INQUIRY QUESTION
What would be the chronic adaptations that would allow Jared Tallent to perform at his best for the 50 km walk?
Chronic adaptations are the long-term physiological changes that occur as a result of participating in a training program. The types of adaptations that lead to improved performance are dependent on the specific type of training that is undertaken.

**KEY KNOWLEDGE**
- Chronic adaptations of the cardiovascular, respiratory and muscular systems to aerobic, anaerobic and resistance training

**KEY SKILL**
- Explain how chronic adaptations to the cardiovascular, respiratory and muscular systems lead to an improved performance

**CHAPTER PREVIEW**

<table>
<thead>
<tr>
<th>Cardiovascular</th>
<th>Respiratory</th>
<th>Muscular</th>
<th>Muscular</th>
<th>Neuromuscular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart size</td>
<td>Pulmonary ventilation</td>
<td>Heart rate</td>
<td>O₂ utilisation</td>
<td>Muscle hypertrophy</td>
</tr>
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<td>Heart capillarisation</td>
<td>Tidal volume</td>
<td>Cardiac output</td>
<td>a-VO₂ difference</td>
<td>Fuel stores</td>
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<tr>
<td>Stroke volume</td>
<td>Respiratory rate</td>
<td>Oxygen stores</td>
<td>Mitochondria</td>
<td>Enzymes</td>
</tr>
<tr>
<td>Heart rate</td>
<td>Pulmonary diffusion</td>
<td>Oxidative enzymes</td>
<td>Myoglobin</td>
<td>Motor unit recruitment</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>O₂ utilisation</td>
<td>Fibre type adaptation</td>
<td>Fuel stores</td>
<td>Lactate tolerance</td>
</tr>
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<td>Blood pressure</td>
<td>a-VO₂ difference</td>
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<tr>
<td>Muscle capillarisation</td>
<td>Mitochondria</td>
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<tr>
<td>Blood volume</td>
<td>Myoglobin</td>
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<tr>
<td>VO₂ maximum</td>
<td>Enzymes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lactate inflection point</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
12.1 Chronic training adaptations

**KEY CONCEPT** Chronic adaptations of the cardiovascular, respiratory and muscular systems occur as a result of long-term participation in a training program. These responses depend on the type, frequency, duration/time and intensity of the training undertaken.

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**Chronic adaptations** are the body’s long-term responses of the cardiovascular, respiratory and muscular systems that develop over a period of time when training is repeated regularly.

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Exercise or training undertaken regularly over an extended period of time (usually at least three times per week for a minimum of 6–8 weeks) leads to the development of chronic adaptations to training. Adaptaions occur when the body responds by making specific changes that allow it to better cope with the demands placed upon it. Some of these adaptations are evident when an individual is at rest and others can be measured when the body is engaged in exercise or activity. Some adaptations are apparent when the individual is working at submaximal exercise intensities, whereas others are evident when the individual is engaged in maximal exercise. Once achieved, these adaptations are retained unless training ceases. Upon cessation, the body will gradually revert to its pre-training condition. This process is referred to as reversibility or detraining (see chapter 11).

Chronic adaptations to training vary greatly and are dependent upon:

- the **type and method** of training undertaken — whether it be aerobic, anaerobic or resistance training. Chronic training responses are very specific to the type of training performed. This is known as the SAID principle: ‘Specific Adaptation to Imposed Demands’.
- the **frequency, duration/time and intensity** of the training undertaken — the greater the frequency, duration and intensity of training, the more pronounced the adaptations. However, factors such as overtraining and the principle of diminishing returns (see chapter 11) need to be considered in relation to this.
- the **individuals capacities and hereditary factors** (genetic make-up or potential), such as VO\textsubscript{2} max and muscle fibre-type distribution (fast-twitch as opposed to slow-twitch fibres). According to some research, 97 per cent of fibre types are genetically determined.

Chronic training adaptations may occur at both the system level, particularly the cardiovascular and respiratory systems, and/or within the neuromuscular system. The combined effect of all chronic adaptations is known as the training effect. Correct application of training methods and principles (see chapter 11), the use of fitness testing (see chapter 9) and monitoring training (see chapter 10) allow individuals to tailor, measure and monitor their progress to bring about the chronic adaptations described in this chapter.

**Chronic adaptations to aerobic training**

The minimum period for chronic adaptations to occur with aerobic (endurance) training is 6 weeks, although they are more evident after 12 weeks. Chronic cardiovascular and respiratory system adaptations to aerobic training are primarily designed to bring about the more efficient delivery of larger quantities of oxygen to working muscles. Specifically, the cardiovascular system increases blood flow and delivery of oxygen to the muscles, and the respiratory system increases the amount of oxygen available.

Aerobic training effects are developed through continuous, fartlek, long-interval and also high intensity-interval training. They may also be developed through circuit and resistance training if the exercises are designed specifically for aerobic and local muscular endurance benefits.

Chronic aerobic adaptations result in an increased ability of the athlete to produce ATP aerobically or an improved **economy**.
Oxygen delivery effectiveness is the most significant factor in aerobic exercise. 

O$_2$ delivery depends on:
- the ability of the lungs to ventilate large volumes of O$_2$
- the ability of the blood to exchange O$_2$ at the lungs (transported by haemoglobin in red blood cells)
- the ability of the heart to pump large volumes of blood to the muscles
  \[ Q = HR \times SV \]
- the ability of the muscles to extract O$_2$ from blood (role of myoglobin)
- the ability of the muscles to use O$_2$ to breakdown fuels to produce ATP (occurs in the mitochondria and requires enzymes (oxidative, glycolytic and lipolytic)).

**Chronic adaptations to anaerobic training**

The minimum period for chronic adaptations to occur with anaerobic training is 6 weeks. The greatest adaptations occur in the muscular system; however, changes also occur in the cardiovascular system. Adaptations to anaerobic training are designed to bring about increased muscle size (hypertrophy), enabling greater force production, power output, strength and speed. Further adaptations at the muscle tissue level improve anaerobic capacity and tolerance to metabolic by-products.

Anaerobic training effects are developed through short and intermediate interval training, plyometric training and circuit training (if designed with anaerobic-based exercises). Anaerobic adaptations will also be achieved by undertaking strength and power type resistance training.

**Chronic adaptations to resistance training**

Many athletes incorporate resistance training into their overall training program. It is an equally important method of training for elite athletes wanting to achieve higher levels of performance as it is for the general population in achieving necessary health benefits. Muscle size is a significant contributor in relation to the strength of a muscle, however, in the initial stages of undertaking a resistance training program, increases in strength can be attributed to the neural adaptations that occur. The neural adaptations are thought to have a substantial impact in the first 8 to 10 weeks of undertaking a resistance training program and after about 10 weeks of training, muscular hypertrophy becomes the predominant factor contributing to increased strength.

The specific neural adaptations that increase the strength and force production of a muscle are not fully understood, however there are some general factors that are thought to contribute and these are discussed later in this chapter.

**FIGURE 12.1** Each of these athletes will develop chronic adaptations specific to their training programs.
12.1 Chronic training adaptations

**TEST your understanding**

1. Define the term *chronic adaptation*.
2. Identify and discuss the three main factors that affect chronic adaptations to training.
3. Name the training methods used that develop:
   (a) chronic aerobic adaptations
   (b) chronic anaerobic adaptations.
4. Outline the main factor that explains strength improvements in the first few weeks of undertaking a resistance training program.

**APPLY your understanding**

5. Select one of the athletes depicted in figure 12.1.
   (a) Explain what type of training method would be most suitable for their sport.
   (b) Suggest the physiological adaptations that would be needed for them to be able to perform at the highest level in their particular sport.
**KEY CONCEPT** There are many cardiovascular adaptations (responsible for transporting oxygenated blood) that occur as a result of aerobic training.

### Increased left ventricle size and volume

Sustained aerobic training results in the enlargement of the heart muscle itself. This enlargement is referred to as cardiac hypertrophy. In endurance athletes, an increase in the size, and therefore volume, of the ventricular chambers, particularly the left ventricle, occurs (see figure 12.2(a) and (b)). This in turn significantly increases stroke volume and cardiac output at maximal intensities, allowing a greater volume of blood to be ejected from the heart, thus providing more oxygen for the athlete to use.

**Figure 12.2**: Effects of aerobic training on cardiac hypertrophy following intense, sustained aerobic training. The size of the ventricular cavities, particularly the left ventricle, increases.

(a) Untrained individual  
(b) Trained endurance athlete

### Increased capillarisation of the heart muscle

Cardiac hypertrophy also leads to an increase in the capillarisation of the heart muscle itself. The increased supply of blood and oxygen allows the heart to beat more strongly and efficiently during both exercise and rest.

**Figure 12.3**: Capillarisation (blood supply) to the heart before (a) and after (b) a long-term aerobic training program.

(a) Untrained individual  
(b) Trained endurance athlete

**Note**: Enlarged left ventricle

**Cardiac hypertrophy** is an enlargement of the heart muscle as a result of training.

**Capillarisation** is an increase in the capillary density and blood flow to skeletal or cardiac muscle as a result of aerobic training.
12.2 Chronic adaptations to aerobic training: cardiovascular

**Increased stroke volume of the heart**

The increased hypertrophy (capacity of the left ventricle) of the heart, reduced systemic peripheral resistance, a greater blood volume (plasma volume expansion), increased venous return and an increased ability of the ventricle to stretch are all factors that contribute to a significant increase in the heart’s stroke volume following aerobic training. Stroke volume is greater at rest, during submaximal exercise and during maximal workloads for a trained athlete compared with an untrained person. For example, the average stroke volume at rest for an untrained male is about 70–80 millilitres per beat, whereas trained male endurance athletes may have stroke volumes at rest of 100 or more millilitres per beat. During maximal exercise, these values may increase to about 110 millilitres per beat for an untrained person, and 130 millilitres per beat for a trained athlete (see figure 12.4).

