This knowledge includes:
- the cardiovascular and respiratory systems, including the structure and function of the heart and lungs, mechanics of breathing, gaseous exchange, blood vessels, blood flow around the body at rest and during exercise.

These skills include the ability to:
- perform, measure and report on changes to the cardiovascular, respiratory and muscular systems at rest compared to during exercise.
This chapter considers the structure and function of the cardiovascular system which is made up of the heart, blood vessels and the blood. It also investigates the structure and function of the respiratory system, which consists of the respiratory airways that bring air into the body and lungs. To transport gases throughout the body, the cardiovascular and respiratory systems must work together. You will discover how the two respond to physical activity to meet performance demands in the short term.

**Cardiovascular system**

**Structure and function of the heart**

Chapter 1 looked at the way the ribs protect the heart by ‘encasing it’ and how the intercostal muscles assist with the mechanics of breathing. The heart is situated behind the sternum and is made up of four chambers:

- two upper chambers – the atria (singular atrium)
- two lower chambers – the ventricles.

The ventricles are more muscular than the atria because they are responsible for pumping blood throughout the body. The atria act more like collecting vessels at the top of the heart. The heart can be divided transversely into superior and inferior parts (atria and ventricles) and sagitally into left and right sides divided by the septum. To ensure blood flows in the right direction through the heart, one-way valves exist. When the atria contract, the valves open, but they close when the ventricles contract to prevent any ‘backflow’. The bicuspid (or mitral) valve on the left side between the atrium and ventricle is made up of two flaps, and the tricuspid valve on the right side is made up of three flaps. Sometimes these valves break down. They can be replaced by artificial valves.
The cardiac cycle

The cardiac cycle involves the heart filling with blood and then pumping this to the rest of the body via the arterial system. This takes just under 1 second to complete a heartbeat. There are four stages to each heartbeat:

- **Stage 1** – atrial diastole
- **Stage 2** – ventricular diastole
- **Stage 3** – atrial systole
- **Stage 4** – ventricular systole

**Stage 1**

The atria fill with blood returning from two key areas: blood from the body returns through the vena cava into the right atrium; blood from the lungs returns through the pulmonary vein into the left atrium. At this time, the heart valves remain shut.

**Stage 2**

The bicuspid and tricuspid valves open because of the pressure build-up in the atria; blood flows into the ventricles and the valves shut again.

**Stage 3**

The atria contract and blood is forced into the ventricles and pressure increases to become greater than that in the aorta and pulmonary artery.

**Stage 4**

The semilunar valves (pulmonary valve and aortic valve at the top of the heart) open and the ventricles contract, forcing blood into the aorta to move the rest of the body or into the pulmonary artery to go to the lungs.
Stroke volume is a measure of how much blood is squeezed out of the heart into the aorta each time it beats, i.e. per systole (think of systolic blood pressure). The average adult stroke volume at rest is between 70 and 90 mL. As you start to exercise, the heart pumps more forcefully and more blood is squeezed out per beat and hence the stroke volume increases. In adults, this typically increases by 40 per cent when maximum exercise levels are reached (see Table 2.1). Cardiac output is the amount of blood pumped out of the heart per minute and is easily calculated:

\[
\text{cardiac output (Q)} = \text{stroke volume} \times \text{heart rate}
\]

At rest, cardiac output might be 80 mL \times 60 \text{bpm} = 4800 \text{mL} or 4.8 litres/min. At maximal exercise, cardiac output might increase to be 130 mL \times 200 \text{bpm} = 26000 \text{mL} or 26 litres/min.

| Stroke volumes and cardiac outputs for untrained, trained and endurance athletes |
|---------------------------------|-----------|-----------|-----------------|
| **Stroke volume (mL)**          | Untrained | Trained   | Endurance athletes |
| "Rest"                          | 80        | 110       | 125              |
| "Maximal exercise"              | 115       | 130       | 185              |
| **Cardiac output (L/min)**      | Untrained | Trained   | Endurance athletes |
| "Rest"                          | 4.8       | 6.0       | 6.5              |
| "Maximal exercise"              | 20        | 26        | 37               |

**Blood**

Adult males have approximately 5–6 litres and adult females have approximately 4–5 litres of blood.

