When individuals begin to train they are trying to improve the way their bodies function. They may wish to improve a particular way their bodies deliver and use energy or they may want to develop strength, flexibility or aerobic or anaerobic endurance. Regardless of the particular type of benefits they want to gain, there are many similarities in the way training programs are designed and the principles that underlie these programs. This chapter explores the way training programs can be designed and the effects on the body of individuals who undertake them.

Energy

Energy can be defined as the capacity or ability to perform work. Without energy there would be no light or heat and everything would be stationary and unchanging. When change takes place, the presence of energy in the process is revealed. Energy is fundamental to everyday living. We are all familiar with the common use of the term ‘energy’ as a description of performance for both humans and machines; for example, ‘I have no energy’ or ‘This washing machine is energy-efficient’. What do such comments mean? First, it is obvious that there are various forms of energy. Second, energy can be used in numerous ways. Third, energy can be measured.
Energy can be categorised into various forms, such as heat, light, electrical, nuclear, chemical and mechanical. Each of these can be converted from one form to another. For example, a light globe converts electrical energy into light energy; a gas heater converts chemical energy into heat energy.

For the purposes of human movement we are mainly concerned with the transfer of chemical energy into mechanical energy. In this process, the breaking of chemical bonds in molecules releases energy for use by the body. An excellent example of this transfer of energy is that of a football player who converts chemicals in the body (derived from food) into mechanical work (for example, jumping to take a mark). Heat energy is also given off in this transfer, which is why a person feels warm after jogging for a short while.

The body does not directly use the energy that is released in the breakdown of food; rather, the energy is used to make a chemical compound called adenosine triphosphate (ATP). Only when the energy is released by the breakdown of this compound can the cell perform its specialised function. This specialised function is dependent on the cell type. For example, cells in the intestine have a digestive function.

**Adenosine triphosphate**

Adenosine triphosphate (ATP) is an energy-rich chemical compound found within the cells of the body. It is almost always the source of energy for the reactions that take place in the body—especially for muscle contraction leading to movement.

As shown in Figure 5.1, ATP is made up of a smaller compound (adenosine) and three chained phosphate (P) groups (hence the name tri/phosphate). The final phosphate group is held on to the chain with a high-energy bond. A great deal of energy is released when this bond is broken and this provides the energy that powers the human body. It provides energy for all processes, from breathing and digestion through to muscular movement.

When ATP is broken down, it releases energy. ATP is broken down into adenosine diphosphate (ADP)—that is, adenosine plus two phosphates—and a separate phosphate group (see Figure 5.2).

![Figure 5.1](image1.png) An ATP molecule

**Figure 5.2** The breakdown of ATP

Food provides the source for ATP. Stored fuels, such as carbohydrates and fats, are not changed into ATP; rather, a portion of the energy that is released when these food chemicals break down triggers the joining together of molecules to form ATP.

**Energy from foods**

There is a strong link between what a person eats and the production of ATP. The three major nutrients found in food—carbohydrates, fats and proteins—all work in different ways to help with the production of ATP.

**Carbohydrates**

Carbohydrates are broken down by the body into glucose. This glucose is then stored in the muscles and liver as glycogen, which is a ready source of energy. Chemical reactions involving glucose or glycogen produce ATP. Sugars (simple carbohydrates) can provide muscle glycogen, but the best sources come from complex carbohydrates, such as grains, cereals, breads, legumes and vegetables. One gram of carbohydrate yields approximately 16 kilojoules of energy when broken down.

Complex carbohydrates are the best sources of muscle glycogen.
Fats

Triglyceride, which is found in fatty foods, is the digested form of fat for energy production. Triglycerides are stored in the muscles and are broken down when needed during exercise to produce glycerol and free fatty acids. Free fatty acids are the primary energy source when fat is used for energy. They can be stored in fat cells and in muscles.

Fatty acids can be stored as adipose tissue (body fat) or they can travel around the body in blood. These substances can produce ATP, but are usually used only at lower intensities over longer periods of exercise. One gram of fat yields approximately 37 kilojoules of energy when broken down.

Proteins

After digestion and absorption, proteins are broken down into amino acids. Under normal conditions, protein is not used to produce ATP. During extreme conditions (for example, starvation or prolonged exercise), however, protein will be used as a fuel source for ATP. Protein is used only when stores of fats and carbohydrates have been exhausted. One gram of protein yields approximately 17 kilojoules of energy when broken down.

Research and Review

1. Outline how energy is measured.
2. Identify the different forms of energy and provide an example of each.
3. Describe the process by which humans are able to engage in physical activity.

There is a strong link between what a person eats and the production of ATP.

**Figure 5.3** Examples of foods that provide energy
Energy systems

ATP does not exist in the muscles and tissues in abundant supply waiting for activity to occur. In fact, the small amount of ATP that is present provides only enough energy for a few seconds of intense activity. The body does not produce ATP continuously, so it must be recycled in a process known as resynthesis. This process rebuilds ATP from ADP using one of three energy systems. The energy system used by the body is dependent on:

- how long the activity will take place
- the intensity of the activity
- how quickly the activity is performed.

The three common energy-yielding processes for the replenishment and recycling of ATP are the:

- **alactacid system** (also called the phosphagen or ATP–PC system)
- **lactic acid** system (also called the anaerobic glycolysis system)
- **aerobic** system (also called the oxygen or oxidative system).

All three systems work in fundamentally the same way to resynthesise ATP. The energy that is released during the reactions occurring within them is used to recombine ADP and P to form ATP. This process is best described by the principle of coupled reactions. This means that the energy produced in one reaction is used to drive another reaction. The coupled reactions for the resynthesis of ATP are shown in Figure 5.5.

The major difference between the systems is that the alactacid and lactic acid systems both resynthesise ATP **anaerobically** (without oxygen present), whereas the aerobic system resynthesises ATP **aerobically** (with oxygen present).

![Figure 5.4](image1.png) **Aerobic and anaerobic energy systems**

![Figure 5.5](image2.png) **ATP resynthesis coupled reactions**

![Figure 5.6](image3.png) **Alactacid system**

**Research and Review**

1. **Explain** what is meant by ATP resynthesis.
2. **Describe** how coupled reactions allow the release of energy for ATP resynthesis.
3. **Define** the terms ‘anaerobic’ and ‘aerobic’.
Alactacid system (ATP-PC)

The alactacid system is used by the body to produce ATP when there is insufficient time to break down glycogen in the presence of oxygen for the replenishment of ATP. At the same time that ATP is being broken down in the muscle, another high-energy substance—phosphocreatine (PC)—is also being broken down. The cells contain more PC than ATP, so PC can be considered to be a phosphate reservoir. The breakdown of PC produces energy, which is used to join ADP and P back together to produce ATP. So the coupled reaction appears as in Figure 5.6 (page 85).

The amount of PC in muscles is limited. After about 5–10 seconds of maximal work the supply is depleted. This reduces its ability to contribute to movement and therefore another energy system is activated. High-intensity activity lasting for 10 seconds or less uses the ATP-PC system as the primary source of energy. Such activities include shot put, 100-metre sprint, jump shot and kicking a football. As the stores of PC are broken down, they are quickly restored; within 2 minutes if resting. This allows for the activity to be repeated in intense, short bouts, without immediate exhaustion. The only way that PC can be restored is to recombine the P and C released to resynthesise ATP. This is done during recovery. This system represents the most readily available source of ATP for use by the muscles. There are several reasons for this, including the following:

- It does not depend on a long series of chemical reactions.
- It does not depend on transportation of oxygen to muscles.
- Both ATP and PC are stored in the contractile tissue of muscles.

**Figure 5.7** The ATP in these athletes is waiting to explode

**Figure 5.8** Lactic acid system

**Critical inquiry**

Explain some of the facts and fallacies surrounding the subject of lactic acid. Use the Internet links below to assist you with your research.

Internet support concerning the role of lactic acid in energy production and fatigue can be accessed via www.oup.com.au/pdhpe12
**Lactic acid system**

The other system that does not require the presence of oxygen to resynthesise ATP in muscles is the lactic acid system. This system involves the partial breakdown (lysis) of glucose to form lactic acid in a series of 12 chemical reactions known as **glycolysis**. The glucose for this process comes either from glucose stored in the blood or from the breakdown of glycogen in the liver or muscles—known as **glycogenolysis**. These reactions occur within the cell. The simple coupled reaction for the resynthesis of ATP via the lactic acid system is shown in Figure 5.8.

The energy provided during this process is very important as it provides a relatively quick supply of ATP. Unfortunately, however, this process can yield only about 5 per cent of the number of ATPs that are produced when oxygen is available. (Yet it does yield more ATPs than by the alactacid system.) The lactic acid system is an important energy system because it provides a very quick supply of ATP for intense, short bursts of activity (usually 30–60 seconds, but may last up to 3 minutes). If the intensity of the activity is maintained, lactic acid will accumulate, which results in muscle fatigue and exhaustion. This will usually cause the performer to decrease the intensity of the activity, or to stop altogether.

To break down and remove lactic acid can take up to 2 hours, and an active recovery will aid this process. During this recovery time, the lactic acid is actually converted back to pyruvic acid.

**Activities using this system include:**

- 200-metre and 400-metre running sprints
- 50-metre and 100-metre swimming sprints
- medium-length sprints in sports such as soccer.

The lactic acid system can last up to 30 minutes if exercise occurs at a **sub-maximal** level (of about 60 per cent).

**Aerobic energy system**

In the previous two energy systems, energy is produced in the muscle. By contrast, aerobic glycolysis occurs in the specialised cellular compartments of the muscle cells known as **mitochondria**. The aerobic energy system can be divided into three main parts:

- aerobic glycolysis
- the Krebs cycle
- the electron transport system.

Each part plays a significant role in the resynthesis of a large amount of ATP, with water and carbon dioxide as by-products.