Elite endurance athletes may have values as high as 190 millilitres per beat. Trained and untrained females have lower stroke volumes than their male counterparts under all exercise conditions, mainly due to their smaller heart size.

As greater stroke volume allows more oxygen to be delivered to the working muscles, this improves the athlete’s ability to use more oxygen and thus improves their ability to resynthesise ATP aerobically. This results in the athlete being able to work at higher intensities for longer, with fewer fatiguing factors, inevitably producing an improved overall performance.

**Decreased resting and submaximal heart rate and faster recovery heart rate**

An athlete's heart rate is a good indicator of their aerobic fitness. Aerobic training has a significant effect on an athlete's resting and submaximal heart rate and also how quickly their heart rate returns to pre-exercise levels during recovery. The effect that aerobic training has on an athlete's maximal heart rate is minimal, as this is largely affected by age and genetics.

**Decreased resting heart rate**

The amount of oxygen required by an individual while at rest does not change as a result of their training status. At rest, it takes about 5 litres of blood per minute (cardiac output) to circulate around the body in order to supply the required amount of oxygen to the body cells (whether the individual is trained or untrained). Cardiac output ($\dot{Q}$) is equal to stroke volume (SV) multiplied by heart rate (HR): 

$$\dot{Q} = SV \times HR$$

However, if an individual has developed a greater stroke volume, the heart does not have to beat as frequently to supply the required blood flow (and oxygen); the heart is more efficient. For example, before training:

$$\dot{Q} = SV \times HR$$

5 L/min = 70 mL/beat × 71 beats/min

After training:

$$\dot{Q} = SV \times HR$$

5 L/min = 100 mL/beat × 50 beats/min

It is for this reason that the resting heart rate is a useful indicator of aerobic fitness. Generally, the lower the resting heart rate, the greater the individual’s level of aerobic fitness. Resting heart rate may be as low as 35 beats per minute for elite endurance athletes, such as marathon runners, triathletes, road cyclists and distance swimmers, compared with the average resting heart rate of around 70 beats per minute for an average adult male.
**Decreased heart rate during submaximal workloads**

Trained aerobic athletes have lower heart rates at submaximal workloads compared with those of untrained individuals. This is mainly a result of their increased stroke volume, which means that more blood is pumped with each beat of the heart, and therefore the heart does not have to work as hard to supply the required blood flow and oxygen. Put quite simply, the heart works more efficiently.

Regular aerobic training also results in a slower increase in heart rate during exercise and a faster attainment of a steady state during similar exercise intensities as prior to training. Figure 12.5 clearly indicates the training effect on heart-rate response to submaximal workloads.

**Faster heart rate recovery rates**

Faster heart rate recovery rates mean that the heart rate of a trained athlete will return to pre-exercise levels (resting heart rate) in a much shorter time than that of an untrained individual (see figure 12.5). A quicker heart rate recovery occurs after both maximal and submaximal exercise. This is due to the greater efficiency of the cardiovascular system to produce energy aerobically. Recovery heart rate is a very good indicator of an athlete’s aerobic fitness. The quicker their heart rate recovers back to resting levels, the more aerobically fit they are.

**Increased cardiac output during maximal exercise**

While cardiac output remains unchanged at rest and even during submaximal exercise, regardless of training status, it does increase during maximal workloads. During maximal exercise, cardiac output may increase to values of 20–22 litres per minute for untrained males and 15–16 litres per minute for untrained females. In contrast, highly trained athletes have recorded values exceeding 30 litres per minute (see figure 12.6). The increase in cardiac output during maximal exercise is mainly due to the increase in stroke volume because maximum heart rate changes due to aerobic training are minimal.
12.2 Chronic adaptations to aerobic training: cardiovascular

Decayed blood pressure

An aerobic training program may lower blood pressure, especially among people who suffer from hypertension. Both systolic and diastolic blood pressure levels may decrease during both rest and exercise as a result of training. This helps to reduce resistance to blood flow and reduces strain on the heart, thereby decreasing the risk of heart attack and other cardiovascular conditions.

Increased capillarisation of skeletal muscle

Long-term aerobic training leads to increased capillarisation of skeletal muscle. The average number of capillaries supplying each muscle fibre is 5.9 for trained athletes compared with 4.4 for untrained individuals. Greater capillary supply means increased blood flow, which in turn allows for greater supply of oxygen and nutrients to the muscles, and increased removal of by-products. An increase in the number of capillaries surrounding each muscle fibre is one of the most significant factors that leads to an increase in an athlete’s VO₂ maximum. The diffusion of oxygen from the capillaries into the mitochondria is a major factor in maximising the rate of oxygen consumption by the muscles.

Increased blood volume

Regular and sustained aerobic training may lead to total blood volume rising by up to 25 per cent (from 5.25 litres to 6.6 litres) for an average adult male. As a result, red blood cells may increase in number and the haemoglobin content and oxygen-carrying capacity of the blood may also rise. This allows for a greater amount of oxygen to be delivered to the muscles and used by the athlete.

Blood plasma volume also increases significantly. As seen in figure 12.7, the blood plasma volumes have increased from 2.8 L to 3.3 L. This results in an increased ratio of plasma in the blood cells, which reduces the viscosity of the blood, allowing it to flow smoothly through the blood vessels. The reduction of blood viscosity accompanies an improved blood flow, enhances oxygen delivery to the muscles and also increases the capacity for thermoregulation.

![Figure 12.7: Aerobic training effects on blood volume](image)

**Pre-aerobic training**

- Plasma volume 2.8 L
- Red blood cells 2.2 L
- Total blood volume = 5.0 L

**Post-aerobic training**

- Plasma volume 3.3 L
- Red blood cells 2.4 L
- Total blood volume = 5.7 L
TEST your understanding

1. (a) Identify three types of athlete most likely to benefit from the cardiovascular adaptations as a result of participating in a long-term aerobic training program.
   (b) Define cardiac output and outline the parameters that it consists of.

2. Complete the table below by indicating whether the physiological parameter has increased, decreased or remained unchanged as a result of participating in a long-term aerobic training program.

<table>
<thead>
<tr>
<th>Physiological parameter</th>
<th>At rest</th>
<th>During submaximal exercise</th>
<th>During maximal exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricle size and volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arteriovenous oxygen difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood volume</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APPLY your understanding

3. (a) Outline four chronic adaptations that may occur in the cardiovascular system as a result of participating in a long-term aerobic training program.
   (b) Clearly explain how these adaptations bring about improved performance.

4. Discuss the relationship between heart rate, stroke volume and cardiac output.

5. Explain why heart rate decreases at rest and during submaximal workloads but not during maximal workloads.

6. Discuss why trained athletes are able to deliver more oxygen to their working muscles as a result of blood volume changes.

7. Practical activity: heart rate
   Work with a partner of the same gender to complete an exercise of the same intensity and for the same amount of time/duration, e.g. 10-minute ride on a stationary bike set at the same cadence and resistance.

   Both wear a heart rate monitor or manually record your resting heart rate, each minute of your exercise heart rate and each minute of your recovery heart rate. Use the Recording sheet digital document in your eBookPLUS to record your results.

   Quick and simple guidelines to manually recording your heart rate:
   (1) Place two fingers on the side of your neck to find your carotid pulse.
   (2) Press firmly so that you can feel the pulse but not too forcefully.
   (3) Count the number of beats for 10 seconds (count the first beat as 0) and multiply by 6.
   (4) This will give you the number of times your heart beats per minute (bpm).

   Analyse the results — the resting heart rates, the exercise heart rates and the recovery heart rates. Discuss the differences and provide reasons for them.
12.2 Chronic adaptations to aerobic training: cardiovascular

**EXAM practice**

(adapted from ACHPER Trial Exam 2012, question 13)

In the 2012 Australian Open Men's Grand Final, Novak Djokovic defeated Rafael Nadal. The following table shows the score, as well as the duration, of each set:

<table>
<thead>
<tr>
<th></th>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
<th>Set 4</th>
<th>Set 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Djokovic</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Nadal</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Minutes per set</td>
<td>80</td>
<td>66</td>
<td>45</td>
<td>88</td>
<td>78</td>
</tr>
</tbody>
</table>

In the second set, during one rally, Djokovic ran 59.0 m and Nadal ran 56.9 m. The rally included 15 shots played between the two competitors and a number of direction changes while running to return a shot.

Djokovic was the world number one in tennis for eighteen months. Considering that he was the best player in the world for this amount of time, it is assumed that his body made a number of chronic adaptations to allow for this achievement. Using the data above, justify two chronic cardiovascular adaptations that you would expect Djokovic to develop and outline how each adaptation contributes to enhanced performance.

(adapted from ACHPER Trial Exam 2015, question 13)

Sharon and Katherine decided that the Cooper's 12-minute run test was a suitable test to assess their aerobic capacity before undertaking their training program. They both completed the test to the best of their ability.

