may not be the cause of fatigue, as some well-trained athletes can tolerate high levels, providing the removal rate is equally high. For example, while the lactate threshold (the point at which lactic acid accumulates rapidly in the blood) for untrained people is around 4 mmol/L, trained athletes have been known to continue aerobic work with blood lactate levels above 20 mmol/L. Proper training positively affects the rate of removal of lactic acid from the body.

Elite athletes train with the intent of producing lactic acid by working above the lactic acid threshold for as long as they can sustain output. The response to this intense training is that the body produces enzymes that hasten the use of lactic acid as a fuel. The ability to use lactate as a fuel therefore varies from one athlete to another because of the trained characteristics of muscle fibres and, particularly in the case of endurance athletes, red muscle fibres.
Application
Sensing lactic acid accumulation
Organise a voluntary group or your class to follow a thorough warm-up with an all-out 400 metre run. Stop when you feel you are unable to run any harder or cannot increase your pace; that is, you are approaching your lactate threshold. Alternatively, use the Running weblink in your Resources tab to read a description of lactate threshold running. Write a brief description of how your body felt when you stopped. Refer to muscles, breathing rate, energy and willpower. Discuss your description with the class.

Rate of recovery
During the post-exercise period, lactic acid diffuses from the muscle and into the bloodstream where its use as a by-product is important. In the liver, lactic acid is reconverted to glycogen and can once again be used as a source of fuel (see figure 5.14). The process takes about 30 minutes to an hour. This further contributes to the body’s efficiency by resynthesising waste for use at a later stage.

FIGURE 5.14 Not only does the liver store glycogen, but also it is able to reconvert lactate back to glycogen to be once again used as fuel.

Inquiry
Identifying the lactic acid system
1. List three sports or activities in which the lactic acid system is the predominant energy system. Suggest strategies an athlete could use to help overcome the build-up of lactic acid in an 800 metre event.
2. Examine the program for the school athletics carnival. Evaluate the impact of lactic acid build-up in relation to recovery periods of athletes wishing to compete in all events.
5.1.3 Aerobic system

Physical activity lasting more than a few minutes requires the presence of oxygen to ensure the continuation of muscular contraction. Oxygen is not immediately abundant to the muscles when we begin exercise; rather, it gradually becomes available as the oxygen-rich blood fills the muscle cells. This allows the third energy pathway, called the aerobic pathway or oxidative system to become the predominant supplier of ATP. This process of fuel degradation is sometimes called aerobic metabolism because glucose and fat (and sometimes protein) are broken down in the presence of oxygen to produce ATP. Lactic acid does not accumulate during aerobic metabolism because oxygen is present. This is in contrast to anaerobic glycolysis.

Source of fuel

Whereas the lactic acid system can use only glucose as fuel, the aerobic system can use carbohydrate, fat and even protein (figure 5.15). During the early stages of endurance work, carbohydrate is the preferred fuel. However, if exercise continues beyond an hour or so, fat becomes increasingly important as a fuel and reigns as the dominant energy source if glycogen supplies become exhausted.

Efficiency of ATP production

The aerobic system is extremely efficient in the metabolism of fuel and provision of energy. Whereas the lactic acid system is able to generate only three moles of ATP from 180 grams of glycogen, the aerobic system is able to generate 39 moles of ATP from 180 grams of glycogen. In effect, it enables the production of much more energy from glycogen, enabling us to continue sustained work for longer periods of time.

Duration of the system

The total amount of glycogen in the body is approximately 350 grams. This is sufficient for 12 hours of rest or one hour of hard work. In intermittent exercise, such as football or netball, glycogen supplies last for approximately four to six hours. However, in the case of marathon runners, supplies could be exhausted in about two hours.
The body has virtually unlimited supplies of fat and this is used as a fuel source as glycogen supplies are depleted. In well-trained athletes, the body mixes carbohydrate and fat in endurance events. This process, called glycolysis, results in some fat fuel being used earlier so that glycogen can be available at a later stage, such as for a sprint finish. These fuels used jointly, yet sparingly, ensure that the body can operate using this system for long periods of time. The aerobic system is the predominant system for use during extended endurance events such as marathons and low demand activities such as walking, sitting and reading.

Cause of fatigue
Because the aerobic system is so versatile in fuel usage (remember it can use carbohydrate, fat and even protein to produce energy), it is not a lack of fuel but other factors that contribute to fatigue while this system predominates. During endurance work, slow-twitch muscle fibres will do most of the work. These fibres have many capillaries and a rich oxygen supply. Before a run, these fibres may be saturated with glucose. However, activity beyond an hour or so results in depletion of fuel and, although some is replaced from the liver, glycogen is exhausted. Glycogen is premium fuel for muscles. When it runs out, the body tires.

A second cause of fatigue is the exhaustion of carbohydrate and subsequent reliance on the secondary fuel, fat. Although fat is much higher in energy than carbohydrate, its use as a sole fuel can cause problems. The point at which the body changes its main fuel supply from glycogen to fat is called ‘hitting the wall’. Fatigue occurs because fat requires more oxygen for metabolism than does carbohydrate. This increases the runner’s body temperature and rate of respiration (breathing).

By-products of energy production
During aerobic activity, oxygen is required to burn the fuels in the body (carbohydrate and fat). As with most fuels that are burnt, by-products are produced, in this case, carbon dioxide and water. The carbon dioxide is breathed out through the process of respiration and the water is available to the cells. These by-products are not harmful to performance.

Rate of recovery
The recovery rate of the aerobic system depends on the duration of use. If used for a short period of time, the system recovers quickly because glycogen stores have not been depleted. However, if used for hours, glycogen storage areas could well be exhausted. In this case, it may take days to fully replenish glycogen reserves.

Inquiry
Fuelling the aerobic system
Identify a sport or activity in which the aerobic system is the predominant energy system. Discuss the strategies that could be used to ensure that the athlete has sufficient fuel for the duration of the activity.

Energy systems summary
The energy systems should not be thought of as individual metabolic units that operate independently of one another. Although the systems have been referred to individually, they actually function together (see figure 5.17). This gives rise to the term predominant energy system, or the system that is being most utilised at that point in time. This concept is further illustrated in figure 5.17, where, after 10 seconds, the ATP/PC system is contributing little to energy supply and by 30 seconds, the lactic acid system is in decline, although still assisting to some extent. The contribution of the aerobic system at this point is predominant and rising gradually.
FIGURE 5.17 Approximate relative contributions of the three energy systems to energy production at maximum sustainable exercise intensity of varying durations.

Application
Experiencing the energy systems
Perform a recognised field test of aerobic fitness such as the Coopers 12-minute run. You may use the Energy systems 2 weblink in the Resources tab to view the procedure. Try to be aware of changes in energy systems as you run.

Inquiry
Experiencing the energy systems
1. Briefly describe your feelings (muscles, breathing rate, fatigue) once your body changed to the aerobic system to supply energy.
2. Examine figure 5.18. Do you think the diagram illustrates the energy contribution from each system during your fitness run? How would the diagram alter if you walked the entire distance? Discuss your response with the class.

FIGURE 5.18 Relationship between running time and energy systems
Inquiry
Analysing the energy systems

Make an enlarged copy of the following table in your workbook. Analyse each energy system in terms of the points listed. Sources of information could include:

- this topic
- table 5.1 (see below)
- the Energy system web links in your Resources tab.

<table>
<thead>
<tr>
<th>Criteria for analysis</th>
<th>ATP/PC</th>
<th>Lactic acid</th>
<th>Aerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel source</td>
<td>Creatine phosphate</td>
<td>Carbohydrate</td>
<td>Carbohydrate</td>
</tr>
<tr>
<td>Efficiency of ATP production</td>
<td>less than 1</td>
<td>Glucose: approximately 2</td>
<td>Fat: more than 100</td>
</tr>
<tr>
<td>System duration</td>
<td>3.6</td>
<td>1.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Causes of fatigue</td>
<td>5–10 seconds</td>
<td>30–45 seconds</td>
<td>3–7 minutes</td>
</tr>
<tr>
<td>By-products</td>
<td>55 per cent</td>
<td>40 per cent</td>
<td>5 per cent</td>
</tr>
<tr>
<td>Process and rate of recovery</td>
<td>Depends on time above lactate threshold. Removal of lactic acid to rest levels:</td>
<td></td>
<td>- 50 per cent removal: 15 minutes</td>
</tr>
<tr>
<td></td>
<td>with active recovery:</td>
<td>- 95 per cent removal: 30 minutes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with passive recovery:</td>
<td>- 50 per cent removal: 30 minutes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 95 per cent removal: 60 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restoration of body glycogen stores:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- after competition of more than 1 hour: 24–48 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- after hard interval training: 6–24 hours</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Continued)
TABLE 5.1 Characteristics of the three energy systems (Continued)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ATP/PC</th>
<th>Lactic acid</th>
<th>Aerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Limiting factor when operating maximally</td>
<td>Depletion of creatine phosphate</td>
<td>Lactic acid accumulation in quantities faster than it can be removed.</td>
<td>Lactate and hydrogen-ion accumulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Depletion of glycogen stores</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Overheating (hyperthermia)</td>
</tr>
<tr>
<td>9. Intensity and duration of activity where the system is dominant ATP provider</td>
<td>Maximal intensity (&gt;95 per cent) and duration of 1–10 seconds</td>
<td>High, sub-maximal intensity (85–95 per cent) and duration of 10–30 seconds</td>
<td>Sub-maximal intensity (85 per cent) and duration of &gt;30 seconds</td>
</tr>
<tr>
<td>10. Specific sporting examples</td>
<td>• Any athletic field event</td>
<td>• 200–400 metre run</td>
<td>• Marathon</td>
</tr>
<tr>
<td></td>
<td>• Elite 100 metre athletic sprint</td>
<td>• 50 metre swim</td>
<td>• Cross-country skiing</td>
</tr>
<tr>
<td></td>
<td>• Golf drive</td>
<td>• Consecutive basketball fast breaks</td>
<td>• Triathlon</td>
</tr>
<tr>
<td></td>
<td>• Gymnastic vault</td>
<td>• High intensity 15–20 second squash rally</td>
<td>• AFL mid field</td>
</tr>
<tr>
<td></td>
<td>• Volleyball spike</td>
<td>• Elite netball centre in close game</td>
<td>• All elite team players</td>
</tr>
<tr>
<td></td>
<td>• Tennis serve</td>
<td></td>
<td>• 2000 metre rowing race</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water polo game</td>
</tr>
</tbody>
</table>