**Aerobic glycolysis**

In the presence of oxygen, glucose broken down into pyruvic acid is converted into a specialised enzyme called acetyl-coenzyme A (acetyl-CoA). This is the first of many reactions that make up the process of aerobic glycolysis.

**The Krebs cycle**

The enzyme acetyl-CoA enters into a series of reactions called the Krebs cycle, in which it is oxidised (broken down) to produce ATP, hydrogen and carbon. The ATP is used for energy, the carbon combines with oxygen to form carbon dioxide (which is breathed out) and the hydrogen moves on to catalyse the next reaction in the aerobic system. If the hydrogen remains, it will make the cell too acidic and unable to function correctly.

**The electron transport system**

The Krebs cycle feeds into another series of reactions called the electron transport system. Hydrogen, which has been produced in both the lactic acid system and the Krebs cycle, is picked up and taken to the electron transport system. Here the hydrogen atom is split into two parts: protons and electrons. The protons combine with oxygen to form water, which also acts to decrease the acidity of the cell. The electrons undergo more reactions to form the energy that allows ADP and P to resynthesise to form ATP.

During exercise, carbohydrates are the major source of fuel. As the activity continues, carbohydrate stores become depleted and fats become the major fuel source. (Fats require far more oxygen than carbohydrate to produce the same amount of ATP.) Protein will usually be used as an energy store only in extreme situations—when the previous two stores have been depleted.
Summary of the aerobic system
The major fuels for the aerobic system are:

- glucose (from glycogen stored in muscle tissue or the liver)
- fatty acids (from triglycerides in adipose tissue and blood)
- amino acids (from proteins stored in muscles or the liver; but these are not used for energy production to the extent of the two sources above).

This whole process is best understood by a diagram, as shown in Figure 5.10.

In summary, the general characteristics of the three systems by which ATP is formed appear in Table 5.1 (page 89).

During physical activity the body uses a combination of all three energy systems, depending on the duration and intensity of the activity. For example, soccer mid-fielders use the aerobic system to provide the constant energy required to continually move back and forth on the field—usually at moderate levels of intensity. Occasionally, they may need to sprint down the wing to assist in attack or defence. These short sprints usually last 3–10 seconds, and use the anaerobic energy systems. In most sporting situations, energy systems are used in various combinations.

Athletes should be able to pace themselves to ensure that their ATP supplies are not depleted too early in the race. If athletes go out too hard, or begin the final sprint too soon, lactic acid will accumulate to high levels and decrease their performance. Fatigue results when lactic acid levels are high and muscle glycogen stores are depleted. Coaches and athletes aim to delay the onset of fatigue until after the event. Table 5.2 explains the relative contributions of aerobic and anaerobic energy systems to the various running distances held in major athletic competitions. Table 5.3 shows the contribution of energy systems to a variety of sporting activities.
Table 5.1 ATP from all sources

<table>
<thead>
<tr>
<th>System</th>
<th>Source of fuel</th>
<th>Duration of system</th>
<th>Cause of fatigue</th>
<th>Efficiency of ATP production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alactic system (ATP-PC)</td>
<td>PC</td>
<td>Up to 10 secs</td>
<td>Depletion of PC stores</td>
<td>Rapid but limited</td>
</tr>
<tr>
<td>Lactic acid system</td>
<td>Glucose</td>
<td>Up to 3 mins</td>
<td>Build-up of lactic acid in muscles</td>
<td>Rapid but limited</td>
</tr>
<tr>
<td>Aerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic system</td>
<td>Glucose, fats, protein</td>
<td>Indefinite at low intensities</td>
<td>Depletion of fuel sources</td>
<td>Slow but unlimited</td>
</tr>
</tbody>
</table>

Adapted from ML Foss & SJ Keteyian, *Physiological Basis for Exercise and Sport*, 6th edn, WCB McGraw-Hill, USA

Table 5.2 Relative contributions of the energy systems to running events

<table>
<thead>
<tr>
<th>Duration of event</th>
<th>10 secs</th>
<th>30 secs</th>
<th>60 secs</th>
<th>2 mins</th>
<th>4 mins</th>
<th>10 mins</th>
<th>30 mins</th>
<th>60 mins</th>
<th>120 mins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic</td>
<td>90%</td>
<td>80%</td>
<td>70%</td>
<td>50%</td>
<td>35%</td>
<td>15%</td>
<td>5%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>Aerobic</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>50%</td>
<td>65%</td>
<td>85%</td>
<td>95%</td>
<td>98%</td>
<td>99%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Event (run)</th>
<th>100 m</th>
<th>200 m</th>
<th>400 m</th>
<th>800 m</th>
<th>1500 m</th>
<th>5000 m</th>
<th>10 000 m</th>
<th>Marathon</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic</td>
<td>ATP-PC/</td>
<td>ATP-PC/</td>
<td>ATP-PC/</td>
<td>Aerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
<td>PC/LA</td>
</tr>
</tbody>
</table>


Table 5.3 Various sports and their predominant energy systems

<table>
<thead>
<tr>
<th>Sport or activity</th>
<th>ATP-PC and anaerobic glycolysis</th>
<th>Anaerobic glycolysis and aerobic</th>
<th>Aerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Aerobic dance</td>
<td>5</td>
<td>15–20</td>
<td>75–80</td>
</tr>
<tr>
<td>2 Baseball</td>
<td>80</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>3 Basketball</td>
<td>60</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>4 Hockey</td>
<td>50</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>5 Football</td>
<td>90</td>
<td>10</td>
<td>Negligible</td>
</tr>
<tr>
<td>6 Golf</td>
<td>95</td>
<td>5</td>
<td>Negligible</td>
</tr>
<tr>
<td>7 Gymnastics</td>
<td>80</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>8 Rowing</td>
<td>20</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>9 Skiing</td>
<td>a Slalom, jumping</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>9 Skiing</td>
<td>b Downhill</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>9 Skiing</td>
<td>c Cross-country</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10 Soccer</td>
<td>a Goalie, wing, strikers</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>10 Soccer</td>
<td>b Halfbacks or sweeper</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>11 Swimming and diving</td>
<td>a Diving</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>11 Swimming and diving</td>
<td>b 100-m swim</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>11 Swimming and diving</td>
<td>c 400-m swim</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>11 Swimming and diving</td>
<td>f 1500-m swim</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>12 Tennis</td>
<td>70</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>13 Walking</td>
<td>Negligible</td>
<td>5</td>
<td>95</td>
</tr>
</tbody>
</table>

Adapted from ML Foss & SJ Keteyian, *Physiological Basis for Exercise and Sport*, 6th edn, WCB McGraw-Hill, USA
Tests of physiological responses of the energy systems

The following are three tests that explore the physiological responses of the three energy systems.

Performance-decrement test (ATP-PC)

Objective
To measure the degree to which performance is affected by engaging in various intensities of exercise

Equipment
- Measured distances of 35 metres and 70 metres
- Whistle, pens, recording sheet and witch’s hats
- Stopwatches (one for each person participating)

Procedure
1. Subjects should warm up.
2. Timers stand at the timing line; that is, the 35-metre mark along the 70-metre track. Timers will record each sprint time as subjects cross the line.
3. Subjects begin at one end line and prepare to run towards the other end line.
4. At the blast of a whistle, the subjects sprint 35 metres to cross the timing line, and then slow down and jog/walk to the other end line. The subjects turn, rest and prepare to sprint in the opposite direction. Six 35-metre sprints are performed: three in each direction. The time between whistle blasts (that is, between sprints) is 30 seconds. A 5-second warning signal is given before each whistle blast.
5. Each 35-metre sprint is timed to the nearest 0.01 seconds, and the time recorded.
6. If a subject starts a sprint before the whistle blast, the run will not count. That person will have to run an extra sprint.
7. At the end of the sprint, partners are to record (on the recording sheet) the feelings of the subject by asking questions regarding breathing, feeling in legs and overall body feelings. The subject’s heart rate is also recorded. Record in a copy of Table 5.4.
8. Once the sprint distance is covered, subjects are to continue to jog or walk until the heart rate returns to resting levels. Record the time that this takes.
9. The subjects then reverse roles with their partners.

Results
1. Time 1 is recorded. This time is set aside as the original base-line time. (Record this as Time 1.) Times 2–6 are then recorded. (Record these as Time 2, Time 3, Time 4, Time 5 and Time 6.)
2. Times 2–6 are then totalled, and averaged. (Record this as Average Time.)
3. The performance decrement is then calculated by subtracting the Average Time from Time 1. This difference is then expressed as a percentage of Time 1. Also record the data requested in procedure step 7 above; this will be used later.

400-metre sprint (lactic acid system)

Objective
To measure the degree to which performance is affected by engaging in various intensities of exercise

Equipment
- Measured distance of 400 metres
- Whistle, pens, recording sheet and witch’s hats
- Stopwatches (one for each person participating)

Procedure
1. Subjects are to work in pairs: one performing and one recording. Then roles are reversed.
2. An adequate warm-up is required. Take heart rates before the warm-up, and before the sprint.
3. Subjects are to sprint at maximal effort for 400 metres.
4. At the end of the sprint, partners are to record (on the recording sheet) the feelings of the subject by asking questions regarding breathing, feeling in legs and overall body feelings. The subject’s heart rate is also recorded. Record in a copy of Table 5.4.
5. Once the sprint distance is covered, subjects are to continue to jog or walk until the heart rate returns to resting levels. Record the time that this takes.
6. The subjects then reverse roles with their partners.

1.6-kilometre run (aerobic system)

To measure the degree to which performance is affected by engaging in various intensities of exercise

Equipment
- Measured distance of 1.6 kilometres
- Whistle, pens, recording sheet and witch’s hats
- Stopwatches (one for each person participating)

Procedure
1. Subjects are to run/walk for 1.6 kilometres, in company with a partner. Partners are to give encouragement and keep count of the laps completed.
2. Partners are to talk to the subject during and after the 1.6-kilometre run and record the subject’s feelings in a copy of Table 5.4. Record details at the end of the first lap, at the 800-metre mark (in the middle) and at the end of the 1.6 kilometres.
3. At the conclusion, subjects continue to jog/walk until heart rate returns to normal resting levels.
4. Partners reverse roles.