During the Cooper's 12-minute run test, the students' heart rate data (measured in beats per minute) were collected and are presented in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Resting heart rate</th>
<th>Immediately before run</th>
<th>At the conclusion of 1st minute</th>
<th>At the conclusion of 2nd minute</th>
<th>At the conclusion of 3rd minute</th>
<th>At the conclusion of 4th minute</th>
<th>At the conclusion of 5th minute</th>
<th>At the conclusion of 6th minute</th>
<th>At the conclusion of 7th minute</th>
<th>At the conclusion of 8th minute</th>
<th>At the conclusion of 9th minute</th>
<th>At the conclusion of 10th minute</th>
<th>At the conclusion of 11th minute</th>
<th>At the conclusion of 12 minute</th>
<th>1 minute following run</th>
<th>2 minutes following run</th>
<th>3 minutes following run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharon</td>
<td>72</td>
<td>96</td>
<td>160</td>
<td>170</td>
<td>171</td>
<td>170</td>
<td>170</td>
<td>171</td>
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<td>172</td>
<td>172</td>
<td>185</td>
<td>188</td>
<td>200</td>
<td>185</td>
</tr>
<tr>
<td>Katherine</td>
<td>61</td>
<td>98</td>
<td>170</td>
<td>171</td>
<td>170</td>
<td>171</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>172</td>
<td>188</td>
<td>198</td>
<td>200</td>
<td>185</td>
</tr>
</tbody>
</table>

(a) Using data from the table, identify the range of minutes that Sharon remained in steady state during the test.

1 mark

(b) Identify which of the girls, Sharon or Katherine, has a better aerobic capacity.

1 mark

(c) Provide two pieces of evidence from the table to support your choice in part (b).

2 marks
12.3 Chronic adaptations to aerobic training: respiratory

**KEY CONCEPT** Respiratory adaptations derived from participation in an aerobic training program lead to improved performance.

**Increased pulmonary ventilation during maximal exercise**

Regular aerobic training results in more efficient and improved pulmonary ventilation, which is sometimes also referred to as minute ventilation. At rest and during submaximal exercise, ventilation may in fact be reduced due to improved oxygen extraction. However, during maximal workloads, ventilation is increased because of increased tidal volume (TV) and respiratory frequency (RF). Pulmonary diffusion is also enhanced as a result of training.

**Increased tidal volume**

Aerobic training increases the amount of air inspired and expired by the lungs per breath. This is attributed to the increased strength and endurance of the respiratory muscles, allowing an athlete to exhale more air and inhale more air. This allows for a greater amount of oxygen to be diffused into the surrounding alveoli capillaries and delivered to the working muscles.

**Decreased resting and submaximal respiratory frequency**

The number of times an athlete breathes in and out per minute is reduced at rest and submaximal levels. This is mainly due to the improved pulmonary function and an increase in the extraction of oxygen from the alveoli to the surrounding capillaries.

**Increased pulmonary diffusion**

Aerobic training results in an increase in the surface area of the alveoli, which in turn increases the pulmonary diffusion. This allows for a greater amount of oxygen to be delivered to the working muscles.

**Figure 12.8**
and carbon dioxide exchange between the alveoli and the surrounding capillaries. A
greater amount of oxygen is extracted from the alveoli to the surrounding capillaries
and, conversely, a greater amount of carbon dioxide is diffused from the surrounding
capillaries into the alveoli.

The increase in ventilation and pulmonary diffusion allows more oxygen to be
inhaled, extracted and transported to the working muscles.

### TEST your understanding

1. Complete the following table by indicating whether the physiological parameter
   has increased, decreased or remained unchanged as a result of involvement in a long-term aerobic training program.

<table>
<thead>
<tr>
<th>Physiological parameter</th>
<th>At rest</th>
<th>During submaximal exercise</th>
<th>During maximal exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary diffusion</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. (a) Identify three types of athletes most likely to develop chronic respiratory adaptations as a result of participating in a long-term aerobic training program.
   (b) Define pulmonary ventilation and outline the parameters that it consists of.

### APPLY your understanding

3. Explain how aerobic training can result in more efficient pulmonary ventilation.

4. Explain pulmonary diffusion and how it is affected by aerobic training.

5. Discuss how the aerobic adaptations of pulmonary ventilation and pulmonary diffusion lead to the improved performance of a marathon runner.

### EXAM practice

(adapted from ACHPER Trial Exam 2015, question 9)

Amber is a 16-year-old who completes a VO₂ maximum test on a cycle ergometer just before commencing the cycling training program. She recorded a VO₂ maximum of 56 ml/kg/min. After 12 weeks of training, she completes a VO₂ maximum test on a cycle ergometer again and her VO₂ maximum has improved to 59 ml/kg/min.

Discuss one respiratory adaptation that would lead to Amber’s improved VO₂ maximum.

2 marks
Chronic aerobic training adaptations within muscle tissue are best produced through continuous, fartlek and long-interval training, high-intensity interval training or high-repetition, low-weight resistance training.

**Increased oxygen utilisation**

Aerobic training enhances the body's ability to attract oxygen into the muscle cells and then use it to resynthesise adenosine triphosphate (ATP) for muscular contractions. More oxygen initially surrounds the muscle by the increased capillary density and then the myoglobin and mitochondria work together to utilise the oxygen to resynthesise ATP aerobically.

This process occurs in the following ways:

- **Increased size and number of mitochondria.** The **mitochondria** are the sites of aerobic ATP resynthesis and where glycogen and triglyceride stores are oxidised. The greater the number and size of the mitochondria located within the muscle, the greater the oxidation of fuels to produce ATP aerobically.

- **Increased myoglobin stores.** Aerobic training significantly increases the **myoglobin** content in the muscle and therefore its ability to extract oxygen and deliver it to the mitochondria for energy production. When oxygen is diffused into the muscle fibre, it binds with myoglobin, which then shuttles the oxygen to the mitochondria. Myoglobin stores can increase up to 80% from undertaking an aerobic training program. Figure 12.8 illustrates the effect of aerobic training on these parameters.

**Increased arteriovenous oxygen difference**

Trained athletes are able to extract more oxygen from their bloodstream into their muscles during exercise performance compared with untrained individuals. This is due to increased muscle myoglobin stores and an increased number and size of mitochondria within their muscles (muscular aerobic adaptations). As a result of this, the concentration of oxygen within the venous blood is lower, and subsequently the arteriovenous oxygen difference increases.

**Mitochondria** are cell structures or organelles in which oxidative ATP resynthesis takes place.

**Myoglobin** is an oxygen-binding protein in skeletal muscle cells that attracts oxygen from the bloodstream and shuttles it to the mitochondria in the muscles for aerobic energy production.

**FIGURE 12.9** Effects of aerobic training on muscle tissue

![Diagram showing effects of aerobic training on muscle tissue](image_url)

**FIGURE 12.10** Aerobic training effects on a-VO$_2$ difference

![Diagram showing aerobic training effects on a-VO$_2$ difference](image_url)

**Questions**

- **What is the max a-VO$_2$ Diff?**
  - (a) Pre-aerobic training: AVO$_2$ difference during exercise
    - Arteriole: Oxygen consumption in blood = 20 mL/100 mL
    - Muscle: Oxygen concentration in blood = 8 mL/100 mL
    - Venule: Oxygen concentration in blood = 2 mL/100 mL
  - (b) Post-aerobic training: AVO$_2$ difference during exercise
    - Arteriole: Oxygen consumption in blood = 20 mL/100 mL
    - Muscle: Oxygen concentration in blood = 8 mL/100 mL
    - Venule: Oxygen concentration in blood = 2 mL/100 mL

**KEY CONCEPT** Muscle tissue adaptations derived from participation in an aerobic training program lead to improved performance.

**Mitochondria** are cell structures or organelles in which oxidative ATP resynthesis takes place.

**Myoglobin** is an oxygen-binding protein in skeletal muscle cells that attracts oxygen from the bloodstream and shuttles it to the mitochondria in the muscles for aerobic energy production.
12.4 Chronic adaptations to aerobic training: muscular

**Arteriovenous oxygen difference** (a-VO\textsubscript{2} diff.) is a measure of the difference in the concentration of oxygen in the arterial blood and the concentration of oxygen in the venous blood. It is measured in millilitres per 100 millilitres of blood.

**Oxidative enzymes** are enzymes that, with the use of oxygen, speed up the breakdown of nutrients to resynthesise ATP.

**Glycogen sparing** is the process whereby glycogen stores are not used as early in an exercise bout due to the increased ability to use triglycerides to produce energy. This delays depletion of these stores, and thereby delays the time to exhaustion due to glycogen depletion.

**Increased muscular fuel stores and oxidative enzymes**

Aerobic training increases the muscular storage of glycogen and triglycerides in the slow-twitch muscle fibres and there is also an accompanying increase in the oxidative enzymes that are responsible for metabolising these fuel stores to produce ATP aerobically. This means that there is less reliance upon the anaerobic glycolysis system until higher intensities.

**Increased oxidation of glucose and triglycerides**

The muscular adaptations already discussed in this section result in an increase in the capacity of muscle fibres to oxidise both glucose and triglycerides. In other words, the capacity of the aerobic system to metabolise these fuels is increased (see figure 12.9). Furthermore, the increased oxidation of fats as a fuel source — due to the increased storage of triglycerides, plus the vastly increased levels of enzymes associated with triglyceride metabolism — means that, at any given exercise intensity, a trained athlete has to rely less on glycogen, thereby ‘sparing’ their glycogen stores. This process is referred to as **glycogen sparing**. In essence, this allows the athlete to sustain a higher level of intensity, maintaining a faster pace, which ultimately results in an improved aerobic performance.