Resources:
- Weblink: Energy systems 2
- Weblink: Energy systems

studyon

Core 2 > Question 1 > Topic 1 > Concept 3

Aerobic system (Oxygen system) Summary screen and practice questions

5.2 Types of training and training methods

To prepare athletes adequately, training is essential. However, the type of training and methods used depends on the type of movements, skill requirements and specific demands of the activity in question. Weight-lifters, for instance, have different training requirements from golfers; soccer players from tennis players; sprinters from endurance runners; and dancers from gymnasts. The four types of training are:

- aerobic training
- anaerobic training
- flexibility training
- strength training.
5.2.1 Aerobic training

Aerobic training uses the aerobic system as the main source of energy supply. It includes a number of training types including:

- continuous training
- Fartlek training
- aerobic interval training
- circuit training.

Continuous training

In continuous training there is sustained effort — that is, effort without rest intervals. For training to be categorised as continuous, it needs to persist for not less than 20 minutes. During continuous training, the heart rate must rise above the aerobic threshold and remain within the target zone for the duration of the session. Examples of continuous training are jogging, cycling and aerobics. In the case of an endurance running program, a period of time in excess of 30 minutes per session is needed for an improvement in fitness to occur.

The two types of continuous training are:

- *Long, slow distance training.* This is standard for those who need to improve general condition. Subjects work at between 60 and 80 per cent of their maximal heart rate and focus on distance rather than speed
- *High intensity work of moderate duration.* This is very demanding as the athlete works at 80 to 90 per cent of maximal heart rate. Only well-conditioned athletes use this training and, even then, intervals of relief are required. High intensity training requires work at or near competition pace and is essential for developing leg speed.

Fartlek training

The word ‘Fartlek’ means ‘speed play’. In *Fartlek training*, participants vary their speed and the terrain on which they are working, ultimately engaging both anaerobic and aerobic energy systems. Fartlek training resembles a combination of interval and continuous training because of its random use of variations in speed and intensity. Using this type of training, the amount of effort is not predetermined as a percentage of heart rate, but rather by ‘feel’ according to how the body is responding. Short, sharp surges dictate an anaerobic energy supply and the development of this system. Fartlek training is good for most athletes, but is particularly beneficial for games players who are frequently asked to sprint, stop, jog, change direction and accelerate as part of the activity.

Some ways of incorporating speed play into continuous training are:

- regular bursts of speed every two or three minutes
- running up and down sand-hills
- group running with changing leadership
- cross-country running, covering a variety of terrain types.

Fartlek training is beneficial for pre-season training and in preparation for activities where there is frequent changes between predominant energy systems; for example, rugby, basketball and soccer.
FIGURE 5.20 A sample speed play program

Speed play program
1. Warm-up jog
2. Light callisthenics such as push-ups, sit-ups and star jumps
3. Form one or two lines depending on numbers.
4. Jog 400 metres with the person at the back of the line moving to the front every 50 metres.
5. Walk 100 metres.
6. Run 500 metres over varying terrain, changing speed between walk, jog, sprint.
7. Repeat steps 4, 5, 6.

Aerobic interval training

Aerobic interval training involves alternating sessions of work and recovery. Using this method, an athlete performs a given amount of work, such as a 400 metre run, in a particular time or at a specific level of intensity. This is followed by a recovery period before the task is repeated a number of times in the same manner (see figure 5.22). The rest period is important in differentiating aerobic interval from anaerobic interval training. During aerobic interval training the rest period is very short, say 20 seconds, between exercise bouts. The short rest period does not allow enough time for full recovery and thus maintains stress on the aerobic system.

This training method effectively develops aerobic endurance because:
- sustained effort of moderate intensity ensures that the aerobic system is stressed but not completely fatigued
- the level of intensity can be adjusted to achieve the desired level of aerobic capacity.

The overload principle (see section 5.3.1) can easily be applied to interval training by manipulating the following four variables:
- work intensity (how difficult the exercise is to perform)
- lasts
- the number of repetitions
- the work–rest ratio.
Circuit training

Circuit training develops aerobic capacity and has the potential to make substantial improvements in strength, endurance, flexibility, skill and coordination. While it can be used anytime, circuit training is generally preferred in the pre-season to develop a solid fitness platform for the numerous physical demands of the season ahead.

A typical general conditioning circuit is illustrated in figure 5.23. Here, participants move from one activity to the next after completing the required repetitions (or performing for the specified time) for that exercise. Participants usually aim to complete the circuit in the shortest period with decreasing times indicating improving fitness levels. Circuit training can be used as an anaerobic or aerobic training program depending on the type of activity, the time spent at each activity and the number of circuits required. Once again, the effectiveness of circuit training relies heavily on how well the overload principle is applied. Progressive overload in circuit training is achieved by:

- increasing the number of stations
- increasing the time at each station
- increasing the repetitions at each station
- decreasing the time allowed for the circuit
- increasing the repetitions of the circuit
- determining the repetitions at each station on the basis of the individual's target zone for their heart rate response. Fitter athletes will do more repetitions at each station than less fit athletes.

The greatest benefits are achieved when:
- the overload principle is applied
- the skills at each station concentrate on the attributes needed for a particular game/activity
• all fitness components essential to the particular sport or activity are developed
• record cards are kept to monitor improvement to keep athletes aware of their progress.

**Application**

**Designing and trialling a circuit**

As a class or in small groups, design a circuit to improve aerobic capacity. Include at least 10 activities and ensure a logical progression from one activity to the next. Make a card for each activity in your circuit that names (and perhaps illustrates) what is to be done at each station. On each card indicate the number of repetitions of the movement that are required before progression to the next activity. Finally, perform your circuit as quickly as possible and record the time taken.

**Inquiry**

**Evaluating the circuit**

Comment on how well the circuit taxed your current level of physical condition. Explain the value of your circuit in enhancing the aerobic fitness of a group of athletes who are about to begin training for your chosen sport.

**study on**

[Core 2 Question 1 Topic 2 Concept 1]

**Aerobic training** Summary screen and practice questions

5.2.2 Anaerobic training

Anaerobic training uses high intensity work coupled with limited recovery to develop systems of energy supply that function in the absence of oxygen. Anaerobic training is shorter in duration than aerobic training, lasting less than two minutes. While activity is brief, effort is maximal and followed by short rest periods that do not allow full recovery of systems that supply energy. Anaerobic training seeks to enhance systems that supply energy under periods of intense activity while developing greater tolerance for the lactic acid created as a result of the work.

There are three types of anaerobic training:

• **short anaerobic** training lasts less than 25 seconds and develops the ATP/PC systems of energy supply
• **medium anaerobic** training lasts from 25 seconds to one minute and develops the lactic acid system for energy supply
• **long anaerobic** training lasts one to two minutes and develops the lactic acid/aerobic systems.

**Anaerobic interval**

Anaerobic interval training can best be described as sprint training over short distances using maximal effort. Most anaerobic interval training is directed towards the development of speed as might be required in 100 metre sprinting and for short bursts in games such as touch football. Table 5.2 shows differences in anaerobic interval training programs depending on activity type. To develop speed while focusing on technique, the rest period needs to be slightly extended to allow lactate to disperse, as lactate build-up inhibits the development of quality with the sprinting action.
Recently, high intensity interval training (HIIT) has gained increasing popularity. HIIT involves repeated bouts of high intensity exercise followed by varying periods of complete rest or recovery at lower intensity.

During this type of interval training, work periods may be as short as 5 seconds and are performed at 80%–95% of maximal heart rate (MHR). The recovery period will depend on the type of exercise but is usually the same as, but certainly not more than, double the work period. Near maximal intensity is a prerequisite for work periods, making it necessary to push the body to its limits during every exercise set. Intensity during the recovery period should drop to around 40%–50% MHR with sessions lasting anywhere from 20 minutes to an hour.

HIIT can be adapted to a range of exercise modes including cross-training, swimming, cardio sessions, cycling and sprinting. Whatever the activity, it is important that the work/recovery ratio remains around 1:1. For example, a sprint training program may involve a series of 60m sprints in 10 seconds with walk/jog recovery taking 20–25 seconds. A general exercise/cardio program may incorporate a series of exercises such as push-ups and high knee lifts for 30 seconds with a 30 second rest between sets. The biggest benefits of HIIT relate to its adaptability to most training types, non-reliance on expensive equipment and the possibility of significant fitness/weight loss gains in a short period of time.