Results
1. Record the following:
   a. resting heart rate (HR upon waking in the morning)
   b. pre-event HR
   c. post-event HR
   d. time taken to recover.
2. Complete a copy of Table 5.4 for both the 400-metre sprint and 1.6-kilometre run.
Table 5.4  Energy systems recording sheet

<table>
<thead>
<tr>
<th>Event</th>
<th>Stage in event</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beginning</td>
<td>Middle</td>
<td>End</td>
</tr>
<tr>
<td>35-m sprint</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Breathing: rate, depth, ease</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Legs: sore, heavy, light</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Overall body feeling</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>400-m sprint</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Breathing: rate, depth, ease</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Legs: sore, heavy, light</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Overall body feeling</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>1.6-km run</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Breathing: rate, depth, ease</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Legs: sore, heavy, light</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>Overall body feeling</td>
<td></td>
<td>Not applicable</td>
<td></td>
</tr>
</tbody>
</table>

practical application

Physiological responses of the energy systems

1. Construct a flow chart of the processes involved in all three energy systems.
2. Describe one of the energy systems to your partner.
3. Perform the three tests on page 90. After completing each test, answer the related questions below.
   Performance-decrement test (ATP-PC)
   a. What happened to your times from trial 1 to trial 5?
   b. What does performance decrement measure?
   c. If you trained for this test, what would you expect your percentage score to do, and why?
   d. An average score for an elite sportsperson is 10 per cent or less. What does your score indicate and what type of training would improve it?

400-metre sprint (lactic acid system)
   e. Were you able to maintain the same pace for the entire lap?
   f. Describe the feeling in your legs. How long did the feeling last following the run?
   g. Compare the amount of energy you felt you used compared with the ATP-PC test.

1.6-kilometre run (aerobic system)
   h. Critically analyse how you experienced the energy systems operating in each of the three tests. Identify the changes in them.
   i. What is meant by an aerobic steady state? Explain in terms of the energy systems and fuel metabolism.
   j. Did you reach steady state at any time? How did you recognise this?

Research and Review

1. Identify the by-products of energy production and the process and rate of recovery for each energy system.
2. Explain which energy system is the most efficient at producing ATP.
3. Predict, using Table 5.3 (page 89), the predominant energy systems for the following activities: golf, 200-metre swimming, snowboarding, rugby league and lawn bowls.
4. Describe the use of the energy systems in a 1500-metre running event.
Fatigue and recovery

Fatigue
The causes of fatigue vary, and are usually activity-specific. For instance, the sensation of fatigue is different for a 400-metre runner than for a marathon runner. However, both will experience the feeling of an inability to continue at a given pace, or with increased exertion. Many factors affect performance, of which fatigue is one. Others are discussed elsewhere in this book.

There are generally three areas of the body that can account for the fatigue felt by an individual. These are the central and peripheral nervous systems, energy systems and muscle fibres.

Central and peripheral nervous systems
When people exercise at maximum intensity they get the sensation of exhaustion before it has actually occurred in the muscles. Examples of this are the footballers who make one more tackle when the crowd cheers them on, or the marathon runners who can manage a sprint when entering the stadium. This is, perhaps, a biological protective mechanism. It might be that, under certain conditions of fatigue, nerves in the central and peripheral systems are unable to activate muscles to work.

Energy systems
Each of the energy systems has its own process of fatigue. In the alactacid system fatigue occurs as a result of ATP-PC depletion. The aerobic energy system will fatigue due to muscle glycogen and blood glucose depletion.

Muscle fibres
Fatigue might occur if the muscle lacks oxygen, or is unable to contract due to insufficient blood flow; for example, as a result of an injury.

Lactic acid accumulation in the muscles and blood is often blamed for the onset of fatigue in short, intense activities. However, the lactic acid does not cause the fatigue. Rather, the fatigue is caused by a change in pH (a measure of overall acidity), which is brought about by the breakdown of lactic acid. The change in pH (in this case, a decrease) affects cell functions, and causes sensations of pain. Fatigue can also be caused by psychological and environmental factors.

### Table 5.5  Recovery times for various physiological functions

<table>
<thead>
<tr>
<th>Function</th>
<th>With active recovery</th>
<th>With rest only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restoration of ATP-PC</td>
<td>2 minutes</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Increase in oxygen consumption</td>
<td>3 minutes</td>
<td>6 minutes</td>
</tr>
<tr>
<td>Replenishment of muscle glycogen</td>
<td>10 hours (continuous exercise)</td>
<td>46 hours</td>
</tr>
<tr>
<td>Replenishment of liver glycogen</td>
<td>5 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Reduction of lactic acid in muscles and blood</td>
<td>30–60 minutes</td>
<td>1–2 hours</td>
</tr>
<tr>
<td>Restoration of oxygen stores</td>
<td>10–15 seconds</td>
<td>1 minute</td>
</tr>
</tbody>
</table>

Adapted from ML Foss & SJ Keteyian, *Physiological Basis for Exercise and Sport*, 6th edn, WCB McGraw-Hill, USA
Recovery

The processes that are involved in recovery from exercise are designed to restore the body to its pre-exercise state. The time to fully recover will depend on the type, intensity and duration of the exercise or activity. Table 5.5 suggests some recovery processes and rates.

In general, after an all-out exhaustive effort, an active recovery is recommended to restore ATP-PC stores and to remove lactic acid. Active recovery includes performing light tasks, such as slow running, walking, stretching and minor games. Post-activity ingestion of complex carbohydrates aids muscle and liver glycogen replenishment. Even athletes who do not exercise to exhaustion should still engage in active recovery, and in food and fluid replacement.

Excess post-exercise oxygen consumption (EPOC)

Have you noticed that at the end of a run you seem to be breathing in more air than you were during the actual run? Does your breathing return to its normal resting levels straight away? Most people have experienced these phenomena. With knowledge of energy systems, these physiological changes can be explained.

As we know from experience, our bodily functions do not return to normal immediately after exercise. Heart rate, body temperature and breathing all remain elevated following the completion of exercise. This is especially true after maximal exercise—in which case the body requires quite some time to return to resting levels. During sub-maximal effort, recovery occurs much more quickly.

The elevated physiological effects of exercise upon completion of exercise allow body temperature to return to normal, to assist in removal of lactate, and help in the replenishment of ATP-PC and glycogen stores to the muscles. Oxygen stores are also replenished during this time.

The amount of oxygen that is consumed above resting levels (once exercise has stopped) has traditionally been called the ‘oxygen debt’. More recently, it has been described as ‘recovery oxygen’ or ‘excess post-exercise oxygen consumption’ (EPOC).

Research and Review

1. Outline the reasons that exhaled air contains more carbon dioxide than does inhaled air.

2. a. Identify recovery activities and recovery times after each of the following:
   - a 50-metre swim sprint
   - a 10-kilometre cross-country skiing event
   - a basketball game.

   b. For each of the sports listed in task 2a above, identify which physiological functions need to be most carefully observed during recovery.

3. Explain the difference between rest recovery and active recovery.

4. Predict the way the body will respond during recovery following a 20-minute jog.

Figure 5.12 An active recovery can include food and fluid replacement
Types of training and training methods

For athletes to be prepared to perform they need to train. Coaches and athletes need to understand that there are various types of training that are specifically designed to develop aerobic capacity, strength and flexibility, and that each is closely linked to the energy systems and principles of training.

Aerobic training

The two most common training methods used for developing aerobic fitness are continuous training and aerobic interval training. There are a number of popular modifications of these two techniques.

Continuous training

The most common form of aerobic training is called continuous training. In this form of training, the heart rate is elevated and maintained by using jogging, power walking, cycling, swimming, aerobic floor classes, or any other form of exercise that elevates the heart rate. It should be performed continuously for a minimum of 20 minutes. Continuous training is generally of a long duration and moderate intensity: 70–85 per cent of maximum heart rate for 30 minutes to 2 hours.

Although continuous training is effective in producing a training effect, it might not necessarily replicate the performance requirements. In other words, it might not be specific enough for the requirements of some sports or positions, or it might be too difficult to train at the same level as the competition requires. Consequently, other forms of aerobic endurance training have been developed.

Aerobic interval training

Interval training involves the breakdown of the training period into intervals of exercise or work, followed by intervals of rest or relief. Two basic rationales underpin interval training. These are that such training:

- is better for adapting the nervous system to the movement patterns experienced in competition
- allows the athlete to exercise for a longer period of time at high intensity, thereby aiding adaptations in the aerobic metabolic systems in the muscle.

The major variables that are manipulated in interval training are time (duration) and intensity. These can be adjusted to provide improvements in both aerobic and anaerobic training.

In aerobic training, the duration of the exercise interval needs to be long enough to allow athletes to reach their maximal oxygen uptake (max VO2), but be short enough not to bring on fatigue. It is usually suggested that both brief and longer periods of exercise be included in interval training programs.

The intensity should allow athletes to reach their max VO2, but the rest intervals should usually be active, such as walking or jogging slowly. This helps to remove accumulated lactic acid from the blood, and allows athletes to train longer. Two factors that are important here are training time and training distance. Training time is the rate at which the work is to be completed.

Aerobic interval training involves moderate-duration and high-intensity ‘pace or tempo’ training: 85–90 per cent of maximum heart rate, very near to lactate threshold for 30–60 minutes in bouts of 4–10 minutes. Swimmers use this type of training regularly when they complete a series of sets while training; for example, completing five sets of 400 metres every 7–8 minutes. Runners might run 1200 metres then walk for half a lap then repeat the process four to five times.