**Adaptation of muscle fibre type**

On the basis of various structural and functional characteristics, skeletal muscle fibres are classified into three types: type 1 slow-twitch oxidative fibres, type 2A fast-twitch oxidative fibres and type 2B fast-twitch glycolytic fibres. Some evidence has shown that fast-twitch skeletal muscle type A fibres can take on the characteristics of slow-twitch type fibres as a result of endurance training. Some researchers have also demonstrated that fast-twitch type 2B fibres are recruited more in a manner that represents the more oxidative fast-twitch type 2A fibres as a result of endurance training. Slow-twitch muscle type fibres will increase in cross-sectional area as a result of endurance training, however the extent of the increase is dependent upon the intensity and duration of training.

**Type 1 slow-twitch oxidative fibres** contain large amounts of myoglobin, and large numbers of mitochondria and blood capillaries. Type 1 fibres are red, split ATP at a slow rate, have a slow contraction velocity, are very resistant to fatigue, and have a high capacity to generate ATP by oxidative metabolic processes.

**Type 2A fast-twitch oxidative fibres** contain a large amount of myoglobin, and large numbers of mitochondria and blood capillaries. Type 2A fibres are red, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity, and are resistant to fatigue.

**Type 2B fast-twitch glycolytic fibres** contain a low myoglobin content, relatively few mitochondria and blood capillaries, and large amounts of glycogen. Type 2B fibres are white, are geared to generate ATP by anaerobic metabolic processes, fatigue easily, split ATP at a fast rate, and have a fast contraction velocity.
TABLE 12.1 Characteristics of fast- and slow-twitch muscle fibres

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Slow-twitch</th>
<th>Fast-twitch oxidative</th>
<th>Fast-twitch glycolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Also known as</td>
<td>Type 1</td>
<td>Type 2A</td>
<td>Type 2B</td>
</tr>
<tr>
<td>Colour</td>
<td>Red</td>
<td>Red</td>
<td>White</td>
</tr>
<tr>
<td>Used for</td>
<td>Aerobic</td>
<td>Anaerobic (long-term)</td>
<td>Anaerobic (short-term)</td>
</tr>
<tr>
<td>Fibre size</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Motor neuron size</td>
<td>Small</td>
<td>Large</td>
<td>Very large</td>
</tr>
<tr>
<td>Resistance to fatigue</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Force production</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Speed of contraction</td>
<td>Slow</td>
<td>Fast</td>
<td>Very fast</td>
</tr>
<tr>
<td>Hypertrophy potential</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capillary density</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Myoglobin content</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Oxidative capacity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Glycolytic capacity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Major fuel</td>
<td>Triglycerides</td>
<td>Creatine phosphate/</td>
<td>Creatine phosphate/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>glycogen</td>
<td>glycogen</td>
</tr>
</tbody>
</table>

Individual muscles are a mixture of the three types of muscle fibres, but their proportions vary depending on the action of the muscle and the genetic make-up of the individual. The Type 2B muscle fibre transformation is a very gradual process and can actually take years to manifest. The transformed fibres show a slight increase in diameter, mitochondria and capillaries but not a change in fibre type. This brings them to a level at which they are able to perform oxidative metabolism as effectively as the Type 1 slow-twitch fibres of untrained individuals.

**FIGURE 12.11** Cross-section of skeletal muscle fibre
TEST your understanding

1 Complete the table below by indicating whether the physiological parameters have increased, decreased or remained unchanged as a result of involvement in a long-term aerobic training program.

<table>
<thead>
<tr>
<th>Physiological parameter</th>
<th>At rest</th>
<th>During submaximal exercise</th>
<th>During maximal exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen utilisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size and number of mitochondria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myoglobin stores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscular fuel stores (glycogen, triglycerides)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxidisation of fats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle fibre type adaptations</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 Outline the adaptations to muscle fibre type that have been shown to occur as a result of aerobic training.

3 (a) Identify the role of mitochondria and explain how they are affected by undertaking an aerobic training program.
   (b) Identify the role of myoglobin and explain how it is affected by undertaking an aerobic training program.

APPLY your understanding

4 Explain how increased mitochondria and myoglobin in the muscle cell improves aerobic performance.

5 Refer to the figure at right. Which column (X or Y) indicates muscle glycogen stores after completion of a 20-week aerobic training program? Explain your answer.

6 Explain which particular characteristics of fast-twitch type 2A fibres would be of benefit to an endurance athlete.

7 Explain how an increase in the number of oxidative enzymes will benefit the performance of an endurance athlete.

EXAM practice

8 (adapted from ACHPER Trial Exam 2013, question 3)

At the London 2012 Olympic Games, Yuliya Zaripova won the Women’s 3000m Steeplechase in a time of 9 minutes and 6.72 seconds. Identify two chronic muscular adaptations from Yuliya’s training program and outline how these adaptations are beneficial to her performance. 4 marks
12.5 Chronic adaptations to aerobic training: cardiovascular, respiratory and muscular

**KEY CONCEPT** Understanding chronic adaptations of the cardiovascular, respiratory and muscular systems to aerobic training: VO\textsubscript{2} maximum and lactate inflection point.

**Increased maximum oxygen uptake: VO\textsubscript{2} max**

Aerobic training results in an increase in the maximum oxygen uptake (VO\textsubscript{2} max) during maximal exercise. This improvement can be in the range of 5–30 per cent, following a regular and sustained training program. It comes about because of adaptations such as increases in cardiac output, red blood cell numbers, \(\Delta\text{VO}_2\) difference and muscle capillarisation, as well as greater oxygen extraction by the muscles by the myoglobin.

VO\textsubscript{2} max is the maximum amount of oxygen that can be taken in by the respiratory system, transported by the cardiovascular system and utilised by the muscular system to produce ATP. It is the point where an athlete cannot increase the amount of oxygen they take in, transport and utilise, despite an increase in their exercise intensity. An increase in VO\textsubscript{2} max resulting from aerobic training is due to the aerobic chronic adaptations that occur in all three systems that have already been discussed in this chapter; e.g., increased pulmonary diffusion (respiratory system), increased blood haemoglobin concentration (cardiovascular system) and an increase in mitochondria (muscular system).

**TABLE 12.2 Maximum oxygen uptake values in a variety of sportspersons**

<table>
<thead>
<tr>
<th>Sport</th>
<th>Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball</td>
<td>18–32</td>
<td>48–55</td>
<td>52–57</td>
</tr>
<tr>
<td>Basketball</td>
<td>18–30</td>
<td>40–60</td>
<td>43–60</td>
</tr>
<tr>
<td>Cycling</td>
<td>18–26</td>
<td>62–74</td>
<td>47–57</td>
</tr>
<tr>
<td>Canoeing</td>
<td>22–28</td>
<td>55–67</td>
<td>48–52</td>
</tr>
<tr>
<td>Football (USA)</td>
<td>20–35</td>
<td>42–60</td>
<td></td>
</tr>
<tr>
<td>Gymnastics</td>
<td>18–22</td>
<td>52–58</td>
<td>35–50</td>
</tr>
<tr>
<td>Ice Hockey</td>
<td>10–30</td>
<td>50–63</td>
<td></td>
</tr>
<tr>
<td>Orienteering</td>
<td>20–60</td>
<td>47–53</td>
<td>46–60</td>
</tr>
<tr>
<td>Rowing</td>
<td>20–35</td>
<td>60–72</td>
<td>58–65</td>
</tr>
<tr>
<td>Skiing alpine</td>
<td>18–30</td>
<td>57–68</td>
<td>50–55</td>
</tr>
<tr>
<td>Skiing nordic</td>
<td>20–28</td>
<td>65–94</td>
<td>60–75</td>
</tr>
<tr>
<td>Soccer</td>
<td>22–28</td>
<td>54–64</td>
<td>50–60</td>
</tr>
<tr>
<td>Speed skating</td>
<td>18–24</td>
<td>56–73</td>
<td>44–55</td>
</tr>
<tr>
<td>Swimming</td>
<td>10–25</td>
<td>50–70</td>
<td>40–60</td>
</tr>
<tr>
<td>Track &amp; Field – Discus</td>
<td>22–30</td>
<td>42–55</td>
<td></td>
</tr>
<tr>
<td>Track &amp; Field – Running</td>
<td>18–39</td>
<td>60–85</td>
<td>50–75</td>
</tr>
<tr>
<td>Track &amp; Field – Running</td>
<td>40–75</td>
<td>40–60</td>
<td>35–60</td>
</tr>
<tr>
<td>Track &amp; Field – Shot</td>
<td>22–30</td>
<td>40–46</td>
<td></td>
</tr>
<tr>
<td>Volleyball</td>
<td>18–22</td>
<td>40–56</td>
<td></td>
</tr>
<tr>
<td>Weight Lifting</td>
<td>20–30</td>
<td>38–52</td>
<td></td>
</tr>
<tr>
<td>Wrestling</td>
<td>20–30</td>
<td>52–65</td>
<td></td>
</tr>
</tbody>
</table>

*Source:* https://www.brianmac.co.uk/vo2max.htm

Maximum oxygen uptake (VO\textsubscript{2} max) is the maximum amount of oxygen per minute that can be taken in, transported and utilised by the body for energy production.
Chronic adaptations to aerobic training: cardiovascular, respiratory and muscular

Relative VO\textsubscript{2} max takes into account body weight and is measured in ml/kg/min.

Absolute VO\textsubscript{2} max is a measurement of the total amount of O\textsubscript{2} consumed in L/min.

Lactate inflection point (LIP) represents the highest intensity point where there is a balance between lactate production and removal from the blood.

An athlete’s VO\textsubscript{2} max is simply a combination of their cardiac output (Q) x a-VO\textsubscript{2} difference. It is measured in ml of O\textsubscript{2} per kg of body weight per min (ml/kg/min). Body weight is taken into account so that comparisons can be made relative to the athlete. This measurement determines how much oxygen per kilogram of body weight is utilised. Whereas absolute VO\textsubscript{2} max is measured in litres per min (L/min) and identifies the amount of oxygen that is consumed, irrespective of body weight, which does not allow for comparisons to be made between athletes.