**TABLE 5.2 Various types of anaerobic interval training**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Use</th>
<th>Work duration</th>
<th>Rest duration</th>
<th>Work–rest ratio</th>
<th>Repetitions</th>
<th>% of maximum speed</th>
<th>% of maximum heart rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>Anaerobic threshold training</td>
<td>2–5 min</td>
<td>2–5 min</td>
<td>1 : 1</td>
<td>4–6</td>
<td>70–80</td>
<td>85–90</td>
</tr>
<tr>
<td>Medium</td>
<td>Anaerobic training</td>
<td>60–90 sec</td>
<td>120–180 sec</td>
<td>1 : 2</td>
<td>8–12</td>
<td>80–90</td>
<td>95</td>
</tr>
<tr>
<td>Short</td>
<td>High energy training</td>
<td>30–60 sec</td>
<td>90–180 sec</td>
<td>1 : 3</td>
<td>15–20</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Sprint</td>
<td>Speed (anaerobic)</td>
<td>10–30 sec</td>
<td>30–90 sec</td>
<td>1 : 3</td>
<td>25+</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

5.2.3 Flexibility training

Muscles require not only strength but also length. Muscle length can be enhanced through a sound flexibility training program. A flexibility program is essential for:

- prevention of injury
- improved coordination between muscle groups
- muscular relaxation
- decreasing soreness and tightness following exercise
- an increased range of movement around joints, maximising performance potential.

Sports such as football, basketball, netball and hockey can cause muscle tightness and shortening because the muscles do not undergo the full range of movement. Stretching during the warm-up and cool-down phases can promote the flexibility that assists these activities. Flexibility is affected by a number of factors including:

- age. Muscles shorten and tighten as we grow older.
- sex. Generally, females are more flexible than males
- temperature. Increased atmospheric and body temperature both improve flexibility
- exercise. People who are frequently involved in exercise tend to be more flexible than more sedentary people.
- specificity. Flexibility is joint specific. The fact that a person is flexible in the shoulders does not automatically mean similar flexibility exists in the hips.

The four common types of stretching methods used in flexibility programs are:

- static
- ballistic
- proprioceptive neuromuscular facilitation (PNF)
- dynamic.

Static stretching

During static stretching, the muscle is slowly stretched to a position (end point or limit) which is held for about 30 seconds. The movement is smooth and performed slowly, taking the muscle to a point where there is stretch without discomfort. Static stretching is safe and is used extensively in the rehabilitation of injury and the warm-up and cool-down phases of training. An example of a static stretch is sitting down with legs extended, gently reaching forward and holding the position for 30 seconds.

Ballistic stretching

Ballistic stretching involves repeated movements such as swinging and bouncing to gain extra stretch. This form of stretching activates a mechanism in the muscle called the stretch reflex (see figure 5.26), causing the muscle to contract. The force and momentum of the movement can be potentially harmful as the contracted muscle is then stretched well beyond its preferred length.
Ballistic stretching should be used *only* by advanced athletes and even then should follow a thorough warm-up and another form of stretching. The movements must be executed rhythmically to avoid jerky actions and too much momentum at the end point of the stretch. An example of ballistic stretching would be touching toes using a bouncing motion.

**Proprioceptive neuromuscular facilitation (PNF) stretching**

PNF stretching involves lengthening a muscle against a resistance usually provided by a partner. It incorporates static stretching, strength development using isometric contractions and periods of relaxation in a progressive sequence. The steps are:

- the muscle group to be stretched is determined
- the muscle group is stretched using a static contraction
- while in the stretched position, the person isometrically contracts the muscle (that is, he/she pushes against an immovable object, such as the ground or a partner, and holds the position for 10 seconds)
- the participant relaxes in the lengthened position for five seconds
- a further static stretch is applied followed by an isometric contraction.

PNF stretching is useful in rehabilitation programs because the isometric component strengthens the muscle fibres during the stretching process. PNF is also recommended as an integral part of the warm-up and cool-down phases of training programs because of its ability to provide added stretch under safe conditions.
Dynamic stretching

Dynamic stretching is popular for warm-ups and pre-training routines as it attempts to imitate many of the movements experienced in the game. Dynamic stretching uses movement speed together with momentum to gradually warm up muscle fibres and extend them through the degree of stretch required in the game. Bouncing movements, common in ballistic stretching, are avoided. Actions attempt to reduce muscle tightness rather than lengthen muscle fibres.

In contrast to static stretching, dynamic stretch movement is continuous but the end position is not held. Dynamic stretching is not as safe as static or PNF stretching due to tension exerted by specific movements on muscles and across joints. However, many prefer to use it just prior to a game because its movements simulate those required in the game. An example of dynamic stretching is arm circling. To find out more about dynamic stretch movement in action, use the Dynamic stretches weblink in your Resources tab.

Application

Categorising different forms of stretching

From figure 5.29, choose five exercises that could be developed into static stretches and five that could be developed into PNF stretches. In pairs perform your exercises. Briefly describe your exercises and say why each fits the specified category.
FIGURE 5.29 Flexibility exercises
5.2.4 Strength training

Strength training is a form of training where muscular contraction is resisted by calculated loads, thereby building the strength of the muscle. Stimulus in the form of resistance causes muscle hypertrophy as more fibres are engaged to aid the movement. There are many ways of creating resistance — that is, an opposing force (as in lifting, pushing) — including:

- free weights
- fixed-weight machines
- elastic and hydraulic forces.

Strength training programs can be used for many purposes including:

- building strength
- developing power
- developing muscular endurance
- injury rehabilitation
- body building
- general health benefits.

Strength training is fundamental to improvement in most sports, particularly those in which lifting a weight or opposing a force (such as in football) is involved.

Strength programs can be divided into two categories:

- isotonic programs — participants raise/lower or pull/push free weights to contract/lengthen muscle fibres. Nearly all strength training is isotonic.
- isometric programs — participants develop strength by applying a resistance and using exercises in which muscle length does not change.

These programs are useful for body building, improving muscle tone, increasing strength/power and rehabilitation following injury. The differences are illustrated in figure 5.30.

Like many sports, strength training has its own terminology. The most common terms used include:

- repetitions — the number of times an exercise is repeated without rest
- repetitions maximum (RM) — the maximum weight you can lift a number of times. For example, 1 RM is the maximum weight you can lift only once; 8 RM is the maximum weight you can lift eight times.

Therefore, the actual weight or mass lifted during an RM varies from one individual to another.

- set — a number of repetitions done in succession; for example, one set equals 10 repetitions
- resistance — the weight or load
- rest — the period of time between exercises, sets or sessions.
There are a number of principles that you need to be aware of when considering the type of strength and method you use in its development.

- **Target specific muscle groups.** Only those muscles that encounter the resistance will benefit from the work.
- **Progressive overload.** The load (resistance) needs to be progressively increased as adaptations take place.
- **Volume.** Lifting more by increasing the number of days on which you train or the amount per session is of benefit to a point. Care needs to be taken to avoid injury and overtraining, and to allow periods of time for muscles to rest.
- **Variety.** Using different methods (free weights/machine weights), changing muscle groups, introducing new exercises and utilising a circuit format adds interest and enhances motivation.
- **Rest.** Allow rest between sets. The amount varies according to your program aims, such as power or endurance.
- **Repetition speed.** To increase power, perform repetitions quickly. Focusing on strength or bulk necessitates slower speeds.
- **Repetition numbers.** Generally, absolute strength is developed by low repetitions (3–8), anaerobic strength endurance by medium range repetitions (10–20) and aerobic strength endurance by high range repetitions (20–40 or more).
- **Recovery.** Train every second day to allow muscles to recover. If training each day, target different muscle groups to those of the previous day.

Well balanced isotonic programs include a range of exercises that address all major muscle groups. Some of the more commonly used isotonic exercises are illustrated in table 5.4.

### TABLE 5.3 Examples of strength training programs

<table>
<thead>
<tr>
<th>Method</th>
<th>How it works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free weights</td>
<td>For example, use of barbells, dumbbells and hand weights. Weights are used to develop all muscles in a group at the same time; for example, the quadriceps muscles in the upper leg. With free weights, most resistance is encountered when initiating the movement. Using free weights can be time-consuming as users may need to frequently load and unload plates. It also requires strict form and good technique to avoid injury, together with the ability to balance the weight while performing the exercise.</td>
</tr>
<tr>
<td>Weight machines</td>
<td>There are many different types of weight machine. Resistance is usually provided by stacked weights where users can adjust loads by changing pin placements. They are often preferred to free weights by beginners as there is less chance of injury because tracks restrict the way each movement can be performed. This enhances stability and can give more confidence to first time users. Weight machines are particularly beneficial for isolating specific muscles for development.</td>
</tr>
</tbody>
</table>

(Continued)
### TABLE 5.3 Examples of strength training programs (Continued)

<table>
<thead>
<tr>
<th>Method</th>
<th>How it works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance bands</td>
<td>Resistance bands are a cheap and portable form of resistance training and are commonly used in home gyms. Most resistance bands are colour coded, with light bands being recommended for small muscle groups and heavy bands for large muscle groups. With the bands anchored by a wall fixture or against part of the body, the strong rubber bands are stretched, creating a resistance. Most of the resistance is experienced at the end of the movement because this is where the elastic material is under the greatest tension. As a result, it is this part of the muscle where most strength gains are made.</td>
</tr>
<tr>
<td>Hydraulic resistance</td>
<td>During hydraulic resistance training each effort made is confronted by an opposing force. Resistance is felt through the entire movement; that is, if you lift something, you must also pull it back. For example, a biceps curl requires that you curl the weight by contracting the biceps, then returning it to the original position using the triceps. Unlike free weights, gravity does not assist the return, making effort necessary through the full range of movement. Greatest resistance is felt when performing movements at higher speeds.</td>
</tr>
</tbody>
</table>