Although interval training is highly regarded, it is only one of many forms of training. The application of intervals to a training program greatly benefits both athletes and non-athletes, but close attention needs to be paid to the methodology employed.

A website that explains how different intervals can be applied may be accessed via www.oup.com.au/pdhpe12
Fartlek training is the Swedish name for Speed Play. Speed Play is a combination of continuous training and interval training in that it involves continuous effort with periods of high intensity, followed by a recovery period. Generally speaking, the bursts of speed are usually of 5–10 seconds duration, and are repeated every 2–3 minutes. Speed Play is usually performed over undulating terrain (such as up and down hills) and is less formalised than interval training. The degree of aerobic versus anaerobic work is dependent on the athletes, and how they feel during the workout. The predominant improvement is seen in aerobic capacity. Speed Play can be easily adjusted to meet the needs of most athletes, and the needs of both interval and continuous systems.

An example of a Fartlek training session is:

1. Jog for 10 minutes to warm up, then stretch.
2. Run for 800–1500 metres at a fast, steady speed.
3. Walk rapidly for 3 minutes.
4. Run continuously for 2000 metres, interspersing with a 50-metre sprint every 300 metres.
5. Run three lots of 400 metres at a fast pace, with a 400-metre jog between each fast run.
6. Run slowly for 2 minutes.
7. Cool down and stretch.

Circuit training
Circuit training is an arrangement of exercises that requires the athlete to spend some time completing each exercise before moving on. It is an excellent way to improve mobility and, at the same time, build strength and stamina. Depending on the equipment available, circuits can be developed to improve general fitness or can be highly specialised to meet the specific needs of certain athletes. Circuit training usually consists of 6–10 strength-type exercises that are completed one after the other. Body parts are also alternated so that consecutive exercises don’t work the same muscle groups. The strength-type exercises can be interspersed with more aerobic-type activities, or with rest. A simple circuit can be performed up to three times in a training session, depending on time constraints.

There are two types of circuits: fixed resistance circuits and individual resistance circuits.

Fixed resistance circuits
In fixed resistance circuits, the resistance and the number of repetitions are fixed. The main advantage of this system is that the time taken to perform the circuit can be recorded to measure progress. For example, a person may perform 20 sit-ups, 20 push-ups, 100 skips, and so on, and time how long it takes to complete each circuit. As the time to complete the circuit falls the person may begin to increase the number of repetitions performed.

Individual resistance circuits
In individual resistance circuits, each exercise is carried out with a fixed resistance for as many repetitions as possible in a given period of time; usually 30 seconds. In some cases, athletes also count the number of repetitions that they perform in the fixed time period. This method allows individual athletes to work at their own pace, and is consequently very popular in commercial fitness centres.

Individual resistance circuits are very popular in commercial fitness centres as they allow individuals to work at their own pace.
Anaerobic training

Anaerobic training involves activities requiring the use of the two anaerobic energy pathways as the major supply of energy. This means that the activities undertaken need to have a very high intensity, with most activities being undertaken with a heart rate in excess of 85 per cent of its maximum level.

One of the most effective ways to train for the development of the anaerobic system is the use of short intervals (anaerobic intervals). As shown earlier, to develop aerobic endurance, intervals are designed to last for at least 4 minutes and rest periods are relatively short. Anaerobic intervals generally range between 10 seconds and 2 minutes, with a work to rest ratio of 1:3, meaning for every 10 seconds you work you rest for 30 seconds. The rest component of interval training, also known as the relief interval, may mean just (sitting and stretching following the activity) or it may involve some gentle work (such as walking or slow jogging). These ratios can be seen in Table 5.6.

The intervals are performed in sets of repetitions that are designed to overload the anaerobic energy systems. Maximal effort repetitions (those lasting for 10 seconds or less) are designed to improve the ATP-PC stores within the muscles. Slightly longer efforts (those lasting up to 2 minutes) aim to improve the body’s tolerance to lactic acid within the blood stream. There is not enough time for all the lactic acid to be removed from the body between repetitions and sets. Therefore, the body will be working with higher levels of lactate in the blood, which will lead to improved tolerance over time.

Many teams use anaerobic intervals in their training to develop the speed component their sport requires. For example, football teams will spend the early part of preseason training developing an aerobic base within the players and will then design and employ an anaerobic interval program in the weeks leading up to the start of the season to increase the speed and anaerobic endurance of the players before the first game. Table 5.6 outlines the way running and swimming can be used to design anaerobic interval training programs.

More information on anaerobic training can be found in Option 4 (Improving Performance) in this book.
Flexibility training

Flexibility is the ability of joints to bend, stretch and twist through a range of motion without injury. Each joint has a specific range of motion. This range varies from person to person—with elite performers displaying better flexibility than those who are inactive. Thus, the degree of flexibility depends on the person, the joint and the form of exercise in which the person engages (specificity). Flexibility is important in:

- preventing injuries and muscle soreness
- improving the body’s mechanical efficiency
- increasing the ability of muscles to stretch
- improving coordination among muscle groups
- improving the relaxation of muscles
- reducing the tightening of muscles after performance
- counteracting the restricting effects of muscle growth resulting from resistance training.

Within each muscle there exist sensory nerve endings called ‘muscle spindles’. The main function of the muscle spindles is to send messages back from the muscle to the brain about the state of the stretch. When a muscle is stretched, the muscle spindles automatically protect the muscle from over-stretching. They do this by counteracting the stretch—a so-called stretch reflex. The degree of force exerted by the stretch-reflex mechanism is proportional to the force and speed of the stretch. When these two forces work against each other, the likelihood of muscle tearing increases. To avoid this, muscles must be stretched slowly, and stretches must be held in a pain-free position after a suitable warm-up.

Table 5.6  Pertinent information for writing interval training prescriptions based on training distances

<table>
<thead>
<tr>
<th>Major energy system</th>
<th>Training distances (m)</th>
<th>Approximate training time (min:sec)</th>
<th>Sets per workout</th>
<th>Repetitions per set</th>
<th>Work–relief ratio</th>
<th>Type of relief interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alactacid</td>
<td>Run 50 Swim 25</td>
<td>0:10</td>
<td>5</td>
<td>10</td>
<td>1:4</td>
<td>Rest–relief (e.g. walking, flexing)</td>
</tr>
<tr>
<td></td>
<td>Alactacid or lactic acid</td>
<td>200 Run 50 Swim 50</td>
<td>0:30–0:45 1:20–1:30</td>
<td>4 2</td>
<td>1:3 1:2</td>
<td>Work–relief (e.g. light to mild exercise, jogging)</td>
</tr>
<tr>
<td>Anaerobic: glycolysis or aerobic</td>
<td>600 Run 125–150 Swim 200</td>
<td>1:45–2:15 2:30–3:00</td>
<td>1 2</td>
<td>5 2</td>
<td>1:2 1:1</td>
<td>Work–relief Rest–relief or work–relief</td>
</tr>
</tbody>
</table>

Data from EL Fox and Donald K Mathews, Interval Training: Conditioning for Sports and General Fitness, WB Saunders, Philadelphia

A website that explains anaerobic intervals can be accessed via www.oup.com.au/pdhpe12

practical application

Anaerobic interval training

Outline an anaerobic interval training program for a sprinter and another for an 800-metre runner.
Types of stretching

There are four types of stretching: static, dynamic, ballistic and proprioceptive neuromuscular facilitation (PNF).

Static stretching

Static stretching is also called ‘passive stretching’. This involves the gradual lengthening of the muscle to a point where it is held for 10–30 seconds. The point at which it is held should elicit a stretched feeling within the muscle. Static stretching is a safe and effective method of stretching muscles and joints because it is slow and sustained, and because it overcomes the stretch-reflex mechanism and allows the muscle to be stretched to its fullest possible length.

Dynamic stretching

Dynamic stretching is also called ‘active’ or ‘range-of-motion’ (ROM) stretching. It stretches muscle groups that cross over joints. Dynamic stretching involves the gentle repetition of the types of movements that will be experienced in a performance. It is usually very specific to the performance. Such stretching is commonly carried out in an exercise class to music. First the body is warmed up using rhythmic movements of the large muscle groups. Following the warm-up, the body is stretched to gently take the major joints through their full range of motion before increasing the intensity. An example of this type of stretching is a full lunge where the back knee touches the ground before the next leg is moved forward.

Ballistic stretching

Ballistic stretching is generally known as ‘bounce stretching’. It was very popular in the 1950s and 1960s but has since been discredited because of the damage it causes to muscles. Due to the force of the stretch, the stretch reflex comes into play and places great pressure on the muscle fibres. Extended use of ballistic stretching will, in fact, decrease flexibility. This is because it leaves muscles in a state of contraction and the repair of the micro tears (and, in some cases, macro tears) leads to a further reduction in flexibility. However, ballistic stretching can be useful in some performances where ballistic and explosive actions are required. In these cases it should form part of the third stage of warm-up after a general warm-up, a static stretch period and an active stretch period.

Proprioceptive neuromuscular facilitation (PNF) stretching

Another form of stretch is known as proprioceptive neuromuscular facilitation (PNF). This has emerged from the field of rehabilitation, and is one of the most effective forms of stretching. It is based on two guiding principles:

- A muscle can relax better after it has undergone a maximum isometric contraction as its resistance to stretching is reduced.
- A muscle becomes stronger if its antagonist is isometrically contracted immediately beforehand.

PNF stretching involves:

- a static stretch
- an isometric contraction that is held for 6 seconds
- a further static stretch, which may be assisted.

Due to the nature of the stretch, overstretching is a possibility. A person performing this form of stretching should therefore watch for a feeling of tension, mild pain or quivering muscles.