### Increased lactate inflection point (LIP)

As a result of the aerobic adaptations that improve oxygen delivery and use in the muscles (more efficient aerobic energy system usage) and economy, a higher lactate inflection point (LIP) is developed. LIP represents the highest intensity point where there is a balance between lactate production and removal from the blood. The advantage of having a higher LIP is that the aerobic system can produce energy at a faster rate, so there is less reliance on the anaerobic glycolysis system until higher exercise intensities are reached. Consequently, lactic acid and hydrogen ion accumulation will be delayed until these higher workload intensities are attained. Put simply, this means that the athlete can work at higher intensities for longer periods without the fatiguing hydrogen ion accumulation. Exercise intensities beyond the LIP are associated with fatigue; the greater the exercise intensity above the inflection point, the more rapid the fatigue.

As seen in figure 12.12, LIP is the point of inflection on the curve of blood lactate vs. exercise intensity (running speed) above which the rate of lactate production exceeds removal and blood lactate concentrations continue to increase disproportionately with increasing exercise intensity (running speed). There is a right shift on the graph for a trained athlete with a higher LIP.

Aerobic training at an intensity near LIP is appropriate for an untrained individual, but a higher intensity is necessary for endurance-trained athletes (as discussed in chapter 11). An athlete’s LIP can be delayed until higher intensities without any variations to their VO\textsubscript{2} max. This is due to an increased ability to absorb, transport and metabolise hydrogen and lactate more efficiently, resulting in the exponential accumulation of lactic acid at higher exercise intensities. An increase in mitochondria size and density allows for greater aerobic ATP resynthesis and also an increased ability to remove lactate from the cell cytoplasm via the following different mechanisms:

- some lactate is re-converted to pyruvate for immediate oxidation in the mitochondria
- some lactate is transported out of the cell into the blood
- most blood lactate is oxidised by other muscles (particularly cardiac muscle and slow-twitch muscle fibres)
- some of the blood lactate is converted to glucose or glycogen in the liver.

Where maximal oxygen uptake (VO\textsubscript{2} max) is equivalent between athletes, LIP is more likely to distinguish the performances of middle- and long-distance athletes. LIP is often expressed as a percentage of an athlete’s VO\textsubscript{2} max or maximum heart rate (MHR). An elite endurance athlete will reach their LIP at 80–90% VO\textsubscript{2} max or 85% MHR.

**FIGURE 12.12** Training effects on blood lactate level in relation to running speeds

TEST your understanding

1. Explain the physiological aspects that combine to determine a person’s VO$_2$ maximum.
2. Identify the approximate maximum oxygen uptake values of three different types of Australian sportspeople.
3. Define lactate inflection point and outline the percentage of maximum heart rate at which LIP generally occurs in elite athletes.

APPLY your understanding

4. Discuss how each of the three systems (cardiovascular, respiratory and muscular) contribute to an athlete’s VO$_2$ maximum.
5. Discuss why VO$_2$ maximum is measured in ml of O$_2$ per kg of body weight.
6. Explain how one specific aerobic adaptation for each system would lead to an improvement to an athlete’s VO$_2$ maximum.
7. Examine the difference between male and female VO$_2$ maximum values.
8. Justify how aerobic training can improve an athlete’s LIP.
9. Identify the type of athlete that would benefit from having an improved LIP and explain how having a higher LIP improves that particular athlete’s performance.

EXAM practice

10. (adapted from ACHPER Trial Exam 2013, question 2)
Running economy is a key factor in determining endurance performance for athletes with similar VO$_2$ maximums.
   a. Define VO$_2$ maximum and indicate an elite score for a female marathon runner. 2 marks
   b. Explain how running economy will impact upon endurance performance. 2 marks
   c. An elite male’s VO$_2$ maximum score is generally about 10% above that of an elite female’s. Outline two physiological reasons that may account for this. 2 marks

11. (adapted from ACHPER Trial Exam 2014, question 12)
The graph below shows a recreational runner’s blood lactate concentration during two different running treadmill tests until they reach exhaustion. The second test was completed after the runner completed a four month training program.

![Graph of blood lactate concentration vs. speed](image)

General representation between speed and blood lactate concentration

a. Identify what the points labelled A and B represent. 1 mark
b. Name the training method that would enable the shift from point A to B. 1 mark
c. Explain the benefit of moving from point A to point B when completing the treadmill test. 2 marks
d. The test is completed when the runner is unable to continue, due to fatigue. What is the most likely cause of this fatigue? 1 mark
12.6 Chronic adaptations to anaerobic training

**KEY CONCEPT** Chronic adaptations derived from participation in an anaerobic training program lead to improved performance.

As previously mentioned, anaerobic training effects are best developed through short and intermediate interval training, plyometric training, circuit training and resistance (strength and power) training. The greatest adaptations occur at the muscular system level.

**Muscular hypertrophy**

Anaerobic training can lead to significant enlargement of muscle fibres (mainly Type 2A and 2B fast-twitch fibres), resulting in muscular hypertrophy and, subsequently, greater strength. This hypertrophy occurs as a result of an increased size and number of myofibrils per muscle fibre and increased amounts of myosin and actin myofilaments. Muscular hypertrophy is more pronounced in males than females due to greater levels of testosterone in men.

**Increased muscular stores of ATP, ATPase, creatine kinase enzymes and CP**

Muscular hypertrophy is accompanied by increased muscular stores of ATP and creatine phosphate (CP) (see figure 12.13). Increased muscular stores of ATP and creatine phosphate increases the capacity of the ATP–CP system allowing for faster resynthesis of ATP for high-intensity activities. There is also an increase in the enzymes required to break down and resynthesise ATP: ATPase, which is responsible for breaking down ATP to form ADP and release energy for muscular contraction, and creatine kinase, which initiates the breakdown of PC and provides the energy to resynthesise ATP at a fast rate.

This results in an increased capacity of the ATP–CP system, namely greater energy release and faster restoration of ATP. This benefits the athlete in activities that require speed, strength and power.

**Increased glycolytic capacity**

Enhanced muscular storage of glycogen and increases in the levels of glycolytic enzymes are also adaptations accompanying anaerobic training (see figure 12.13). Consequently, the capacity of the anaerobic glycolysis/non-oxidative system to produce energy is enhanced.
Chronic adaptations to training
Athlete comparison — anaerobic and aerobic

**FIGURE 12.15** Anna’s chronic anaerobic adaptations allow her to generate a greater amount of pedalling force and power output. This results in her achieving faster speeds and quicker times in the 500 m time trial.

**FIGURE 12.16** Emma’s chronic aerobic adaptations allow her to more efficiently resynthesise ATP aerobically and improve her economy in the swim, bike and running legs. This results in her being able to compete in each leg at higher intensities for longer and ultimately produce a faster triathlon time overall.

**TABLE**

<table>
<thead>
<tr>
<th>System</th>
<th>Anna Meares</th>
<th>Emma Moffatt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased muscle hypertrophy</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased ATP, CP and glycogen fuel storage</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased in ATPase and creatine kinase enzymes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased in motor unit recruitment</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased lactate tolerance</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased neuromuscular functioning</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Respiratory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased max ventilation (TV x RF)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased pulmonary diffusion</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased volume of left ventricle</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased capillarisation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased stroke volume</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decreased resting HR and submax. HR</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased max Q</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decreased blood pressure</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Increased blood volume</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Muscular**

- Increased muscle hypertrophy
- Increased ATP, CP and glycogen fuel storage
- Increase in ATPase and creatine kinase enzymes
- Increase in motor unit recruitment
- Increased lactate tolerance
- Increased neuromuscular functioning

**Respiratory**

- Increased max ventilation (TV x RF)
- Increased pulmonary diffusion

**Cardiovascular**

- Increased volume of left ventricle
- Increased capillarisation
- Increased stroke volume
- Decreased resting HR and submax. HR
- Increased max Q
- Decreased blood pressure
- Increased blood volume

**All three systems**

- Increased VO₂ max.
- Increased LIP²
### 12.6 Chronic adaptations to anaerobic training

**Increase in the ability to recruit more motor units**

The ability of the nerve axons to innervate their corresponding muscle fibres increases as a result of anaerobic training. The greater the number of motor units that can be recruited, the greater the strength and power that can be produced by a muscle.

**Increase in lactate tolerance**

Working anaerobically means an athlete works above LIP, therefore producing lactate at a faster rate than it can be removed. The body learns to tolerate the increased levels of lactic acid and increase the buffering capacity. Anaerobic training increases the ability of the muscles to buffer (neutralise) the acid that accumulates from the production of hydrogen ions during an exercise bout. Buffers such as bicarbonate and muscle phosphates combine with the hydrogen ions to neutralise the increases in acidity. The increase in lactate tolerance prevents the onset of fatigue and allows an athlete to continue to generate ATP anaerobically, which is at a faster rate and allows them to work at a higher intensity, producing high lactate levels at the end of performance.

Any athlete that requires a significant contribution from the anaerobic glycolysis system, such as a 400 m or 800 m runner, will benefit from having an improved lactate tolerance.

**Cardiac hypertrophy**

Sustained anaerobic training results in the hypertrophy (enlargement) of the heart muscle itself. However, rather than increasing the size, and therefore volume, of the ventricular chambers, which occurs after prolonged aerobic training, anaerobic training produces an increase in the thickness of the ventricular walls (see figure 12.17(a) and (b)). While little or no change in stroke volume occurs, a more forceful contraction takes place and hence a more forceful ejection of blood from the heart.