### TABLE 5.4 Examples of exercises commonly used in isotonic programs

<table>
<thead>
<tr>
<th>Name</th>
<th>Area developed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Squats</td>
<td>Legs</td>
<td>Use of overgrip (knuckles up to balance bar across shoulders). Keep head up and back flat and squat until the thighs are parallel to the floor.</td>
</tr>
<tr>
<td>2. Bench press</td>
<td>Chest, arms and shoulders</td>
<td>Lying facing up on bench, hold bar with overgrip (palms forward) and with hands slightly wider than shoulders. Push bar up and then lower until it touches the chest.</td>
</tr>
<tr>
<td>3. Barbell curls</td>
<td>Arms (biceps)</td>
<td>With arms shoulder width apart, hold bar at thigh height, palms facing out. Lift bar to shoulders and return in a smooth continuous movement, keeping the back straight.</td>
</tr>
</tbody>
</table>
### TABLE 5.4 Examples of exercises commonly used in isotonc programs (Continued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Area developed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Calf raise</td>
<td>Calf muscles</td>
<td>With bar across shoulders, place balls of feet on a board, keeping heels off the ground. Keeping the body erect, rise on toes as high as possible and lower until heels touch the floor.</td>
</tr>
<tr>
<td>5. Upright rowing</td>
<td>Upper arms and shoulders</td>
<td>Using an overgrip (knuckles on top and away) hold bar in front of body with hands five centimetres apart. Lift the bar to chin height keeping elbows higher than bar and then return.</td>
</tr>
<tr>
<td>6. Sit-ups</td>
<td>Abdominal</td>
<td>Hold weight on the chest. Lie with hips flexed. Sit up with curling action, taking shoulders as far off the ground as possible, then return to floor.</td>
</tr>
<tr>
<td>7. Lateral arm raise</td>
<td>Shoulders</td>
<td>Grasp dumbbells with palms facing towards body and arms at side. Keeping the body straight, raise arm to shoulder height. Elbows remain locked throughout. Gradually return dumbbells to starting position (lower arm).</td>
</tr>
<tr>
<td>8. Leg curl</td>
<td>Hamstrings</td>
<td>With body lying face-down on a bench, lock heels under rollers. Grasp front of bench and bring heels over until rollers touch back of thighs.</td>
</tr>
<tr>
<td>9. Back raise</td>
<td>Lower back</td>
<td>Lie across a bench with heels hooked under roller. Place hands behind head and bend forward until trunk is at right angles to legs. Raise body to straight position.</td>
</tr>
</tbody>
</table>

(Continued)
TABLE 5.4 Examples of exercises commonly used in isotonic programs (Continued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Area developed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Seated barbell twist</td>
<td>Back and lower trunk</td>
<td>Sit on bench with a bar across shoulders and hands well spread. Twist body so that the bar turns at least 180°.</td>
</tr>
<tr>
<td>11. Pull-overs</td>
<td>Chest and shoulders</td>
<td>Lie on bench holding a bar with arms extended and hands slightly wider than shoulder width. Lower weight over head and then bring it on an arc to rest on thighs. Repeat.</td>
</tr>
</tbody>
</table>

Application

Dumbbell exercises
Use the Dumbbell weblink in your Resources tab and watch the animated dumbbell exercises. Comment on the need for correct technique when performing strength training exercises.

Inquiry

Machines or free weights
You are training a sprinter. What type of strength training method would be most appropriate and why? You could use the Machines vs free weights weblink in the Resources tab to assist you in your appraisal.

Inquiry

Training types and methods for different sports
Draw an enlarged copy of the table that follows in your workbook together with the list of sports/activities. For each sport, identify the training type/method that would most enhance performance in that sport. Use the final column to justify your choice by indicating why you prefer that type/method of training and how it would affect your performance.
5.3 Principles of training

All athletes train knowing that repetition of movements required in the game/activity will improve performance. However, the quality of training is very much dependent on our understanding of its anticipated benefits. Effective training requires the implementation of a number of important principles. Whether we are training to improve our aerobic capacity, strength or perhaps our flexibility, certain principles must be applied. Ignorance or disregard for these principles means that the rewards are not matched by the effort.

5.3.1 Progressive overload

The overload principle implies that gains in fitness (adaptations) occur only when the training load is greater than normal and is progressively increased as improvements in fitness occur. This is illustrated in figure 5.31 which shows improvement in performance when overload is applied.

Training produces certain physiological changes that allow the body to work at a higher level of intensity. This higher level is achievable as a result of adaptations that have occurred in response to training stress at the lower level. As the body becomes familiar with a particular level of training stress, it adapts to it and further training at this level fails to sufficiently stress the
system. These adaptations will not take place if the load or resistance is either too small or too big. A resistance that is too low to stress the body system signalled for development fails to produce the necessary adaptations. A resistance that is too high, particularly in the early stages, results in the onset of fatigue as well as possible injury and the discontinuation of the activity. This is illustrated in figure 5.32.

Some examples of application of overload are listed below.

- **Aerobic training** — application of the overload principle is reflected in the heart’s ability to pump more blood to the working muscles (increased cardiac output) and the ability of the working muscles to take up more of the oxygen as it is delivered to the cells (increased oxygen uptake).
- **Strength training** — application of the overload principle results in an increase in the cross-sectional area of a muscle, commonly called muscle hypertrophy. This is usually directly related to an increase in strength.

The overload principle is probably the most important principle in aerobic, strength and flexibility training programs. If there is no overload, the rate of improvement decreases and performance plateaus. It should be noted that not all adaptations take place at the same rate. This is illustrated in figure 5.33. In endurance programs, the load (height of the step) needs to be small and the adaptations (length of the step) take place slowly (figure 5.33a). In other words, gains are made over a longer period of time. Fastest gains are made in flexibility programs where progressive increases in loads produce small adaptations (figure 5.33b). The loads need to be less for peak strength development, but the adaptations are more significant (figure 5.33c).
5.3.2 Specificity

The specificity principle implies that the effects of a training program are specifically related to the manner in which the program is conducted. The principle draws a close relationship between activities selected for training and those used in the game or event. It focuses on what is being performed at training and its similarity to what is done in the game. The specificity principle implies that greatest gains are made when activity in the training program resembles the movements in the game or activity. This is because the body adapts to stresses in a very specific way.

The principle of specificity is particularly important when considering the development of energy systems, muscle groups and components of fitness. Metabolic specificity refers to identifying the energy system or systems most appropriate to the activity and developing these systems through related training procedures. The best way to identify which energy system is predominant is to assess the level of intensity of the activity and establish the time over which it extends. Short-term, explosive activity requires development of the anaerobic systems while continuous, moderate, sustained activity requires development of the aerobic system.

The principle of specificity when applied to muscle groups suggests that those groups used for the activity need to be the same as the groups used during training. This is because the body ‘recruits’ the type of muscle fibre that is best able to do the task. For instance, if the subject is required to run 100 metres, the white fibres (fast-twitch fibres) are required to do most of the work. However, if work continues, the red fibres (slow-twitch fibres) increasingly take over this role. To ensure that the most desirable fibres for the activity are developed, the effort and duration of training activities need to closely resemble those of the game or activity.

Finally, the components of fitness required in the game should closely resemble those developed during training. Coaches need to construct training programs incorporating drills and exercises that, as far as possible, require the same movements as those required in the related competition. For example, a centre in netball needs to make short, sharp movements in creating leads. Activities focusing on agility, reaction time, power and coordination require special attention during training to develop the necessary movement patterns and skills.

Some examples of application of the specificity principle are given below.

- **Aerobic training** — an athlete training for a marathon must target the aerobic system in training. Most activity ensures that the third energy pathway is used for 95 per cent of the time or more. The same athlete should choose activities in training that recruit slow-twitch muscle fibres so that aerobic enzymes in muscle fibres become more efficient in utilising oxygen.

- **Strength training** — if increased leg power is required to improve a person’s ability to sprint, the training program must correctly address the speed and number of repetitions, load and time between sets correctly. For example, if the load is too high and the repetitions too low, the program causes bigger improvements to muscle bulk than muscle power.

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**SNAPSHOT**

**Specificity of training**

An activity such as jogging recruits muscle fibres uniquely suited to the task. Slow fibres are recruited for slow jogging. The metabolic pathways and energy sources are also suited to the task. Daily jogging recruits the same fibres and pathways over and over, leading to the adaptive response known as the training effect.

The outcomes of training are directly related to the activity employed as a training stimulus. We’ve shown that training has effects on muscle fibres as well as on the supply and support systems, such as the respiratory and cardiovascular systems. In general, the effects of training on muscle fibres are very specific, meaning that they are unlikely to transfer to activities unlike the training. So most of the benefits of run training will not transfer to swimming or cycling. On the other hand, the effects on the respiratory or cardiovascular systems are more general, so they may transfer to other activities (Sharkey and Greetzer 1993).

Training leads to changes in aerobic enzyme systems in muscle fibres, so it is easy to see why those changes are specific. In the early stages of training, the muscles’ inability to use oxygen limits performance. Later on, as the fibres adapt and can utilise more oxygen, the burden shifts to the cardiovascular system, including the heart,
blood, and blood vessels. Then the cardiovascular system becomes the factor that limits performance (Boileau, McKeown, and Riner 1984).