Critical inquiry

Outline why a high degree of flexibility is not desired for all sports.

practical application

Stretching

1 a In small groups, develop one of each of the following types of stretches for each of the major muscle groups in the body:
   - static
   - dynamic
   - ballistic
   - PNF.

b Demonstrate your stretches to the class after a suitable warm-up.
Strength training

The term ‘strength training’ implies that strength can be improved through training. Strength can be defined as the ability of muscles to exert force. The greatest force that muscles can exert in a single maximal effort is said to be the performer’s absolute strength. There is a close relationship between strength and sports performance.

To develop strength, resistance must be applied to muscles as they contract. Often strength training is called resistance training. This resistance can take the form of:

- the person’s own body weight
- barbells or dumb-bells
- weight machine systems
- hydraulic resistance machines
- elastic bands
- water (such as swimming or aquarobics)
- pulleys or levers.

Different sporting activities involve different forms of resistance and require different types of resistance training. A swimmer encounters resistance in the water while swimming, but this type of strength training is vastly different from the training undertaken by a shot putter who needs to lift very heavy weights in a fast, explosive manner.

It is helpful to know some of the jargon associated with strength training:

- **repetitions (reps)**—the number of times an exercise is repeated without rest
- **sets**—the number of groups of repetitions of a particular exercise
- **resistance**—the amount of weight used as a load
- **repetition maximum (RM)**—the maximum number of repetitions that can be completed with a given resistance before fatigue becomes apparent; for example, ‘6 RM’ is performed when only six repetitions can be completed, and not seven
- **rest**—the time necessary for the muscle to recover after periods of overload.

Why do improvements occur after strength training? Strength improves because there is an increase in the size of muscle fibres (hypertrophy). This allows for a greater force to be produced during a maximal contraction. In addition to this increase in the size of muscle fibres, connective tissues (such as tendons and ligaments) are strengthened, which makes the athlete more able to resist injury. Another factor in strength training—particularly in explosive-type activities—is the ability to maximise the number of muscle fibres working to produce a movement and to coordinate the timing of their contraction. This allows the muscle to produce greater force. Therefore, strength can be enhanced through adaptations within the muscle and within the nervous system.

Resistance training can be used in numerous ways to obtain gains in the following:

- **strength**—the ability to exert force
- **power**—the ability to exert force in a short period of time
- **endurance**—the ability of the muscle to repeatedly contract against a resistance
- **muscular bulk**—an increase in muscle tissue leading to an increase in muscle size
- **aerobic conditioning**—the capacity of the heart and lungs to pump blood to working muscles.

Table 5.7 highlights how resistance training can be used to develop different forms of strength.

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### Table 5.7 Guidelines for an effective resistance training program

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Weight</th>
<th>Repetitions</th>
<th>Sets</th>
<th>Exercise/speed</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Advanced: 2–6 RM</td>
<td>2–6</td>
<td>3–6</td>
<td>Slow/medium</td>
<td>3–5 mins</td>
</tr>
<tr>
<td></td>
<td>Beginner: 8–12 RM</td>
<td>8–12</td>
<td>2–3</td>
<td>Slow/medium</td>
<td>2–3 mins</td>
</tr>
<tr>
<td>Power</td>
<td>Medium/heavy 6–12 RM</td>
<td>2–10</td>
<td>3–6</td>
<td>Fast</td>
<td>3–5 mins</td>
</tr>
<tr>
<td>Endurance</td>
<td>15+ RM</td>
<td>15–30</td>
<td>2–3</td>
<td>Medium</td>
<td>1–3 mins</td>
</tr>
<tr>
<td>Lean body mass</td>
<td>4–10 RM</td>
<td>6–20</td>
<td>3–10</td>
<td>Slow/medium</td>
<td>1–3 mins</td>
</tr>
</tbody>
</table>

Adapted from ML Foss & SJ Keteyian, *Physiological Basis for Exercise and Sport*, 6th edn, WCB McGraw-Hill, USA and <www.brianmac.demon.co.uk/strength.htm>
The variations in training for each type of strength are dependent on a number of factors. Basically, however, a muscle or muscle group will strengthen only if it has been stressed beyond normal. Therefore, the principle of progressive overload is very important in strength training, as is the principle of specificity.

When a muscle contracts it will tend to shorten. If a force is applied in the opposite direction to the contraction, however, the muscle might stay at the same length or even be lengthened. This other force might come, for example, from other muscles, an immovable object or another person.

**Types of contractions**

Two types of contractions play a major role in muscle development: static (isometric) and dynamic (isotonic and isokinetic) contractions. Isotonic contractions may be either eccentric or concentric.

**Isometric contractions**

Isometric contractions occur when tension is developed within the muscle but there is no change in muscle length during the contraction. An example is gripping a squash racquet. There is little or no joint movement as tension is developed in muscles when gripping the racquet. Some other examples include pushing against a wall, pulling against an immovable object and holding a heavy shopping bag.

Because there is no change in muscle length, isometric contractions are specific to particular joint angles. Isometric strength training is useful for developing strength in specific areas. Therefore, coaches need to select angles that are specific to the sport for which the person is training. Sports that require the same position to be held for some time (such as downhill skiing, judo and gymnastics) will particularly benefit from isometric training.

**Isotonic contractions**

Isotonic contractions are those that cause the muscle length to change as tension is developed within the muscle. These contractions are also known as dynamic contractions. In isotonic contractions the weight is a constant load; that is, the weight does not change as it is moved through a range of motion. But the tension developed within the muscle changes as it moves through the range of motion; for example, doing a biceps curl with a bar bell. Isotonic contractions can be eccentric or concentric.

Eccentric contractions occur when tension is developed in the muscle while the muscle is lengthening. Consider the example of a flexed elbow being pushed down by external force while this action is being resisted by the arm muscles trying to flex the elbow and bring the forearm towards the shoulder. In this example, the resisting muscle will lengthen while contracting.

Concentric contractions occur when tension is developed within the muscle as the muscle shortens during contraction. For example, in the first stage of a biceps curl the biceps shorten. This causes tension to develop in the muscle, allowing the weight to be lifted.

Isotonic strength training is often called ‘traditional’ weight training. It uses the body or weight resistance to improve strength. Although the weight is fixed, the tension developed within the muscle varies with the joint angle, and with the efficiency of the lever at the joint. Therefore, although isotonic training is effective, it cannot create the same tension within a muscle through its entire range of motion. This makes it only partially effective.
Isotonic weight training is based on the performance of repetition maximum (RM). As noted earlier, RM is the maximum number of repetitions that can be completed before the muscle is fatigued. The key issue here is fatigue. If the muscle is fatigued it cannot lift the weight. As emphasised earlier, the greatest tension developed within a muscle (when it contracts isotonically) occurs when the muscle is in a lengthened state. Therefore, fatigue is proportional to the degree of tension developed in the muscle in its lengthened state. This limits the effectiveness of training because fatigue is a measure of the muscle’s weakest point.

**Isokinetic contractions**

Isokinetic contractions occur when tension is developed in a muscle throughout its entire range of motion. As the muscle shortens, the resistance is increased to maintain constant tension at all joint angles, and all speeds of movement. Because maximal tension is developed throughout the entire range of motion, a muscle contracted isokinetically is comprehensively fatigued. For this reason, it is the most effective form of training for the development of muscular strength.

Unfortunately, specialised equipment produced by companies such as Cybex and Nautilus is required for isokinetic training. Other machines using the concept of variable resistance have been developed in an attempt to maximise training by providing a variable tension throughout the entire range of motion. Although effective, these machines fail to control the speed of movement. These machines are better known as ‘variable resistance machines’ rather than as ‘isokinetic machines’.

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**practical application**

**Strength training**

1. **Propose** an appropriate strength-training program for each of the following athletes:
   - a weightlifter
   - a sailboarder
   - an artistic gymnast
   - a boxer
   - a 50-metres swimmer

   Each program should include isotonic, isometric and isokinetic exercises.

2. a. **Undertake** a resistance training session at a local fitness centre or within the school using a variety of machines and free weights.
   b. **Analyse** the way each machine could be used to develop strength.

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**Research and Review**

1. **Distinguish** between static stretching and ballistic stretching.
2. **Describe** proprioceptive neuromuscular facilitation.
3. **Explain** the differences between strength training, power training and muscular endurance training.
4. **Discuss** the uses of static stretching and dynamic stretching to improve flexibility in rhythmic gymnastics, hockey goal-keeping and javelin throwing.
Principles of training

A major objective of training is to improve performance. The body has the ability to respond to physiological and environmental stressors and to adapt to them. This adaptation occurs over time and with practice and often leads to improved performance. Training programs are designed to challenge athletes mentally and physically in the pursuit of improving their exercise capacity and efficiency. The following principles can be applied to all types of training to improve performance:

- progressive overload
- specificity
- reversibility
- variety
- training thresholds
- warm-up and cool-down techniques.

Each of these will be considered in the coming pages. Two other terms you will need to understand are maximal effort (or work) and sub-maximal effort. These terms are used at various times throughout this text:

- Maximal effort refers to exercise at the highest intensity possible, which can only be maintained for a short period of time (such as sprinting).
- Sub-maximal effort refers to exercise at a rate less than maximal intensity, which can be maintained for a longer period of time (such as jogging).

It is often impossible to make an all-out effort for an extended period of time. Therefore, it is useful to use tests of sub-maximal intensity in order to predict maximal intensity.

Progressive overload

Every cell in the body is sensitive to various forms of stress, and is able to make a response. As you sit there reading, 2–3 million of your red blood cells are dying (and being replaced) and your muscle cells are repairing themselves. When you train or exercise, your cells are being damaged and your body’s resources are being used up; for example, ATP-PC, water and salts. That is why you feel weaker and more tired (rather than stronger) after a work-out, run, game or swim. How much weaker you feel after exercise depends on the intensity and duration of the exercise.

The cells of the body work to maintain homeostasis, which is the tendency of the body to maintain its internal environment at normal levels. Two responses occur: a repair response and an adaptation response. The second of these is a response that helps the body to adapt and respond better next time. This will minimise future damage and ensure that next time you do not feel as weak and tired.