**FIGURE 12.17** Effects of anaerobic training on cardiac hypertrophy. Following intense sustained anaerobic training, the thickness of the ventricular wall increases, particularly in the left ventricle, but there is no increase in the volume of the ventricular cavity.

---

**A motor unit** consists of one motor neuron and all of the muscle fibres that it innervates.

**Buffering capacity** is the ability of the muscle cell buffers to resist changes in pH (acidity).

The presence of hydrogen ions makes the muscle acidic and will eventually fatigue muscle function.
TEST your understanding

1. Complete the following table by indicating whether the physiological parameters have increased, decreased or remained unchanged as a result of involvement in a long-term anaerobic training program.

<table>
<thead>
<tr>
<th>Physiological parameter</th>
<th>At rest</th>
<th>During submaximal exercise</th>
<th>During maximal exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular hypertrophy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscular fuel stores (ATP and CP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATPase and creatine kinase enzymes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycolytic capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor unit recruitment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac hypertrophy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lactate tolerance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Name the training methods that develop chronic anaerobic adaptations in muscle tissue.

3. Identify three types of athlete most likely to benefit from chronic adaptations as a result of participating in an anaerobic training program.

4. Outline the role of the enzymes ATPase and creatine kinase.

5. What is the benefit of having a larger muscular storage of ATP, CP and glycogen?

6. What is meant by the buffering capacity of a muscle?

APPLY your understanding

7. (a) Outline three chronic adaptations that may occur at the muscular level as a result of involvement in an anaerobic training program of at least 6 weeks’ duration.

(b) Discuss how these adaptations can lead to improved performance.

8. An athlete participates in the following training program over a period of 6 weeks.
   
   Session 1: 5 x 100 m runs, each taking 14 seconds
   5 x 80 m runs, each taking 12 seconds
   Work-to-rest ratio of 1:3
   
   Session 2: 5 x 60 m runs, each taking 9 seconds
   5 x 40 m runs, each taking 7 seconds
   Work-to-rest ratio of 1:5

   The athlete notices a reduction in time taken to complete each of the runs as the weeks progress. Identify and explain the chronic adaptations that have occurred to allow the athlete to run faster.

9. Involvement in a long-term anaerobic training program (i.e. intermediate interval training) may result in an increase in an athlete’s lactate tolerance.
   (a) Identify chronic adaptations to training that help to bring about this improvement in an athlete’s lactate tolerance.
   (b) Explain the advantages of a higher lactate tolerance for both athletes who perform anaerobic exercise (i.e. sprinters) and those who perform aerobic exercise (i.e. longer distance runners).
12.7 Chronic adaptations to resistance training: neuromuscular

**KEY CONCEPT** Explaining the specific chronic neuromuscular adaptations that occur when undertaking a resistance training program.

As with any training, the resulting adaptations are specific to the type of training undertaken. Power and strength resistance training protocols (see chapter 11) will induce anaerobic training adaptations; likewise local muscular endurance resistance training protocols (see chapter 11) will induce some aerobic training adaptations. With any type of long-term training, adaptations occur in the neuromuscular system; however, significant specific neuromuscular adaptations occur with resistance training.

The neuromuscular system is very responsive to training. The increases in strength depend upon the type of resistance training and the muscle groups trained, and the intensity of the resistance training affects the scale of the adaptations.

**Increase in muscle size and change in muscle structure**

Resistance training increases the strength and size of a muscle. Increases in the cross-sectional area of a muscle are the result of an increase in the cross-sectional area of each individual fibre within the muscle. The hypertrophy of each fibre is due to an increase in the total quantity of actin and myosin protein filaments, the size and number of myofibrils and also in the amount of connective tissue that surrounds the muscle.

While most research suggests that individual fibre hypertrophy is the major reason for whole-muscle hypertrophy, some research suggests that fibre hyperplasia may also be a contributing factor to an increase in the number of fibres within a muscle. It is important to note that research is unresolved as to whether or not fibre hyperplasia contributes to increases in whole-muscle hypertrophy.

**Muscle fibre type adaptations**

Each single motor unit contains only one type of muscle fibre (fast or slow twitch). Resistance training will cause certain types of muscle fibre adaptations based upon the specificity of the program. Research shows that Type 2 fast-twitch fibres show greater increases in size, particularly with higher loads, than do Type 1 slow-twitch fibres. This may be explained by the fact that there is a greater need to recruit more muscle fibres to produce the required force. The size principle suggests that all motor unit types would be recruited to lift heavy loads and therefore there is a greater involvement of the Type 2 fast-twitch fibres, which would explain why they hypertrophy to a greater relative amount.

**Neural control**

A combination of adaptations that occur at both the muscular and neural systems explains the increased strength gained from resistance training. In the absence of hypertrophy (an increase in muscular size), it is the neural adaptations that play a critical role in the increased force production of a muscle resulting from resistance training.
One important aspect of the strength gains that result from resistance training, particularly in the early stages of a program, are the neural adaptations. Increased synchronisation and recruitment of additional motor units, increase in the firing rate (rate coding) of motor units and a reduction in inhibitory signals are some of the neural factors that contribute to strength gains with resistance training.

**Increased synchronisation of motor units**

Motor units are not generally recruited at the same time. As discussed earlier, the ‘size principle’ states that motor units are recruited in order of their size from smallest to largest. Resistance training makes a number of different motor units able to fire at the same time. There is also an improved ability to recruit larger motor units that require a larger stimulus to activate and comprise the largest number of muscle fibres. The ability to recruit more motor units at the same time and to stimulate larger motor units earlier creates a more powerful muscular contraction with greater force application.

**Increase in the firing rate (rate coding) of motor units**

The combination of motor unit recruitment and the firing rate or rate coding of motor units is known as the neural drive. Limited research suggests that the more efficient motor unit recruitment as a result of resistance training may also increase the frequency of stimulation of a given motor unit. An increase in rate coding increases the rate of force development or how quickly a muscle can contract maximally, rather than an increase in the force. This is beneficial for rapid ballistic movements where maximal force is required in a very short period of time.

**A reduction in inhibitory signals**

The role of the inhibitory mechanisms that exist in the neuromuscular system (e.g. the Golgi tendon organs) is to provide an important protective reflex that limits an excessive generation of force within a muscle. This protective reflex is essential in preventing the muscles from exerting a force that is greater than they can tolerate. Resistance training can gradually override or reduce the inhibitory mechanisms and allow for a greater force production within a muscle group. The improved coordination of the agonists, antagonists and synergists is thought to allow for the reduced inhibitory effect.

**TEST your understanding**

1. Outline how resistance training affects the size and structure of muscles.
2. Compare and contrast the difference between fast- and slow-twitch responses to resistance training.
3. Sketch a motor unit.
4. Identify how the size principle is changed by resistance training.
5. List the neural adaptations that account for increases in strength when hypertrophy is not present.

**APPLY your understanding**

7. Explain how an increase in the synchronisation of motor units can improve strength.
8. Discuss the benefit of increased rate coding of motor units. Explain for which type of actions this adaptation would be advantageous.
9. Describe how resistance training can affect the inhibitory signals within a muscle.
KEY SKILLS CHRONIC ADAPTATIONS TO TRAINING

- **yellow** identify the action word
- **pink** key terminology
- **blue** key concepts
- **light grey** marks/markings scheme

## KEY SKILL

- Explain how chronic adaptations to the cardiovascular, respiratory and muscular systems lead to improved performance

## UNDERSTANDING THE KEY SKILL

To address this key skill, it is important to remember the following:

- Describe how each of the adaptations to the cardiovascular system leads to the improved performance of specific activities
- Describe how each of the adaptations to the respiratory system leads to the improved performance of specific activities
- Explain the specific adaptations that occur from undertaking aerobic, anaerobic and resistance training

## PRACTICE QUESTION

(1) (adapted from ACHPER Trial Exam 2015, question 2)

Wayde van Niekerk from South Africa is the current Olympic champion in the men’s 400 m track event. Van Niekerk won this event in Rio in a time of 43.03 seconds. Mo Farah from Great Britain is the current Olympic champion in the men’s 10 000 m track event. He won his gold medal in a time of 27 minutes, 5 seconds.

**Contrast** the chronic muscular adaptations that van Niekerk and Farah would expect to bring about in training for their chosen event and **discuss** how these changes could lead to improved performance. (6 marks)

## SAMPLE RESPONSE

May select to discuss any two of the following contrasting chronic adaptations for each athlete.

**Wayde van Niekerk (400 m — 43.03 sec)**

- An increase in muscle fibre size and strength of connective tissue (ligaments and tendons) allows for a greater force production in each running stride.
- An increase in the muscular stores of ATP and creatine phosphate increases the capacity of the ATP–CP system, allowing a greater percentage contribution from the ATP–CP system, which provides a faster rate of ATP resynthesis, enabling faster running speed.
- An increase in the enzyme ATPase, which speeds up the breakdown of ATP to release energy for muscular contraction, and an increase in the enzyme creatine kinase, which initiates the breakdown of PC that provides the energy to resynthesise ATP at a faster rate, therefore enabling a greater power output and faster running speed.
- Increased levels of glycolytic enzymes assists the anaerobic glycolysis system to quickly resynthesise ATP, contributing to a faster running speed.
- An increased lactate tolerance will increase the ability of van Niekerk to withstand larger amounts of hydrogen ions in his muscles, increasing the capacity of the anaerobic glycolysis system to dominate and allow him to maintain a higher running speed for longer.