Training gains don’t automatically transfer from one activity to another. Training effects can be classified as peripheral (in the muscle) and central (heart, blood, lungs, hormones). Central effects may transfer to other activities, but peripheral changes are unlikely to transfer. However, central changes in blood volume and redistribution may aid performance in another endurance activity. But keep in mind that one-leg training studies show that some part of the heart rate (and stroke volume) change is due to conditions within the muscle fibres, conditions that are relayed to the cardiac control centre (Saltin 1977). These changes are specific and will not transfer from one activity to another.

It makes sense to concentrate training on the movements, muscle fibres, metabolic pathways, and supply and support systems that you intend to use in the activity or sport. This does not imply that athletes should ignore other exercises and muscle groups. Additional training is necessary to avoid injury, to avoid boredom, to achieve muscle balance, and to provide backup for prime movers when they become fatigued. In spite of the widespread affection for the term cardiovascular fitness, the evidence suggests that the concept is overrated. Muscle is the target of training.

Finally, if exercise and training are specific, it stands to reason that testing must be specific if it is to reflect the adaptations to training. This means you should not use a bicycle to test a runner, and vice versa. Training is so specific that hill runners are best tested on an uphill treadmill test. How do we test the effects of training on dancers? We don’t. When studies compare runners and dancers on a treadmill test, the runners exhibit higher VO$_2$ max scores. If that is true, why do runners poop out in aerobic dance, cycling, or swimming? Because the effects of training are specific. At present there is no widely accepted way to accurately assess the effects of aerobic, ballet, modern, or other dance forms.

Source: Human Kinetics Publishers, Inc.

Inquiry
Specificity of training
Read the article ‘Specificity of training’, then answer the following questions.
1. What is meant by training being specific to an energy source?
2. Explain how the principle of specificity would be applied differently in enhancing an aerobic program versus a strength program.

Inquiry
Investigation of training programs
Investigate two different training programs — for example, one that relates to sprinting and one that relates to a game, cycling or rowing. Suggest the type of activities that would be included in the program and describe how the principles of overload and specificity could be applied.
5.3.3 Reversibility

The effects of training programs are reversible. In the same way that the body responds to training by improving the level of fitness, lack of training causes the opposite to occur. This is referred to as the *detraining* effect. The reversibility process applies equally to aerobic, strength and flexibility training programs. Gains made in aerobic fitness are gradually lost if training ceases. For example, the ability of the working muscles to use the oxygen being delivered in the blood is reduced when training stops. Losses here are slower than those experienced in strength/power programs, where minimal regular stimulation is necessary to maintain the benefits achieved by training. In flexibility programs, some elasticity is lost quickly if stretching programs are not carried out on a regular basis.

In general, if big gains have been made during training, greater losses will follow when training stops because there is more to lose. You must be actively participating in the training program to maintain the training benefits. In the case of cardiorespiratory endurance, you can avoid reversing the effects of training only by continuing regular training at 70 per cent MHR (maximal heart rate) and on at least three occasions per week. Runners who are unable to continue normal training due to injury may substitute activities such as swimming or cycling.

5.3.4 Variety

Using the same drills and routines to develop fitness components in every training session is not productive, as repetition without creativity leads to boredom. It is important to continually strive to develop the required attributes using different techniques to ensure that athletes are challenged not only by the activity, but also by initiative and implementation. For example, it is not necessary for a footballer to pass, tackle and practise tactics each and every training session. General endurance, strength and power can be developed using a variety of techniques such as swimming, *plyometrics* and resistance programs to supplement the training experience. Mental wellbeing is vital to maximise effort in physical training.

Some examples of application of the variety principle are given below.

- **Aerobic training** takes many forms. We can train the aerobic system using a variety of activities such as swimming, running, cycling and circuit training.
- **Strength training** uses a variety of methods. Isometric and isotonic methods increase strength, but do so using different equipment such as free weights, elastic bands and hydraulic devices.

5.3.5 Training thresholds

Thresholds generally refer to a specific point that, when passed, take the person to a new level. Most of us are familiar with the tax-free threshold. Below this level of income, tax is not payable. Above this level, tax is progressively increased. Thresholds also apply to physical training. When we train, we expect an improvement
in our physical condition. However, for improvement to occur, no matter how small, we must work at a level of intensity that causes our bodies to respond in a particular way. These changes are called adaptations or fitness gains. The magnitude of improvement is approximately proportional to the threshold level at which we work.

The lowest level at which we can work and still make some fitness gains is called the training threshold or (where it concerns developing aerobic fitness) **aerobic threshold**.

Thresholds are determined by work intensity, which can be calculated using heart rate. A person’s maximal heart rate (MHR) is estimated at 220 beats/minute minus age. Therefore, a 20-year-old person would have an MHR of 200 beats per minute. If the aerobic threshold is 70 per cent of MHR, the athlete would be working at a level of intensity that would cause the heart to beat at approximately 140 beats per minute. For most people between 16 and 20 years of age, this is equivalent to a moderately paced jog.

When a person is working at a level of intensity above the aerobic training threshold and below the anaerobic threshold, they are working in the **aerobic training zone**. Exercise here is referred to as steady-state exercise and results in improvements in physical condition. The uppermost level is called the **anaerobic threshold** or, more accurately, the lactate inflection point (LIP), a point at which further effort is characterised by fatigue. The LIP reflects the balance between lactate entry and removal from the blood. If exercise intensity increases after the LIP is reached, blood lactate concentration increases substantially. The exercise intensities for the aerobic threshold (training threshold) and anaerobic thresholds are shown in figure 5.34.

Sometimes while exercising in the aerobic training zone, we wish to increase our intensity. An example is to increase the pace during the final half of a 12-minute run. This causes the muscles to require more oxygen, which is supplied by an increase in respiration and heart rates. If we increase the pace to a point where the cardiorespiratory system is unable to supply all the oxygen required at that point in time, energy will start to be produced anaerobically. In other words, the body will metabolise glycogen in the absence of sufficient oxygen to fulfil immediate ATP requirements.

The result is that the by-product of anaerobic glycolysis, lactic acid, starts to be produced in large quantities and permeates to the muscle cells. This point in training is called the anaerobic threshold. Well-trained endurance athletes can improve their performance by working close to and, in spurts, above the anaerobic threshold. This improves their tolerance of lactic acid, which is a feature of well-trained athletes.
FIGURE 5.35 The body’s response to changing thresholds

<table>
<thead>
<tr>
<th>Lactic acid concentrate (mmol*)</th>
<th>Training for:</th>
<th>Heart rate</th>
<th>% of maximum intensity</th>
<th>Training effect</th>
<th>Training benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0</td>
<td>Maximum anaerobic power</td>
<td>200</td>
<td>85–90%</td>
<td></td>
<td>• High improvements in anaerobic endurance</td>
</tr>
<tr>
<td>12.0</td>
<td>Lactic acid tolerance</td>
<td>200</td>
<td>80–90%</td>
<td></td>
<td>• Overemphasis may result in overtraining</td>
</tr>
<tr>
<td>8.0</td>
<td>MVO₂ (maximum volume of O₂ that can be consumed in one minute)</td>
<td>190–200</td>
<td>70–85%</td>
<td></td>
<td>• Improvement in aerobic endurance</td>
</tr>
<tr>
<td>4.0</td>
<td>Anaerobic threshold</td>
<td>170</td>
<td>60%</td>
<td></td>
<td>• Considerable improvement in aerobic endurance</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>160</td>
<td>50%</td>
<td></td>
<td>• Observe intensity for optimal benefit</td>
</tr>
<tr>
<td>1.1</td>
<td>Resting state</td>
<td>&gt;80</td>
<td>50%</td>
<td></td>
<td>• Little improvement in aerobic endurance</td>
</tr>
</tbody>
</table>

* millimoles per litre


Inquiry

The anaerobic threshold

1. Examine figure 5.35. How have lactate levels and heart rate changed in response to moving from resting state to the anaerobic threshold?
2. Explain why continuous training above the anaerobic threshold would be detrimental to aerobic endurance.

Some applications of training thresholds are given below.

• *Aerobic training* — the efficiency of the cardiorespiratory system is improved if the athlete works closer to the anaerobic threshold than the aerobic threshold. Working at this level increases the capacity and functioning of the cardiovascular system and the athlete’s ability to tolerate inevitable rises in performance crippling lactic acid.

• *Strength training* — bigger gains in strength are made as resistance is progressively increased. If training for absolute strength, the threshold is represented by a high resistance or load ensuring that only a few repetitions can be completed. If training for strength endurance, the threshold is represented in terms of quantity, with a high number of repetitions being required to effectively challenge the threshold.
5.3.6 Warm-up and cool-down

Each training session requires three essential components — warm-up, training (or conditioning) and cool-down. A session that lacks one or more of these components may contribute to injuries or fail to achieve the desired results.

The purpose of the warm-up is to:
- reduce the risk of injury or soreness by increasing joint mobility and muscle stretch
- increase body temperature and enzyme activity to promote faster and more powerful muscle contractions
- mentally prepare the athlete for training
- stimulate the cardiorespiratory system.

The warm-up should follow a set procedure involving:
- general aerobic activity (gross motor) such as jogging to raise body temperature
- specific flexibility exercises to increase the range of motion of joints and to prevent muscle tears
- callisthenics, such as push-ups, star jumps and sit-ups to increase blood flow to the working muscles
- skill rehearsal — that is, performing movements or skills that will be repeated in the game (for example, sidesteps, swerves, dribbling or passing the ball).