The basic principle of progressive overload is that a training effect is produced when the system (for example, the cardiovascular system) or tissue (for example, muscle tissue) is worked harder than it is accustomed to working (that is, when it is ‘overloaded’). As the body adapts to the new levels, training should continue to be progressively increased.

This progressive overloading, over time, will produce greater maximal efforts in the system or tissues being trained.

Considerable stress must be placed on the system or tissue so that improvements can occur. Light, regular training will not achieve this. If gains are to be made, weights must become progressively heavier, running must become longer and training sessions must be harder. If there is too much overload, injuries can result; if there is too little, the training effect will decrease.

Specificity

The principle of specificity states that the type of exercise being used in training should be specific to the:

- task requirements
- energy systems required in the task
- muscle groups required in the task
- components of fitness involved in the task.

For example, to be competitive in their chosen sport, marathon runners need to develop the aerobic energy system—using leg muscles (not shoulders). A discus thrower needs to develop the ATP-PC system to throw while, at the same time, developing the shoulder, back and arm muscles specific for throwing and power. To put it simply—cycling isn’t running, and rowing isn’t swimming.

There is a place for cross-training; that is, training that is not specifically designed for the primary sport being pursued. Cross-training helps with:

- motivation
- maintaining an aerobic base
- avoiding or recovering from injury
- assisting with muscular balance.

Cross-training is a supplement to specific energy system training, however, and not a substitute for it.

Figure 5.19  Discuss throwers need to develop the ATP-PC system to throw and also develop the shoulder, back and arm muscles specific for throwing and power.
Reversibility

The effects of training are reversible. That is, if a person stops exercising (or fails to exercise often enough or hard enough), the training effects will be quickly lost, and the person’s performance will decline. **Reversibility** is evident in aerobic and anaerobic fitness, power, strength, muscular endurance and flexibility. After only one to two weeks of stopping or reducing training, significant physiological reductions can occur. Developing a maintenance program that is designed to maintain (but not improve) training levels can halt (or reduce) the degree of fitness lost. Many athletes engage in such a program during the off-season to maintain their fitness until the next season begins.

Variety

To become proficient at most sports, athletes need to train for many hours every week and over a number of years. This training can often become repetitious and boring, especially if the training is for endurance-type events or for activities involving few technical skills; for example, swimming, running or cross-country skiing. Astute coaches and athletes will vary training sessions to minimise the boredom. Unlike overload, **variety** of training is not absolutely necessary to improve performance. Variety does make training more interesting and fun, however, while achieving training goals.

Training programs should take into account the individual athlete’s current fitness level, injuries, interests, needs and skill level. Different training methods will be appropriate for different circumstances; for example, for an athlete recovering from an injury or for a young performer.

Some examples of variety in training include:
- warm-ups using similar sports; for example, netball at touch football training
- group or paired training sessions to provide a change in routine.

The key is to achieve the original training goals while maintaining interest.

Training thresholds

**Training thresholds** offer an explanation for the complex physiological changes that occur in the body in producing or maximising the training effect. Training thresholds are usually explained in terms of the maximum heart rate in relation to the volume of oxygen uptake (VO2). During exercise, the following three factors become important in relation to training thresholds:
- **heart rate**—the rate at which the heart beats is usually measured in beats per minute (bpm)
- **ventilation**—the amount of air breathed in one minute
- **blood lactate**—the by-product of the lactic acid system.

All these increase in proportion to the intensity of exercise.

It was thought that when athletes exercise at a steady state, or with slightly increasing intensity, most of the ATP produced comes from aerobic sources. However, scientists found that as exercise increases there is an even increase in the amount of lactic acid in the blood. This appears to be related to **maximum oxygen consumption** (max VO2), which is the greatest volume of oxygen used by the cells of the body per unit of time.

![Figure 5.20](image) Varied training programs incorporating different sporting activities makes training more interesting

*A threshold is a starting point for a new state or experience.*
This increase in lactic acid occurs in untrained athletes at around 50–60 per cent of max VO₂, and in trained athletes at about 60–85 per cent of max VO₂. This sudden rise in lactic acid represents an increasing reliance on the anaerobic energy system. Figure 5.21 shows the inflection point at which this occurs for trained and untrained athletes.

The point where lactic acid begins to accumulate can be described as the **anaerobic threshold**. The anaerobic threshold can be defined as that workload intensity (or level of oxygen consumption) at which anaerobic metabolism is increased; that is, when lactic acid starts to accumulate in the blood and muscles. The threshold is the maximum speed or effort that an athlete can maintain and still have no increase in lactic acid. Activity over this limit produces deterioration in performance.

The topic of anaerobic threshold is greatly studied and discussed in exercise physiology. There is argument over the accuracy of the name. Many suggest that **lactate threshold (LT)** or **onset of blood lactate accumulation (OBLA)** is a more precise term because anaerobic energy is produced even at rest, meaning that lactic acid is formed and removed continuously. The basic argument against the term ‘anaerobic threshold’ is that there is uncertainty as to whether the rise in blood lactic acid is due to lack of oxygen in the muscles or a result of other causes. These other causes have been measured, and are valid for describing the inflection point. They include:

- accelerated glycolysis (that is, the conversion of glucose and glycogen to pyruvic acid in the lactic acid system)
- increased use of fast-twitch muscle fibres (more fast-twitch activity leads to more lactic acid production)
- reduced rate of lactic acid removal (that is, lactic acid is produced and removed from the body, but when production exceeds the rate of disappearance, lactic acid accumulates in the blood).

It is possible that any one of the above, or a combination of factors (including lack of oxygen), might explain the LT or OBLA.

It is useful for athletes and coaches to know the inflection point at which LT/OBLA occurs. This information can help to place athletes in specific endurance events. It is a better indicator of aerobic endurance performance than is max VO₂, and it can determine training intensities for optimal improvements in aerobic endurance. The major limitations of using LT to improve performance are:

- It is difficult to measure.
- It requires blood tests and takes a long time.
- There is no real proven benefit in training at this level.
- Athletes differ in their rates of reaching LT.

The **aerobic training threshold** is the intensity at which an athlete needs to work to produce an aerobic training effect or a physiological improvement in performance; that is, an improvement in the body’s ability to use oxygen during exercise. This occurs at about 70 per cent of the person’s maximum heart rate, or at approximately 50–60 per cent of that person’s max VO₂. As exercise intensity increases, so do heart rate, ventilation and blood lactate. In fact, aerobic threshold can be defined as the training rate at which the baseline lactic acid level starts to rise. At this level of exercise, the person can conduct a conversation comfortably. Therefore, as Figure 5.22 shows, to obtain an aerobic training effect an individual should exercise in the aerobic training zone; that is, between the aerobic and lactate thresholds.

**Critical inquiry**

1. Discuss the term ‘anaerobic threshold’. Use the answers to the following questions to help formulate your response:
   a. What are the main issues surrounding the use of the term ‘anaerobic threshold’?
   b. Why is this term not totally acceptable to all?
   c. Which term do you prefer, and why?
Warm-up and cool-down techniques

Warming up and cooling down are important components of all training and performance sessions.

**Warm-up**

The **warm-up** involves warming up the body to prepare for the activity that is to follow. The warm-up increases blood flow to working muscles. This causes an increase in body temperature, which makes the muscles, ligaments and tendons more supple and elastic. The increase in elasticity within body tissues reduces the possibility of a muscular tear causing injury. The warm-up should also provide an opportunity to activate the motor neurons that may be required during the performance. A warm-up and cool-down is necessary for all types of training and performance.

A warm-up should include three stages:

- **General warm-up**
- **Stretching**
- **Specific warm-up**

**General warm-up**

The general warm-up involves a gentle use of the large muscle groups in a rhythmic manner. This will raise the heart rate, and should involve a progressive increase in intensity. A good indication that the body is adequately warm is the appearance of sweat on the forehead.

**Stretching**

The stretching stage of the warm-up involves stretching the major muscle groups in a slow manner. Each stretch should be held (without bouncing) for a period of 10–30 seconds. This is followed by a similar routine in which the specific muscles that will be used are also stretched, and then also held (without bouncing) for a period of 10–30 seconds. Some dynamic stretching has also been shown to be useful in preparing muscles for training or performance.

**Specific warm-up**

The specific warm-up stage involves practising performance-like activities that progressively increase the heart rate and use the muscles and ligaments involved. It should also incorporate the skills that will need to be used. This will help to activate the motor neurons required for the performance.

**Cool-down**

The **cool-down** is effectively the same as the warm-up, but in reverse. The cool-down allows for the active recovery mentioned earlier in this chapter and gives the body time to return blood to the heart, rather than letting the blood pool in the muscles. This allows the oxygenated blood to ‘flush out’ the waste products that form during activity and begin to rebuild the energy stores required for the next performance.

The cool-down should include a period of stretching that enables working muscles to be stretched to their original length, thereby reducing muscle soreness and aiding recovery.
Application of training principles

The basic principles of training can be applied, in varying degrees, to all types of training, including aerobic, anaerobic, strength or flexibility. When designing training programs for various sports or activities it is useful to know the predominant energy system that is involved. This will help to determine the type of training that will best improve performance.

As noted earlier, length and intensity of performance are the main factors that determine the energy system used. A number of sports have periods of intense all-out activity interspersed with long periods of relatively low activity. For example, running to make a tackle in hockey involves intense all-out exertion, whereas waiting for a short corner to be played involves relatively low activity. Hockey players therefore need a good aerobic base and so should not spend 80 per cent of their time in anaerobic training.

To train the body anaerobically, training needs to be of near maximum intensity and of short duration. To overload the anaerobic system you could increase the length of the sprints being undertaken or include more repetitions of sprints. Intensity can be determined by heart rate, pace or lactate threshold, or any combination of these. Frequent training sessions—perhaps four times per week—for a duration of 8–10 weeks are suggested.