All of the above chronic adaptations will help van Niekerk to complete the 400 m in as fast a time as possible.

**Mo Farah (10000 m — 27 minutes, 5 seconds)**

- An increase in myoglobin, which is responsible for extracting oxygen from the red blood cells and delivering it to the mitochondria in the muscle cells, will allow for greater for aerobic energy production.
- An increase in mitochondrial density (sites of aerobic ATP resynthesis) would increase the ability to resynthesise ATP aerobically at higher intensities, delaying Farah from reaching his lactate inflection point.
- An increase in the oxidative enzymes that are responsible for metabolising glycogen and triglycerides to produce ATP aerobically means that there will be less reliance upon the anaerobic glycolysis system until higher intensities.
- An increase in Farah’s lactate inflection point, which is the highest intensity running speed he can maintain where there remains a balance between lactate production and removal, will allow him to run at higher intensities with less reliance on the anaerobic glycolysis system.

All of the above chronic adaptations will increase Farah’s lactate inflection point and aerobic capacity, which will improve his running economy, increase his ability to produce ATP aerobically and allow him to run at higher intensities for longer, producing a faster time for the 10 000 m event.
CHAPTER REVIEW CHRONIC ADAPTATIONS TO TRAINING

CHAPTER SUMMARY

- Long-term responses that develop over a period of time (usually a minimum of 6 weeks) when training is repeated regularly are referred to as chronic adaptations to training. The combined effect of all chronic adaptations is known as the training effect.
- Chronic adaptations to training may occur in the cardiovascular, respiratory and muscular systems. The result of these physiological adaptations is an improvement in performance.
- Chronic adaptations to training are dependent on:
  - the type and method of training
  - the frequency, duration/time and intensity of training
  - the individual athlete’s capacities and genetic make-up.
- Aerobic (endurance) training adaptations lead to more efficient delivery of larger quantities of oxygen to working muscles and an improved economy. Specifically, the cardiovascular system increases blood flow and delivery of oxygen to the muscles, and the respiratory system increases the amount of oxygen available and the muscular system increases the amount of O2 utilised for ATP resynthesis.
- Aerobic training effects are developed through continuous, fartek, long-interval and high intensity interval (HIIT) type training.
- Anaerobic training adaptations lead to increased muscle size, enabling greater strength, power and speed, as well as changes at the cellular level that improve anaerobic energy production.
- Anaerobic training effects are best developed through short and intermediate interval training, plyometric training, circuit training and resistance (strength and power) training.
- Resistance training causes a range of neuromuscular adaptations to take place; such as increased neural control, improved synchronicity of motor units and increased firing rate of motor units.
- Aerobic training results in cardiac hypertrophy. An increase in the size and volume of the left ventricle, in particular, occurs. This increases stroke volume and cardiac output, allowing a greater volume of blood to be ejected from the heart, thus providing more oxygen for the athlete to use.
- Cardiac hypertrophy also leads to an increase in the capillarisation of the heart muscle itself. The increased supply of blood and oxygen allows the heart to beat more strongly and efficiently during both exercise and rest.
- Increased heart rate recovery rates mean that the heart rate will return to resting levels in a much shorter time than that of an untrained individual. This is due to the greater efficiency of the cardiovascular system to produce energy aerobically.
- Red blood cells may increase in number and the haemoglobin content and oxygen-carrying capacity of the blood may also rise. There is also an increased ratio of plasma in the blood cells, which reduces the viscosity of the blood allowing it to flow smoothly through the blood vessels. This allows a greater amount of oxygen to be delivered to the muscles and used by the athlete.
- Aerobic training leads to increased capillarisation of skeletal muscle. Greater capillary supply means increased blood flow and greater surface area for gas diffusion to take place. Increasing the oxygen and nutrients into the muscles allows for more removal of by-products
- A greater stroke volume results in the heart not having to beat as often to supply the required blood flow (and oxygen). Aerobic training also results in a slower increase in heart rate during exercise and also a lower steady state that is reached sooner.

TABLE 12.3 Summary of chronic aerobic adaptations to training

<table>
<thead>
<tr>
<th>Physiological adaptation from aerobic training</th>
<th>Explain the adaptation from aerobic training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased left ventricle size and volume (increased stroke volume)</td>
<td>Aerobic training results in cardiac hypertrophy. An increase in the size and volume of the left ventricle, in particular, occurs. This increases stroke volume and cardiac output, allowing a greater volume of blood to be ejected from the heart, thus providing more oxygen for the athlete to use.</td>
</tr>
<tr>
<td>Increased capillarisation of the heart muscle</td>
<td>Cardiac hypertrophy also leads to an increase in the capillarisation of the heart muscle itself. The increased supply of blood and oxygen allows the heart to beat more strongly and efficiently during both exercise and rest.</td>
</tr>
<tr>
<td>Faster heart rate recovery rates</td>
<td>Increased heart rate recovery rates mean that the heart rate will return to resting levels in a much shorter time than that of an untrained individual. This is due to the greater efficiency of the cardiovascular system to produce energy aerobically.</td>
</tr>
<tr>
<td>Increased blood volume and haemoglobin levels</td>
<td>Red blood cells may increase in number and the haemoglobin content and oxygen-carrying capacity of the blood may also rise. There is also an increased ratio of plasma in the blood cells, which reduces the viscosity of the blood allowing it to flow smoothly through the blood vessels. This allows a greater amount of oxygen to be delivered to the muscles and used by the athlete.</td>
</tr>
<tr>
<td>Increased capillarisation of skeletal muscle</td>
<td>Aerobic training leads to increased capillarisation of skeletal muscle. Greater capillary supply means increased blood flow and greater surface area for gas diffusion to take place. Increasing the oxygen and nutrients into the muscles allows for more removal of by-products</td>
</tr>
<tr>
<td>Decreased heart rate at rest and during submaximal workloads</td>
<td>A greater stroke volume results in the heart not having to beat as often to supply the required blood flow (and oxygen). Aerobic training also results in a slower increase in heart rate during exercise and also a lower steady state that is reached sooner.</td>
</tr>
</tbody>
</table>
## RESPIRATORY

<table>
<thead>
<tr>
<th>Physiological adaptation from aerobic training</th>
<th>Explain the adaptation from aerobic training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased alveolar surface area (increased pulmonary diffusion)</td>
<td>Aerobic training increases the surface area of the alveoli, which in turn increases the pulmonary diffusion, allowing more oxygen to be extracted and transported to the working muscles for use.</td>
</tr>
<tr>
<td>Increased tidal volume</td>
<td>Aerobic training increases the amount of air inspired and expired by the lungs per breath. This allows for a greater amount of oxygen to be diffused into the surrounding alveoli capillaries and delivered to the working muscles.</td>
</tr>
<tr>
<td>Increased ventilation during maximal exercise</td>
<td>Aerobic training results in more efficient lung ventilation. Ventilation may be reduced slightly at rest and during submaximal exercise due to improved oxygen utilisation. At maximal workloads, ventilation is increased due to an increase in tidal volume and respiratory frequency. This allows for greater oxygen delivery to working muscles at maximum exercise intensities.</td>
</tr>
</tbody>
</table>

## MUSCULAR

<table>
<thead>
<tr>
<th>Physiological adaptation from aerobic training</th>
<th>Explain the adaptation from aerobic training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased size and number of mitochondria</td>
<td>Mitochondria are the sites of aerobic ATP resynthesis and where glycogen and triglyceride stores are oxidised. The greater the number and size of the mitochondria located within the muscle, the greater the ability to resynthesise ATP aerobically.</td>
</tr>
<tr>
<td>Increased myoglobin stores</td>
<td>Myoglobin is responsible for extracting oxygen from the red blood cells and delivering it to the mitochondria in the muscle cell. An increase in the number of myoglobin stores increases the amount of oxygen delivered to the mitochondria for energy production.</td>
</tr>
<tr>
<td>Increased fuel storage and oxidative enzymes</td>
<td>Aerobic training increases the muscular storage of glycogen and triglycerides in the slow-twitch muscle fibres and there is also an increase in the oxidative enzymes that are responsible for metabolising these fuel stores to produce ATP aerobically. This means that there is less reliance upon the anaerobic glycolysis system until higher intensities. In addition to this, due to increased levels of the enzymes associated with fat metabolism, an aerobically trained athlete is able to ‘glycogen spare’ more effectively and therefore work at higher intensities for longer.</td>
</tr>
<tr>
<td>Increased muscle oxygen utilisation (a-VO2 difference)</td>
<td>All of the above listed factors contribute to the body’s ability to attract oxygen into the muscle cells and then use it to produce adenosine triphosphate (ATP) for muscle contraction. A measure of this is the difference in the amount of oxygen in the arterioles in comparison to the venules.</td>
</tr>
<tr>
<td>Increased muscle fibre adaptation</td>
<td>Some research has indicated that skeletal muscle fast-twitch type 2A can take on some of the characteristics of slow-twitch as an adaptation of aerobic training. This would allow for a greater ability to generate ATP aerobically with fewer fatiguing factors.</td>
</tr>
</tbody>
</table>