An effective warm-up should be sustained for at least 10 minutes. For athletes such as elite sprinters whose events require explosive movements, the warm-up could last for 30 minutes. Stretching should be avoided until the body is warm. ‘Never stretch before you sweat’ is a good guide for players to observe. Rest periods may well be essential during the warm-up to avoid fatigue but should not be longer than necessary.

The cool-down is the period that follows the training session and is the reverse of the warm-up. The purpose of the cool-down is to minimise the muscle stiffness and soreness that could result from a strenuous training session. While not as intense or involved as the warm-up, it is still an important component and should include:
- aerobic work, (for example, jogging), which gradually decreases in intensity and allows the body temperature to return to normal
- the stretching of muscle groups used extensively during the training session (for example, leg muscles).

The cool-down helps to disperse and metabolise lactic acid concentration and to replenish the body’s energy stores. It is an essential component of aerobic, strength and flexibility programs.

Inquiry

Training and performance

Copy and complete the web diagram in figure 5.36 to analyse the following critical question: ‘How can the principles of training improve performance?’
Inquiry
Applying the principles of training to aerobic and resistance training

Draw an enlarged copy of the following table in your workbook, leaving plenty of space in the blank squares. The principles of training are listed in the centre of the table. Use the columns either side to describe how each principle can be applied to aerobic and resistance training. Use examples to clarify your points.

<table>
<thead>
<tr>
<th>Aerobic training</th>
<th>Principles of training</th>
<th>Resistance training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Progressive overload</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specificity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reversibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training thresholds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warm-up/cool-down</td>
<td></td>
</tr>
</tbody>
</table>

5.4 Physiological adaptations in response to training

In response to training, the body makes adaptations or adjustments to the level of stress imposed on it. These adaptations allow it to function more comfortably at existing levels of stress and respond more efficiently to new levels of stress. The time taken before improvements are noticed varies from one individual to another and depends upon the biological systems affected. Although progressive improvements will be seen throughout a training program, it usually takes about 12 weeks to realise the entire benefits. Training will cause adaptations to a number of capacities, including resting heart rate, stroke volume, cardiac output, oxygen uptake, lung capacity, haemoglobin levels, muscle size and muscle recruitment.

5.4.1 Resting heart rate

Heart rate measurement at rest and during exercise is a reliable indicator of how hard the heart is working. All things being equal, the trained athlete has a lower resting heart rate than the untrained athlete. This is due to the efficiency of the cardiovascular system and, particularly, a higher stroke volume.

Training decreases resting heart rate. For example, a sedentary person with a resting heart rate of 72 bpm can expect it to reduce by about one bpm each week for the first few months of training. After 10 weeks of endurance training, the resting heart rate of the same subject should decrease from 72 to about 60 bpm. Highly conditioned endurance athletes have resting heart rates below 40 bpm and some are less than 30 bpm. Figure 5.37 illustrates the benefits of a training program on heart rate. The most appreciable difference is evident in the recovery period. Figure 5.38 illustrates the difference between trained and untrained individuals at rest and during maximal exercise.
5.4.2 Stroke volume

Stroke volume (SV) is the amount of blood ejected by the left ventricle during a contraction. It is measured in mL/beat. A substantial increase in SV is a long-term effect of endurance training (see figure 5.39). In other words, stroke volume is notably higher at maximal exercise following an endurance training program. This occurs because training causes the left ventricle to fill more completely during diastole (the relaxation phase of cardiac contraction) than it does in an untrained heart. There is also more blood in circulation following training as a consequence of an increase in blood plasma volume. This means that more blood is able to enter the ventricle. In fact, blood volume can increase by half a litre after only eight days of endurance training. This results in a further stretch by the ventricular wall which increases the elastic recoil of the chamber. The enlarged ventricle enables contractions that are more powerful, resulting in less blood remaining in the ventricles following systole. The increased oxygen available to the working muscles results in improved performance.

FIGURE 5.37 The effect of training on heart rate


FIGURE 5.38 Heart rate responses before, during and after exercise for a trained athlete and an untrained athlete

Study on

Core 2 Question 1 Topic 4 Concept 1

Resting heart rate Summary screen and practice questions

TOPIC 5 How does training affect performance? 183
5.4.3 Cardiac output

Cardiac output (CO) is the volume of blood ejected by the heart per minute. It is determined by multiplying heart rate and stroke volume. A large cardiac output is the major difference between untrained people and endurance athletes. Untrained individuals may have a CO of 15 to 20 litres per minute. For trained athletes, CO is 20 to 25 litres per minute. In highly trained endurance athletes, CO may even rise as high as 40 litres per minute. What is more exceptional is that the maximal heart rate of the trained athlete may be slightly lower than that of the untrained person even when each person is working to their highest capacity. It follows that the trained athlete achieves a considerably higher CO not from heart rate, but as a direct result of a huge increase in stroke volume. This is illustrated in figure 5.40. However, as shown in figure 5.41, maximal values for CO, stroke volume and heart rate are affected by age, decreasing gradually as we grow older.

5.4.4 Oxygen uptake

The most significant improvements in response to aerobic training are in oxygen uptake (VO$_2$). The body consumes only small amounts of oxygen at rest. However, as we begin to exercise, the mitochondria in the cells use more oxygen in the provision of energy. Maximal oxygen uptake, or VO$_2$ max, is regarded as the best indicator of cardiorespiratory endurance because it indicates the maximal amount of oxygen that muscles can absorb and use at that level of work.

Maximal oxygen uptake is relatively easy to estimate using tests such as bicycle ergometry in the laboratory, or field tests such as the 12-minute run or the multistage fitness test. A high VO$_2$ max indicates a superior
oxygen delivery system and contributes to outstanding endurance performance. Most tests that measure VO\textsubscript{2} max are able to take account of individual differences. Measurements are expressed in millilitres of oxygen per kilogram of body weight per minute (mL/kg/min). Average VO\textsubscript{2} max values are about 45 mL/kg/min for 17-year-old boys and 40 mL/kg/min for girls. The lower value for girls reflects the fact that females have less muscle tissue as a percentage of total body weight (less lean body mass) than males and less oxygen-carrying capacity due to lower haemoglobin levels. Oxygen uptake decreases at the rate of about one per cent per year after the age of 25, but is influenced greatly by aerobic training.

Training appreciably increases VO\textsubscript{2} max even in an eight- to 12-week period. A 15–20 per cent increase is typical for the average inactive person who applies the FITT formula for a six-month period. This reflects an improvement of 35 to 42 mL/kg/min. The highest recorded value for a female, world-class, endurance athlete is 75 mL/kg/min and the highest for a male athlete is 94 mL/kg/min.

If VO\textsubscript{2} max readings are higher in the pre-training state, the improvements are smaller. In other words, sedentary people make significant improvements when compared to trained athletes following similar training programs. Increases in VO\textsubscript{2} max readings are accompanied by a remarkable jump in the number of oxidative enzymes. This causes mitochondria numbers and size to increase. The mitochondria use the oxygen to produce energy, leading to higher VO\textsubscript{2} max readings. Some increase in VO\textsubscript{2} max is also due to increased blood volume as a result of the endurance training program.

**Inquiry**

**Maximal oxygen uptake**

The tests of aerobic power mentioned earlier can be performed in school situations because they require little equipment. However, there can be some variation in results, even with the same subjects performing the same tests on successive occasions. Investigate how maximal oxygen uptake is calculated using direct measurement. The VO\textsubscript{2} max test weblink in the Resources tab may assist. Why would the results be more accurate?
5.4.5 Lung capacity

No matter how efficient the cardiovascular system is in supplying adequate blood to the tissues, endurance is hindered if the respiratory system does not supply enough oxygen to meet demand. Oxygen is absorbed in the lungs, where lung capacity (the amount of air that the lungs can hold) is important.

Total lung capacity is about 6000 mL in males and slightly less in females due to their smaller size. In general, lung volumes and capacities change little with training. Vital capacity (the amount of air that can be expelled after maximal inspiration) increases slightly. Residual volume (the amount of air that cannot be moved out of the lungs) shows a slight decrease. Overall, total lung capacity remains relatively unchanged. Following training, tidal volume (the amount of air breathed in and out during normal respiration) is unchanged at rest and submaximal exercise. However, it appears to increase at maximal levels of exercise.

5.4.6 Haemoglobin level

Haemoglobin is contained in the red blood cells of the body. Each red blood cell contains about 250 million haemoglobin molecules, all capable of carrying considerable quantities of oxygen. The average male has about 14.3 grams of haemoglobin per 100 mL of blood, while the average female has 13.9 grams per 100 mL of blood. Women’s lower levels of haemoglobin contribute to lower VO$_2$ max values.

Most oxygen in the body is transported by the haemoglobin in the red blood cells. Some oxygen is transported in body fluids such as plasma, but the amount is relatively low because oxygen does not dissolve readily in ordinary fluids. Without haemoglobin, we would need to have about 80 litres of blood (or much more than fills the average car’s petrol tank) to transport enough oxygen to enable us to remain alive at complete rest.

Haemoglobin levels increase as a result of training and this increases oxygen-carrying capacity. One important way of increasing haemoglobin levels is to train at high altitudes. Figure 5.44 shows the effect of altitude on haemoglobin levels, which partly explains the success of Kenyan endurance runners in middle- and long-distance events.