Developing aerobic conditioning relies on similar principles to those of anaerobic conditioning. The main differences lie in the intensity of training and the duration of the work sessions. Increasing the distance or lowering the time to complete a set distance is an effective way to overload the aerobic energy system.

The overload and specificity principles are easily applied to strength training too. Strength exercises should be specific to the predominant energy systems involved and to the specific muscles and movement patterns required. Gains in strength are more pronounced if the muscles are progressively overloaded. This may be done by increasing the number of times a single weight is lifted and then, over time, increasing the weight—and then repeating this program. There are many more ways by which this can be done and they are discussed in more detail in Option 4 Improving Performance.

Stretching should be carried out on the specific muscles, tendons and ligaments that will be used in the sport or activity. Such activity should use a variety of techniques that stress these structures comfortably through the full range of movement needed. Improvements in flexibility do occur with practice and overload, but they are also reversible, as for all types of training effects.

Critical inquiry

1. Using a table such as the one below, propose ways in which the principles of training can be applied to aerobic and strength training. Suggest one sporting activity that relies heavily on aerobic training and then one that requires strength training.

<table>
<thead>
<tr>
<th>Overload</th>
<th>Variety</th>
<th>Specificity</th>
<th>Thresholds</th>
<th>Warm-up</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

b. Describe a basic exercise that might be used to improve performance and shows how the principle of training can be applied to the sport.
Physiological adaptations in response to training

When people undertake any type of training their main aim is to change some aspect of their body so that their performance improves. Whether they are undertaking strength training, aerobic training or anaerobic training or attempting to increase their flexibility, the process of training leads to changes in the body. These changes can influence future performances.

Many of the changes occur to the cardiorespiratory system and lead to an improved ability to deliver oxygen to working muscles, more efficient energy production and a greater ability to remove waste products. Other changes relate to the size and recruitment of the muscle fibres that produce the movements required when performing physical activity.

This section of the chapter will look at a series of adaptations that are experienced by the body following specific types of training and how these adaptations can lead to improved performance.

Before we begin to examine these changes, a number of terms need to be explained. These are rest, sub-maximal exercise and maximal exercise.

Rest is a state where no extra demands are placed on the body. Energy requirements are for the maintenance of normal bodily functions, such as breathing, heartbeat and digestion. This minimal level of energy is known as our basal metabolic rate.

Sub-maximal exercise is exercise performed at a level that leaves the heart rate in a plateau (a consistent rate for an extended period of time) below its maximum number of beats per minute. Generally, this level of exercise can be maintained for more than 20 minutes at a time. Jogging, lap swimming and road cycling are all examples of sub-maximal exercise. Tests such as the Queens College Step Test (see page 111) are also undertaken at a sub-maximal level so that improvements in fitness can be measured using a reliable test.

Maximal exercise is activity that leads to a heart rate that approaches its maximal level; that is, 220 BPM – age. Sprinting (100 to 400-metre running) and 100-metre swimming are examples of maximal exercise.

Resting heart rate

Heart rate is measured in beats per minutes and at rest will beat enough times per minute to deliver oxygen via the blood stream to all the cells of the body. This minimum requirement for oxygen is reflected by the resting heart rate. The amount of oxygen required at rest is determined by your basal metabolic rate. Your level of fitness does not have a significant influence on this requirement.

When you undertake an aerobic training program your heart will undergo a significant change and this can lead to a reduction in the number of beats required to meet the needs of the body at rest. In other words, your resting heart rate will fall as your body adapts to the training program being undertaken. Your heart rate will also be lower while undertaking sub-maximal work, such as a step test or other exercises where the same amount of work needs to be performed.
The main reason for the fall in resting heart rate is the increase in stroke volume (see Fig 5.26). This increase allows more blood to be pumped out for every beat the heart makes. Therefore, to deliver the same amount of oxygen to the body, fewer beats will be made. For example, an individual who has a resting heart rate of 72 beats per minute prior to a training program and a stroke volume of 70 mm per beat will have a cardiac output (see Fig 5.26) of 5.04 litres per minute. This amount of blood represents the basal metabolic rate for the individual. Following an aerobic training program, the individual's stroke volume may rise to 80 mm per beat. This would lead to a resting heart rate of 63 bpm, which is a fall of nine beats per minute (even though the person's cardiac output remains at 5.04 litres per minute).

Resting heart rate and heart rate during sub-maximal work both fall as a result of aerobic training. However, heart rate during maximal exercise will be the same for both trained and untrained individuals. The difference is that the trained person is capable of doing a lot more work at a maximal level than is the untrained person.

**Stroke volume and cardiac output**

The total amount of blood to leave the heart has a direct effect on the individual’s performance. The stroke volume of the heart and its cardiac output will determine the amount of blood being circulated and how much oxygen will reach working muscles.

**Stroke volume**

Stroke volume is the amount of blood that leaves the left ventricle each time the heart beats. The ability of the heart to push oxygen-rich blood into the arteries and towards working muscles is the biggest factor affecting an aerobic-based performance. The more blood that the heart can push out, the more work an individual will be able to do. The person will be able to exercise longer and faster.

Stroke volume is determined by a number of factors associated with the heart. These include the:

- size of the ventricles
- thickness of the ventricle walls
- flow of blood through the veins back to the heart
- volume of blood in the body.

Aerobic training has a positive effect on stroke volume and, therefore, on an individual’s potential to perform aerobically. Training causes the physical size of the heart and ventricles to increase. Additionally, the walls of the ventricles will become thicker and therefore stronger. These two factors allow more blood to enter the heart as it is now bigger and the stronger walls allow much more of the blood to be ejected each time a beat occurs.

When combined with an increase in blood volume, lower blood pressure and an improved ability to move blood through the veins back to the heart, a rise of 25 per cent in stroke volume can be achieved through aerobic training. That is, if stroke volume was 72 millimetres per beat prior to undertaking an aerobic training program this could be increased to 90 millimetres following a program. This increased stroke volume leads to higher cardiac output, more blood going to working muscles and improved performance in endurance events.

Stroke volume will increase regardless of whether exercise is being undertaken. At rest, stroke volume increases and this leads to the resting heart rate falling and cardiac output remaining steady. During sub-maximal exercise, stroke volume will have increased, resulting in a lower heart rate (again, cardiac output will remain steady). At maximum levels the increased stroke volume will lead to a large increase in cardiac output. It is this ability to deliver more blood to working muscles that improves performance for an individual following training.
Cardiac output

Cardiac output is the amount of blood leaving the heart each minute. To determine cardiac output (Q), multiply stroke volume (SV) by the number of times the heart beats (HR) per minute (Q = HR x SV). Cardiac output reflects the ability of the heart to deliver oxygen-rich blood to working muscles. This oxygen enables the aerobic energy system to produce ATP and therefore to maintain movement.

As discussed above, during rest and sub-maximal work, undertaking an aerobic training program does not change cardiac output results. This is because the energy demands are unchanged and the same amount of blood (oxygen) is required. The biggest change occurs during maximal exercise. As the maximum heart rate will be the same for a trained or untrained individual (that is, 220 – age), the greater stroke volume will lead to an increase in the cardiac output.

Table 5.8 shows us how a trained individual is able to deliver more blood to the working muscles: 19 litres per minute after training compared with 16.5 litres per minute before. This change is what has improved the individual’s potential following a training program.

Table 5.8  Cardiac output for trained and untrained individuals

<table>
<thead>
<tr>
<th>Exercise level</th>
<th>Volume of blood (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untrained</td>
<td>Trained</td>
</tr>
<tr>
<td>Rest</td>
<td>5.04</td>
</tr>
<tr>
<td>Sub-maximal</td>
<td>13.3</td>
</tr>
<tr>
<td>Maximal</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Oxygen uptake and lung capacity

The ability of the body to move oxygen into the blood stream and remove carbon dioxide from it is not only determined by the heart and its functioning. The size of the lungs and the ability of the blood to absorb and carry the oxygen to the working muscles are also important aspects of performance.

Oxygen uptake

Oxygen uptake is the amount of oxygen absorbed into the blood stream during exercise. As discussed earlier, if more oxygen reaches working muscles then they will be able to work for longer at a higher level. Improving this capacity is one of the goals of aerobic training.

Oxygen uptake is measured in litres per minute. Over many years, exercise physiologists (those who study the effects of exercise on the body) have determined how much oxygen is required to perform various activities. By using standard tests, such as the Queens College Step Test (see the Practical Application task on page 111) you can work out what your maximum oxygen uptake is. This figure is known as your max VO2 (maximum volume of oxygen).

The higher your max VO2 becomes the better your aerobic system is functioning, and this will lead to an improved performance in aerobic events.

For reasons shown earlier, the demands placed on the body during rest and sub-maximal exercise are unchanged as a result of aerobic training. During maximal efforts, the difference in oxygen uptake can be shown. Before training an individual may have a max VO2 of 2.5 litres per minute. After training this figure may rise to 3.2 litres per minute. Once again, the rise in the ability to deliver oxygen to the working muscles causes the improvement in performance after training.

Oxygen uptake improves following a training program for a number of reasons. These include the factors already discussed (such as improved stroke volume and cardiac output) as well as greater lung capacity and higher haemoglobin levels within the blood. All these capacities, when combined, allow the increased flow of oxygen-rich blood to working muscles.

Figure 5.27  The Queens College Step Test is used to measure oxygen uptake
**Lung capacity**

*Lung capacity* is the amount of air that can move in and out of the lungs during a breath. Many measures can be made of lung function, including tidal volume and vital capacity. The basic principle that needs to be understood is that the greater the volume of air that can be inhaled and exhaled during exercise the greater the amount of oxygen that can be absorbed into the blood stream. More oxygen leads to improved performance during aerobic work.