### ALL THREE SYSTEMS — CARDIOVASCULAR, RESPIRATORY AND MUSCULAR

<table>
<thead>
<tr>
<th>Physiological adaptation from aerobic training</th>
<th>Explain the adaptation from aerobic training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased VO2 max</td>
<td>An increase in the maximum oxygen uptake (VO2 max) allows for a greater amount of oxygen that can be taken in by the respiratory system, transported by the cardiovascular system and utilised by the muscular system to produce ATP, improving the economy of the athlete.</td>
</tr>
<tr>
<td>Increased lactate inflection point</td>
<td>LIP represents the highest intensity point where there is a balance between lactate production and removal from the blood. The advantage of having a higher LIP is that the anaerobic glycolysis system isn’t contributing as much until higher exercise intensities are reached. This means that the athlete can work at higher intensities for longer periods without the fatiguing hydrogen ion accumulation.</td>
</tr>
</tbody>
</table>
### TABLE 12.4 Summary of chronic anaerobic adaptations to training

<table>
<thead>
<tr>
<th>Physiological adaptation from anaerobic training</th>
<th>Explain the adaptation from anaerobic training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular hypertrophy</td>
<td>An increase in muscle fibre size due to an increase in the size and number of myofibrils and the protein filaments actin and myosin. This increase in muscle size allows for a greater production of strength and power.</td>
</tr>
<tr>
<td>Increased muscular stores of ATP and CP</td>
<td>Increased muscular stores of ATP and creatine phosphate increases the capacity of the ATP-CP system, allowing for faster resynthesis of ATP for high intensity activities.</td>
</tr>
<tr>
<td>Increase in ATPase and creatine kinase enzymes</td>
<td>ATPase is responsible for breaking down ATP to form ADP and release energy for muscular contraction. Creatine kinase initiates the breakdown of PC, which provides the energy to resynthesise ATP at a fast rate.</td>
</tr>
<tr>
<td>Increased glycolytic capacity</td>
<td>Increased muscular storage of glycogen and consequently the increased levels of glycolytic enzymes, enhances the capacity of the anaerobic glycolysis system to produce energy.</td>
</tr>
<tr>
<td>Increase in the number of motor units recruited</td>
<td>An increase in the number of nerve axons and their corresponding muscle fibres increases the power and strength of muscular contractions.</td>
</tr>
<tr>
<td>Increased lactate tolerance</td>
<td>An increase in the ability of the muscles to buffer (neutralise) the acid that accumulates from the production of hydrogen ions during an exercise bout. The increase in lactate tolerance prevents the onset of fatigue and allows an athlete to continue to generate ATP anaerobically, which is at a faster rate, and allows them to work at a higher intensity, producing high lactate levels at the end of performance.</td>
</tr>
</tbody>
</table>

### TABLE 12.5 Summary of chronic adaptations to resistance training

<table>
<thead>
<tr>
<th>Physiological adaptation from resistance training</th>
<th>Explain the adaptation from resistance training and how it affects performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in the cross-sectional area of a muscle (muscle hypertrophy)</td>
<td>An increase in the total quantity of actin and myosin protein filaments, the size and number of myofibrils and also in the amount of connective tissue that surrounds the muscle. This allows the muscle to create a greater amount of strength and power with each contraction.</td>
</tr>
<tr>
<td>Increased synchronisation of motor units</td>
<td>An increase in the ability for a number of different motor units to fire at the same time and an improved ability to recruit larger motor units that require a larger stimulus to activate. The ability to recruit more motor units at the same time and to stimulate larger motor units creates a more powerful muscular contraction.</td>
</tr>
<tr>
<td>Increase in the firing rate (rate coding) of motor units</td>
<td>An increase in the frequency of stimulation of a given motor unit (rate coding) increases the rate of force development or how quickly a muscle can contract maximally. This is beneficial for rapid ballistic movements where maximal force is required in a very short period of time.</td>
</tr>
<tr>
<td>A reduction in inhibitory signals</td>
<td>The improved coordination of the agonists, antagonists and synergists is thought to allow for the reduced inhibitory effect. The reduction in the inhibitory mechanisms allow for a greater force production within a muscle group.</td>
</tr>
</tbody>
</table>

### EXAM PREPARATION

**MULTIPLE CHOICE QUESTIONS**

1. A chronic adaptation of aerobic training is an increase in plasma volume. This increase aids performance by
   (A) improving the ability of the blood to carry oxygen.
   (B) enabling an increase in haemoglobin.
   (C) facilitating an increase in red blood cells.
   (D) improving the effectiveness of by-product removal.

2. The world record for the men’s 100 m Butterfly event is 49.82 seconds, set by American swimmer, Michael Phelps in 2009. Successful performance by a swimmer such as Phelps is enabled because he would have a
   (A) larger finite capacity of the ATP–CP energy system.
   (B) larger finite capacity of the anaerobic glycolysis energy system.
   (C) larger finite capacity of the aerobic energy system.
   (D) higher lactate inflection point.

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*Interactivity*

Chronic adaptations to training quiz
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**studyon**

Sit VCAA exam
3. (ACHPER Trial Exam 2015, question 11)

VO₂ maximum is calculated by which of the following formulae?
(A) (220 – age) x 85% of maximum heart rate
(B) (heart rate x stroke volume) x arteriovenous oxygen (a-VO₂) difference
(C) maximum heart rate x 85%
(D) lactate inflection point x maximum ventilation

4. (ACHPER Trial Exam 2014, question 12)

A previously untrained year-12 student completed a 6-week training program to improve aerobic capacity. Which of the following would be a chronic vascular adaptation to a long-interval training program for this student?
(A) Increased size of the left ventricle
(B) Increased contractility of the heart
(C) Increased myoglobin levels
(D) Increased haemoglobin levels

5. Which of the following is not a chronic adaptation to training?
(A) Increased red blood cell count
(B) Increased capillarisation of the heart muscle
(C) Increased muscular storage of glycogen
(D) Increased resting heart rate

6. Which of the following chronic adaptations to training would indicate an improved level of aerobic fitness?
(A) Decreased stroke volume at rest
(B) Increased cardiac output during maximal exercise
(C) Increased blood pressure at rest
(A) Decreased arteriovenous oxygen difference during submaximal exercise

7. (adapted from ACHPER Trial Exam 2016, question 12)

Following a two-month training program, aiming to increase muscular strength, adaptations that are likely to occur include an increase in:
(A) mitochondrial mass and myoglobin.
(B) stroke volume and cardiac output.
(C) ATP and oxidative enzymes.
(D) contractile proteins and number and size of myofibrils.

8. (adapted from ACHPER Trial Exam 2013, question 9)

Lactate inflection point can occur when an athlete
(A) exercises at submaximal intensity.
(B) fails to improve their lactate tolerance.
(C) depletes their muscle and liver glycogen stores.
(D) exceeds their VO₂ maximum.

9. (adapted from ACHPER Trial Exam 2011, question 10)

When a comparison is made between an untrained person and an elite athlete runner of the same age in the same 5 km fun-run event, which of the following is true of the elite runner?
(A) Submaximal heart rate is lower, stroke volume is lower
(B) Submaximal heart rate is higher, stroke volume is lower
(C) Submaximal heart rate is lower, stroke volume is higher
(D) Submaximal heart rate is higher, stroke volume is higher

10. (adapted from ACHPER Trial Exam 2011, question 11)

To increase a person’s lactate inflection point (LIP), which of the following training programs is recommended?
(A) Both elite and non-elite performers should engage in continuous training at, or slightly below, their LIP
(B) Both elite and non-elite performers should engage in continuous training at, or slightly above, their LIP
(C) Elite performers should engage in continuous training at, or slightly below, their LIP, while non-elite performers should perform continuous training at, or slightly above, their LIP
(D) Elite performers should engage in continuous training at, or slightly above, their LIP while non-elite performers should perform continuous training at, or slightly below, their LIP
TRIAL EXAM QUESTIONS

Question 1 (adapted from ACHPER Trial Exam 2008, question 6)

a. List two chronic/long-term adaptations that could be expected to occur within each of the listed body systems as a result of participation in a long-term aerobic (endurance) training program.

<table>
<thead>
<tr>
<th>Body system</th>
<th>Chronic adaptations due to aerobic training</th>
</tr>
</thead>
</table>
| Cardiovascular    | i.  
|                   | ii.                                        |
| Respiratory       | i.  
|                   | ii.                                        |

4 marks

b. Outline how these chronic adaptations contribute to improved performance.

4 marks

Question 2 (adapted from ACHPER Trial Exam 2014, question 11)

Caitlin Sargent from Queensland ran the fastest 400 m by an Australian female athlete in 2013.
She completed the race in a time of 52.16 seconds. Caitlin would include interval training as part of her training routine. As a result of her training, she would expect to develop an increase in glycolytic enzymes, an increase in contractile proteins and an increased tolerance to hydrogen ions.

a. Which of the following interval sessions would be most likely to bring about these adaptations?

Please circle the most appropriate session — either A, B or C.

1 mark

<table>
<thead>
<tr>
<th>Sets</th>
<th>Repetition number</th>
<th>Distance (metres)</th>
<th>Time (seconds)</th>
<th>Recovery (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>8</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>5</td>
<td>150</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>5</td>
<td>600</td>
<td>120</td>
</tr>
</tbody>
</table>

b. Complete the table below to describe how an increase in each factor can lead to improved performance in the 400 m by Caitlin.

6 marks

<table>
<thead>
<tr>
<th>Role in improving performance in the 400m event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycolytic enzymes</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Contractile proteins</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Tolerance to hydrogen ions</td>
</tr>
</tbody>
</table>
Question 3  (adapted from ACHPER Trial Exam 2013, question 8)

The lactate inflection point (LIP) and lactate tolerance are terms related to exercise science. With specific reference to these parameters, complete the following table.

<table>
<thead>
<tr>
<th></th>
<th>Lactate inflection point</th>
<th>Lactate tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Appropriate training method to achieve improvement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Event likely to benefit from this parameter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outline how improvement in this parameter will benefit performance</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8 marks