General endurance training programs increase haemoglobin levels from about 800 grams to about 1000 grams per 100 mL of blood, representing a 20 per cent increase. This is directly attributable to an increase in blood plasma (and therefore blood volume) and a boost in red blood cell numbers. However, although the total quantity of haemoglobin may increase, the concentration may in fact lessen because more plasma, which contains mostly water, has been produced. Endurance athletes, therefore, tend to have thinner blood in terms of haemoglobin concentration, but more of it than non-athletes.
5.4.7 Muscle hypertrophy

Muscle hypertrophy is a term that refers to muscle growth together with an increase in the size of muscle cells. While length remains unchanged, the size of the muscle becomes larger as a result of an increase in its mass and cross-sectional area. Hypertrophy is induced by training programs that stimulate activity in muscle fibres causing them to grow. Without stimulation, muscle fibres can reduce in size, a condition known as muscular atrophy. Figure 5.45 shows the impact of hypertrophy on muscles in the upper arm.

Training causes structural changes in muscle fibres, leading to hypertrophy. The growth and cross-sectional size increase of muscle is a direct result of mass increases in:

- *actin* and *myosin filament* — thin protein filaments that produce muscle action
- *myofibrils* — contractile elements of skeletal muscle
- *connective tissue* — tissue that surrounds and supports muscle.

Training needs to address the overload principle to encourage muscle hypertrophy. The principle of specificity is also important in targeting muscles or regions of the body where hypertrophy is required. The extent of hypertrophy depends on:

- *muscle type* (fast-twitch or slow-twitch; see below). White muscle fibres are genetically larger in their cross-sectional area when compared to red fibres. Resistance training can cause white muscle fibres to increase their area from around 55 per cent of skeletal muscle to 70 per cent or more. It should be noted that training cannot change the type of fibre (red to white or vice versa), only the cross-sectional area.
- *type of stimulus*. As hypertrophy is enhanced through progressive overload, resistance training using low repetitions with high resistance yields the best results.
- *regularity of training*. Regular training promotes hypertrophy while irregular or absence of training may result in muscular atrophy (wasting away or decrease in size).
- *availability of body hormones*. Hypertrophy is more easily achieved in males due to a higher concentration of testosterone.

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**FIGURE 5.45** Training, particularly resistance training, causes growth in the size of muscle known as hypertrophy.
5.4.8 Effect on fast- and slow-twitch muscle fibres

There are two types of muscle fibre:

- **Slow-twitch muscle fibres** (ST) or red fibres. Slow-twitch muscle fibres, or type I fibres, contract slowly and for long periods of time. They are recruited for endurance-type activity such as marathons.
- **Fast-twitch muscle fibres** (FT) or white fibres. Fast-twitch muscle fibres type II fibres reach peak tension quickly and are recruited for power and explosive movements such as throwing and lifting.

A range of red and white fibres are identified in figure 5.46. Note that the white fibres tend to be slightly larger than the red fibres.

While most people have approximately even numbers of red and white fibres, some individuals genetically have higher proportions of one type or the other. This is significant when assessing the effects of training, because different fibres respond to stimulus in different ways.

The most significant physiological adaptations to muscle fibres occur when they are subjected to training programs that are specific to their role. While all muscles shorten and lengthen during movement, the bulk of the work is performed by muscles most suited to the specific type of activity. White muscle fibres benefit most by anaerobic training, such as sprints, short intervals and resistance training. Red muscle fibres benefit most from endurance type activities that engage the aerobic system.

Slow-twitch fibres contract slowly and release energy gradually as required by the body during sustained activity such as jogging, cycling and endurance swimming. These fibres are efficient in using oxygen to generate fuel (ATP), making them resistant to fatigue but unable to produce the power of fast-twitch fibres. When the body is engaged in endurance-type activity, slow-twitch fibres are preferentially recruited for the movement because they are more efficient in meeting the immediate metabolic demands of the working muscles.

Aerobic training causes the following adaptations to occur in muscle fibres.

- **Hypertrophy.** Endurance activity such as jogging recruits slow-twitch fibres, which experience some growth.
- **Capillary supply.** Aerobic training causes an increase of up to 15 per cent in the number of capillaries surrounding muscle fibres. This significantly improves muscle efficiency by improving gaseous exchange together with the movement of nutrients and waste between blood and fibres.
- **Mitochondrial function.** Mitochondria are the energy factories of cells, the ‘powerhouses’ where ATP is manufactured. Aerobic training results in an increase in the number of mitochondria, as well as increasing their size and efficiency in utilising oxygen to produce ATP (see figure 5.47).
• **Myoglobin content.** Myoglobin is very important in the functioning of muscle action, quantities of which are characteristically much higher in slow-twitch fibres. Myoglobin is responsible for transporting oxygen from the cell membrane to mitochondria and storing it for use when necessary. Endurance training significantly increases myoglobin content, in some cases by up to 80 per cent.

• **Oxidative enzymes.** The level of activity of oxidative enzymes increases, making the production of energy more efficient.

Fast-twitch (FT) or white fibres contract quickly but fatigue rapidly, a feature of anaerobic metabolism used to supply their energy needs. There are two types of fast-twitch fibres — FT_a and FT_b. FT_a fibres are intermediate fast-twitch fibres that can produce a high output for lengthy periods because they have the ability to draw on both aerobic and anaerobic metabolism to support contraction. FT_b muscle fibres are ‘classic’ white fibres, possessing high amounts of glycolytic enzymes and drawing energy solely from anaerobic sources. It is thought that training intensity can alter the relative proportions of subtypes in FT muscle fibres, with high amounts of explosive work potentially changing some FT_a to FT_b fibres.

The body preferentially recruits fast-twitch fibres to perform explosive type activities such as weight-lifting, javelin throwing and sprinting. White fibres have a high anaerobic capacity because they are able to contract quickly and ultimately release energy rapidly.

Anaerobic training causes the following adaptations in fast-twitch fibres.
• **ATP/PC supply.** Fuel supply and the efficiency with which fuel is used increases.
• **Glycolytic enzymes.** These increase, improving the functioning within cells.
• **Hypertrophy.** This has the potential to be considerable and depends on the type of training, frequency and intensity.
• **Lactic acid tolerance.** Training increases the ability of FT fibres to tolerate lactic acid, allowing anaerobic performance to be sustained for longer periods of time.

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**Inquiry**

**Principles of training, physiological adaptations and improved performance**

Use the following list of questions to examine the relationship between principles of training, physiological adaptations and improved performance.

1. What type of performance is best improved by aerobic training?
2. What type of performance is best improved by anaerobic training?
3. What principles are most important in causing a training effect in predominately aerobic performances?
4. What principles are most important in causing a training effect in predominately anaerobic performances?
5. What adaptations take place in the following areas as a result of training?
   (a) resting heart rate
   (b) stroke volume
   (c) cardiac output
   (d) oxygen uptake
   (e) lung capacity
   (f) haemoglobin level
   (g) muscle hypertrophy
   (h) fast/slow-twitch fibres

6. Use sporting examples to analyse the importance of:
   (a) overload in developing muscle hypertrophy
   (b) training thresholds in improving stroke volume and cardiac output
   (c) specificity in improving oxygen uptake
   (d) reversibility on resting heart rate
   (e) variety on haemoglobin levels
   (f) warm-up and cool-down on lung capacity.
Inquiry

Summarising physiological responses and adaptations

Copy and complete the diagram in figure 5.47 to create an overview of the physiological adaptations in response to training (refer to sub-topic 5.4).

FIGURE 5.48 Physiological adaptations

Physiological adaptations to aerobic training

5.5 Topic review

5.5.1 Summary

- The human body has three systems that provide energy — the alactacid, lactic acid and aerobic systems. They are commonly called energy pathways.
- All energy systems function by converting the chemical energy in food into ATP, which enables muscular contraction.
- Fuel energy is efficiently stored in high energy bonds within adenosine triphosphate (ATP) and its backup energy supply, creatine phosphate (CP).
- There is limited ATP in the body. ATP breaks down quickly when we move and needs to be resynthesised to once again provide energy. The study of energy systems is about mechanisms for building up the partly destroyed ATP molecule.
- The alactacid system provides energy for maximum activity lasting about 10 to 12 seconds. Its fuel source is creatine phosphate and the system does not produce any by-products.
- The lactic acid system provides energy for anything up to two to three minutes of moderate to high intensity exercise and longer for low intensity exercise. Its fuel source is glycogen. In contrast to the alactacid system, the lactic acid system generates a by-product called lactic acid, which can inhibit performance.
- The aerobic system provides energy for sustained work of moderate intensity. It uses carbohydrate and fat to provide large quantities of ATP. Carbon dioxide and water are the by-products, neither of which are harmful to performance.
- The four main types of training are aerobic, anaerobic, flexibility and strength.
- Aerobic training methods include continuous, Fartlek, aerobic interval and circuit training. These help improve the efficiency of the cardiorespiratory system.
- The most common method used to improve anaerobic performance is anaerobic interval training. This is characterised by repeated bursts over short distances at high intensity.
• Four methods are used to improve flexibility: static, ballistic, PNF and dynamic. The choice of method used depends mostly on the sport or activity to follow.
• There are two types of strength training — isotonic and isometric. By far the most commonly used is isotonic, where muscle length changes as weights are lifted and lowered.
• Different types of equipment can be used to improve strength including free weights, fixed weights, elastic bands and hydraulic machines. Many factors influence choice of equipment including availability and the intention of the program; for example, power or strength endurance.
• The six most important principles of training for performance improvement are progressive overload, specificity, reversibility, variety, training thresholds and warm-up/cool-down.
• Progressive overload implies that the load needs to be increased as we become comfortable at the existing level of resistance.
• Specificity focuses on the closeness of the relationship between what we do in training and what we are required to do in the game.
• Reversibility implies that fitness, strength and flexibility will be lost once training ceases.
• The principle of variety suggests that the training program needs to include a diverse range of challenging skills to ensure that motivation remains high.
• Thresholds refer to levels of intensity. The lowest level of intensity that will produce a training effect is the aerobic threshold. The highest level is the anaerobic threshold. The zone between the thresholds is the training zone, the area where we need to be working to improve performance.
• Warm-up and cool-down are essential to any training program, and particularly for the prevention of injury.
• Physiological adaptations refer to changes that take place within the body as it responds to the stress of a training program. Heart rate is lowered, stroke volume is increased and cardiac output is increased significantly by aerobic training.
• The biggest difference between the trained and the untrained individual is in oxygen uptake. This refers to the ability of the working muscles to utilise the oxygen being delivered. Aerobic training considerably increases the functioning of the oxygen delivery system and contributes significantly to improved aerobic efficiency.
• Aerobic training improves haemoglobin levels mainly by increasing the volume of blood in the body.
• Muscle hypertrophy is a positive response to training, with fast-twitch fibres being slightly more responsive than slow-twitch fibres.
• Training improves the efficiency of both fast-twitch fibres and slow-twitch fibres. Slow-twitch fibres develop improved capillary function and, with the aid of more oxidative enzymes, enhanced ability to support endurance type movements. Fast-twitch fibres develop increases in glycolytic enzymes and increase their tolerance to lactic acid.