A number of adaptations associated with lung function occur as a result of aerobic training. Four of these are described below.

The number of breaths that can be taken during maximal exercise can be increased. As the muscles around the lungs become larger and stronger they can work faster. Maximal breathing rates can increase from 40 to 50 breaths per second as fitness develops.

The size of the lungs increases slightly, which allows for a greater volume of oxygen to be inhaled and carbon dioxide to be exhaled per breath. As the muscles are stronger a greater amount of the air inside the lungs can be exhaled each breath, leading to a greater turnover of the air as well.

The total amount of air breathed during exercise can increase as a result of training. The increase in lung size and the ability to breathe faster and more fully, allows pulmonary ventilation (the total volume of air moving through the lungs) to increase by up to 15 litres per minute.

The number of *capillaries* in the lungs will increase with training, allowing more oxygen to be absorbed with each breath taken in. In fact, with training, the volume of blood held within the capillaries of the lungs can rise by up to 80 per cent.

*Table 5.9*  Predicting max VO₂ from recovery heart rate

<table>
<thead>
<tr>
<th>Percentile ranking</th>
<th>Recovery HR, female (mL/kg min)</th>
<th>Recovery HR, male (mL/kg min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>128</td>
<td>120</td>
</tr>
<tr>
<td>95</td>
<td>140</td>
<td>124</td>
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<tr>
<td>90</td>
<td>148</td>
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<td>85</td>
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<td>15</td>
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<td>176</td>
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<td>10</td>
<td>184</td>
<td>178</td>
</tr>
<tr>
<td>5</td>
<td>196</td>
<td>184</td>
</tr>
</tbody>
</table>

Haemoglobin level

Haemoglobin is a protein found within red blood cells. Its main function is to absorb oxygen at the lungs and carry this oxygen to the working muscles via the blood stream. The make-up of haemoglobin allows it to absorb oxygen at a very fast rate and this leads to an efficient transportation system for oxygen within the body. It also plays some role in the removal of carbon dioxide from working muscles, but this function is not as important as its role in the delivery of oxygen.

When training takes place, cells within the body become short of oxygen. One of the ways the body adapts to this is to produce more red blood cells and haemoglobin. This allows the needs of these cells to be more easily met. While it is not a large increase, it will improve the ability of the individual to absorb and deliver oxygen to working muscles and this will improve performance in aerobic events.

Muscle hypertrophy

Muscle hypertrophy refers to the increase in the diameter of a muscle; that is, ‘bulking up’. This occurs as a result of strength or resistance training and, unlike the adaptations discussed above, not as a result of aerobic training.

Muscles fibres enlarge after training due to a number of reasons. These include the production of more myofibrils (the contractile part of the muscle). The fibres also enlarge due to the increased stores of glycogen and the energy-supplying compounds of ATP and phosphocreatine (PC).

Muscle hypertrophy will occur if an athlete lifts medium to heavy weights during training, such as training for strength, power or a lean body mass (see Table 5.7, page 99). The heavier weights being lifted will cause the muscles to undergo a significant amount of stress. This enlarges them so that the next time they work they are better prepared for the task; that is, they have adapted.

Queens College Step Test

The Queens College Step Test can be performed to experience some of the physiological responses to aerobic exercise.

Equipment
- Steps or bench with a height of 40 centimetres
- Metronome
- Stopwatch

Procedure
1. Set the metronome to a cadence of 88 steps per minute (22 complete step-ups) for women and 96 steps per minute (24 complete step-ups) for men. (A complete step-up is up with one foot, then the other, then one down, then the other.)
2. Subjects take their pulse rates before a warm-up. Have a 15-second step-up warm-up, then commence the test, which will be performed for 3 minutes.
3. At the end of 3 minutes, subjects stop and measure their pulse. Take the pulse for 10 seconds then multiply it by 6. Find the corresponding pulse rate in Table 5.9 and determine the predicted max VO2 for males and females.

Figure 5.28  Muscular hypertrophy is the result of body building

practical application

Queens College Step Test

1. Perform the Queens College Step Test, then complete the following tasks:
   - Outline the advantages and disadvantages of the Queens College Step Test.
   - Discuss whether this test is a reliable way to measure max VO2.

2. a. Research and participate in another sub-maximal exercise test.
   b. Analyse the similarities and differences between the above test and the Queens College Step Test.
As with other adaptations that occur as a result of training, hypertrophy takes time to develop, and reversibility (muscular atrophy) will occur when training ceases. Muscular endurance training (lifting light weights a large number of times) will assist in reducing the level of fat around the muscle and this will lead to muscular definition but not muscular hypertrophy.

After undertaking a resistance training program, muscles are capable of contracting with a greater force as more myofibrils are contributing to the contraction. This will improve performance in strength-related and power-related sports, such as throwing and sprinting.

**Effect on fast-twitch and slow-twitch muscle fibres**

Muscle fibres can be classified in three ways:

- red slow-twitch fibres—contain a large number of capillaries and produce a large amount of ATP slowly
- red fast-twitch fibres—contain some capillaries and can rapidly produce ATP but fatigue faster than slow-twitch fibres
- white fast-twitch fibres—contain few capillaries and rapidly generate ATP anaerobically.

The amount of each type of fibre in a muscle will depend on the normal function and use of the muscle. A long-distance runner may have up to 75 per cent of muscles as slow-twitch muscle fibre, while sprinters may have up to 80 per cent fast-twitch muscle fibre. Undertaking training that is specific to the requirements of your sport will assist in the development and adaptation of each of the muscle fibre types.

The development of slow-twitch muscle fibres is enhanced through participation in endurance-type activities, such as running, swimming and cycling. These activities encourage the creation of capillaries inside the muscle cells. This allows a greater transfer of oxygen into these muscles when they are working. This type of activity can also result in some fast-twitch muscle fibres being transformed into fibres that utilise oxygen to provide energy. The development of these muscle cells leads to improvements in aerobic endurance and higher levels of performance in events such as triathlon and road cycling.

Sports such as weightlifting and other power events, including jumping and sprinting, require the development of fast-twitch muscle fibres. These fibres can be trained by undertaking the same type of training that creates muscular power; that is, lifting medium to heavy weights quickly. For example, 100-metre sprinters will train the fast-twitch muscle fibres in their legs by undertaking power squats in which they jump off the ground at the conclusion. This type of training will not only increase the capacity of the fast-twitch cells already present in the muscle but will cause some of the red muscle fibres to transform into white fast-twitch fibre. By increasing the volume of this type of muscle fibre, future contractions can be made more quickly and anaerobic sources of energy will be utilised for longer.

**Research and Review**

1. Explain the link between the development of the cardiovascular system and the improvement in endurance activities. In your explanation, include a paragraph on each of the following:
   - a) stroke volume
   - b) cardiac output
   - c) oxygen uptake
   - d) lung capacity.

2. Analyse the application of the principles of training to a training program designed to create muscular hypertrophy.

3. Examine the need for an endurance athlete to undertake short-interval training.

4. Evaluate the effect of aerobic training on the ability of the body to deliver oxygen to working muscles.

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**practical application**

**Fast-twitch muscle training**

Working in pairs, design a weight training program for sprinters that will lead to the development of fast-twitch muscle fibres in their legs. Be specific with the types of exercises they should undertake and the way in which they should be completed.
The source of energy for muscle contraction is adenosine triphosphate (ATP).

Three energy systems are used to resynthesise ATP: ATP-PC, lactic acid and aerobic.

Each energy system provides energy and recovers at different rates, creates a range of by-products and can contribute to energy production for different periods of time.

Aerobic training can include continuous activities, such as running, swimming, circuit training and long-interval training. It is designed to improve the ability of the cardiovascular system to deliver oxygen to working muscles.

Anaerobic training involves high-intensity, short-duration exercise (such as interval training) designed to improve the two anaerobic energy pathways.

Flexibility training includes techniques such as static, ballistic, dynamic and proprioceptive neuromuscular facilitation (PNF).

Strength training utilises weight and hydraulic machines or other devices, such as elastic bands, to provide a resistance against which a muscle can contract. It is designed to improve the amount of force that can be exerted by the muscle during a contraction.

The design of a training program needs to include the principles of training, which are progressive overload, specificity, reversibility, variety, training thresholds and a warm-up and cool-down.

All training is undertaken with the goal of causing the body to adapt in some way so that an improvement in performance can be achieved at a later time.

1. **Predict** the changes to muscle fibre composition of continuous training.
2. **Explain** how ATP provides energy for muscular contractions.
3. **Construct** a list of sports that would benefit from isometric, isotonic and isokinetic training.
4. **Describe** the process of muscle hypertrophy.

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### Extension Activities

1. **Identify** aerobic training activities that will benefit a 100-metre swimmer.
2. Imagine you have been approached by a friend who is going to open a new gym in your town or suburb. **Recommend** a range of equipment that would benefit the development of strength for the gym’s customers.
3. **Analyse** the use of flexibility training to improve performance in a team sport of your choice.
4. Observe the table below showing an interval training program. **Evaluate** its effectiveness for a 1500-metre runner.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 x 40 m</td>
<td>30 secs</td>
</tr>
<tr>
<td>5 x 80 m</td>
<td>1 min</td>
</tr>
<tr>
<td>4 x 100 m</td>
<td>1.5 mins</td>
</tr>
</tbody>
</table>

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### Exam-Style Questions

1. **Identify** the by-products of energy production for the lactic acid and aerobic energy systems. (3 marks)
2. **Distinguish** the roles that interval training can play for aerobic and anaerobic performance. (8 marks)
3. **a** **Describe** four principles of training. (4 marks)
   **b** **Analyse** how these can be applied to a program designed to develop muscular hypertrophy. (8 marks)
4. **a** **Outline** the adaptations that can occur as a result of aerobic training. (4 marks)
   **b** **Explain** how these adaptations lead to an improvement in performance. (6 marks)