5.5.2 Questions
Revision
1. Explain the role of ATP in energy supply. (H7) (6 marks)
2. Explain how the alactacid system functions to supply energy in a 100 metre sprint. (H7) (4 marks)
3. Discuss the relationship between effort and fatigue in a 400 metre race. (H7) (5 marks)
4. Compare the efficiency of the energy systems with regard to their ATP production, by-products and rate of recovery. (H7) (6 marks)
5. Describe the fuel source for each of the energy systems. (H7) (3 marks)
6. Explain the possible causes of fatigue for a runner in an 800 metre event. (H7) (3 marks)
7. How does lactic acid accumulation affect performance? (H7) (2 marks)
8. Compare the work rate and fitness benefits for two athletes — one who trains regularly at a level of intensity close to the aerobic threshold and the other who trains close to the anaerobic threshold. (H10) (5 marks)
9. Identify the predominant energy system in each of the following activities and provide reasons for your selection. (H7) (10 marks)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Alactacid</th>
<th>Lactic acid</th>
<th>Aerobic</th>
<th>Why this system?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot-put</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triathlon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 metre run</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500 metre swim</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High jump</td>
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<td></td>
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<tr>
<td>Rock climbing</td>
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</tr>
<tr>
<td>Basketball</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Rowing</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Snooker</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 metre dash</td>
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10. Investigate how the energy systems function during a triathlon. (H7) (6 marks)
11. Explain the difference between continuous and Fartlek training. (H7) (2 marks)
12. List and briefly describe six activities that you would include in a circuit that aimed to develop aerobic capacity. (H8) (6 marks)
13. Choose two methods of flexibility training. Describe one exercise from each and suggest how progressive overload could be used to gradually improve flexibility using that program. (H8) (4 marks)
14. Explain how PNF stretching differs from ballistic stretching. (H7) (2 marks)
15. What are three important principles of training? How could they be used by a coach to improve aerobic capacity? (H8) (3 marks)
16. Explain why some athletes might choose to use free weights over other methods of strength training. (H10) (2 marks)
17. Explain how the principle of reversibility would apply to a resistance training program. (H10) (4 marks)
18. Outline the purpose of a warm-up in preparation for training. (H8) (2 marks)
19. Using a diagram, explain the difference between the aerobic and anaerobic thresholds. How can knowledge of thresholds improve performance? (H17) (4 marks)
20. Examine figure 5.40 (sub-topic 5.4.3). Explain the effect of endurance training on cardiac output. (H8) (2 marks)
21. Discuss the meaning of \( VO_2 \) max. Suggest why its measurement is commonly regarded as the most significant indicator of physical fitness. (H7) (3 marks)
22. Outline the long-term effects of aerobic training on haemoglobin levels and lung capacity. (H7) (2 marks)
23. Explain the term ‘muscle hypertrophy’. What type of training program contributes most to muscle hypertrophy? (H7) (2 marks)
24. Outline the effect of training on slow- and fast-twitch muscle fibres. (H7) (3 marks)

Extension
1. Compare the two anaerobic systems. (H7) (6 marks)
2. Complete a test of maximal aerobic power such as the Coopers 12-minute run or the multistage fitness test. (Use the relevant weblinks in your Resources tab to view these.) Determine your oxygen uptake and indicate what the readings mean. Discuss how the results could be improved. (H8, H16) (6 marks)
3. Investigate the training programs of a hurdler and a marathon runner. Outline the general activities that comprise their programs. Compare each in terms of use of energy systems, flexibility exercises and resistance training methods. (H7, H8, H10) (8 marks)
5.5.3 Key terms

**adenosine triphosphate (ATP)** is a high energy compound that stores and transfers energy to body cells, allowing them to perform their specialised functions, such as muscle contraction. *p. 146*

**aerobic interval training** involves alternating sessions of work and recovery. The rest period is important in differentiating aerobic interval training from anaerobic interval training. *p. 161*

**aerobic metabolism** is the breakdown of fuel in the presence of oxygen to produce energy (ATP). *p. 155*

The **aerobic threshold** refers to a level of exercise intensity that is sufficient to cause a training effect. This is approximately 70 per cent of a person’s maximal heart rate (MHR). *p. 179*

The **aerobic training zone** refers to a level of intensity that causes the heart rate to be high enough to cause significant training gains. *p. 179*

**anaerobic** means that the reaction occurs in the absence of oxygen. *p. 152*

**anaerobic glycolysis** is a process where glucose is broken down in the absence of oxygen to produce energy. *p. 152*

The **anaerobic threshold** refers to a level of intensity in physical activity where the accumulation of lactic acid in the blood increases very quickly. *p. 179*

**atrophy** refers to wasting away or decrease in size. *p. 187*

**capillaries** are tiny blood vessels that connect the smallest arteries to the smallest veins. *p. 156*

**cardiac output** is the amount of blood pumped by the heart per minute. *p. 184*

**chemical energy** is energy stored in bonds between atoms. *p. 146*

**circuit training** requires participants to move from one ‘station’ to another, performing specified exercises at each until they complete the circuit. *p. 162*

**creatine phosphate (CP)** is an energy-rich compound that serves as an alternative energy source for muscular contraction. *p. 148*

**dynamic stretching** uses speed and momentum with movements experienced in a game to increase flexibility. *p. 167*

In **Fartlek** (‘speed play’) training, participants vary their speed and the terrain on which they are working, ultimately engaging both anaerobic and aerobic energy systems. *p. 160*

**fast-twitch muscle fibres** or type II fibres reach peak tension quickly and are recruited for power and explosive movements such as throwing and lifting. *p. 188*

**flexibility** is the range through which joints and body parts are able to move. *p. 165*

**glycogen** is the storage form of glucose and is used for fuel when blood glucose levels decline. *p. 152*

**glycolysis** is the process of using glycogen or glucose as fuel. *p. 152*

**haemoglobin** is the substance in blood that binds to oxygen and transports it around the body. *p. 186*

**High intensity interval training (HIIT)** involves repeated bouts of high intensity exercise followed by varying periods of complete rest of recovery at lower intensity. *p. 164*

**muscle hypertrophy** is a term that refers to muscle growth together with an increase in the size of muscle cells. *p. 169*

A **kilojoule** (or calorie) measures the energy value of food. A calorie is the equivalent of 4.2 kilojoules. *p. 146*

The **lactate inflection point (LIP)** is a point beyond which a given power output cannot be maintained. It is characterised by lactic acid accumulation and decreased time to fatigue. *p. 179*

The **lactate threshold** is the point at which lactic acid accumulates rapidly in the blood. *p. 153*
lactic acid is a by-product of the incomplete breakdown of carbohydrate in the absence of oxygen. p. 148
lung capacity is the amount of air that the lungs can hold. p. 186
mechanical energy is motion or movement energy. p. 146
metabolism is the sum of all chemical processes within cells that transforms substances into energy. p. 153
A mole is the gram-molecular weight of a substance. 1 mole (mol) = 1000 millimoles (mmol). p. 152
muscle hypertrophy is a term that refers to muscle growth together with an increase in the size of muscle cells. p. 187
oxygen uptake is the ability of the working muscles to use the oxygen being delivered. p. 184
plyometrics refers to a special range of exercises in which a muscle is lengthened using an eccentric contraction. This is rapidly followed by a shortening or concentric contraction. p. 178
PNF stretching is a progressive cycle incorporating a static stretch, an isometric contraction and a period of relaxation in the lengthened position. It is aimed at stretching and strengthening muscle in a safe movement. p. 166
respiration is the process of breathing. p. 156
resting heart rate is the number of heartbeats per minute while the body is at rest. p. 182
resynthesis is the process of restoring ATP to its former state. p. 147
slow-twitch muscle fibres or type I fibres contract slowly and for long periods of time. They are recruited for endurance-type activity such as marathons. p. 188
static stretching is a safe form of stretching in which the stretch is held for a period of 10–30 seconds. p. 165
strength is the ability of a muscle or muscle group to exert a force against a resistance. p. 169
The stretch reflex is an involuntary muscle contraction that prevents fibre damage if muscles are lengthened beyond their normal range. p. 165
stroke volume is the amount of blood ejected by the left ventricle of the heart during a contraction. It is measured in mL/beat. p. 183