**Functions of blood**

Blood is responsible for:

- transportation of gases, fuels, and minerals
- protection against infection and dehydration
- maintaining equilibrium (homeostasis) via enzyme and hormone regulation.

Blood transports oxygen from the lungs and heart to working muscles and cells, and then removes metabolic by-products such as carbon dioxide from muscle sites. It also transports fuels such as glucose to working muscles and removes lactate that might be produced under anaerobic conditions (see Chapter 3). Blood acts to protect the body by moving white blood cells to sites of infection and platelets to areas that need blood flow stopped and clotted so as to limit haemorrhaging and cell damage.

The blood moves enzymes and chemicals to areas where metabolic processes require them – especially for maintaining a constant pH. The blood also regulates temperature and maintains homeostasis by moving heat away from working muscles to other areas of the body including the skin’s surface. So the blood is very important in bringing about peak performance during physical activity.
**Blood composition**

Blood consists of plasma and blood cells. Red blood cells give blood its colour. They are produced in bone marrow (in bones such as the sternum, ribs and vertebrae). They contain the protein haemoglobin, which carries oxygen to body tissues and muscles. Women have slightly lower haemoglobin levels than men.

White blood cells fight infection by absorbing and digesting disease-causing organisms. They are produced in bone marrow, lymph tissue and the spleen.

Platelets are cells that help form blood clots to stop bleeding. They are produced in bone marrow.

Blood plasma is a clear yellowish fluid that carries nutrients. It also transports waste products and assists with their removal from the body. Plasma is 90 per cent water, which counters dehydration, but importantly contains the protein fibrinogen, which assists platelets in blood clotting.

**DID YOU KNOW?**

Blood makes up around 8 per cent of your total body weight and it takes approximately 20 seconds for a blood cell to circulate around the entire body at rest.

**Blood vessels**

Blood vessels make up the vascular network through which all blood flows to all parts of the body. The vascular network consists of arteries that branch into arterioles, which further branch into capillaries (smallest blood vessels in the network), which then connect to venules that then become veins.

Veins and arteries transport blood around the body. Arteries transport blood away from the heart and veins return blood back to the heart. The largest artery in the body is the aorta and this is found closest to the heart. The aorta subdivides many times into arterioles; every time this division or ‘split’ happens, the cross-sectional area of the blood flow through the vascular network.
vessel increases. This then allows for greater exchange of gases, nutrients, fuels and wastes. Arteries have their own pulse due to the fact they have strong elastic walls. Arteries transport oxygen-rich blood, which gives them their bright red blood colour.

Arterioles ‘connect’ to capillaries which in turn ‘connect’ to venules. Capillaries are so small that only single red blood cells can pass through. Blood flow through capillaries is controlled by minute structures called precapillary sphincters. These bands of smooth muscles encircle each capillary branch at the point where it branches from the arteriole. Forceful contraction of the precapillary sphincter can close the branches off to blood flow while opening others. In this way, more blood is sent to working muscles and less to major organs as exercise intensities increase (see Figure 2.3). This leads to more oxygen and fuels being transported to muscles and assists quicker metabolic waste removal.

Venules become veins and these vessels return blood to the heart that is relatively low in oxygen (deoxygenated blood) and high in carbon dioxide due to exchanges occurring at the capillaries. For this reason, blood transported in veins tends to be a dark red or blue colour. Veins are much less elastic than arteries and keep blood flowing back to the heart in one direction via pocket valves that close intermittently to prevent the backflow of blood. The pumping of the heart is actively assisted by the action of muscles surrounding veins contracting and pushing blood towards the heart. For this reason, an active recovery involving low-intensity exercise is recommended at the completion of vigorous physical activity.

Once blood reaches the heart it is pumped to the lungs through the pulmonary artery which quickly subdivides into the pulmonary capillaries where gaseous exchange takes place. Carbon dioxide and other excretory products are exchanged (exhaled) for oxygen (which is inhaled).
Blood pressure is the force exerted by the blood against the blood vessel walls. Blood pressure in the arteries increases and decreases during the cardiac cycle. It is greatest when blood is pumped into the aorta during ventricular systole and lowest during ventricular diastole. By the time blood reaches the capillaries, blood pressure is much less than when it travelled through the coronary (heart) arteries. Systolic blood pressure is experienced when blood is pumped into the system from the heart, and diastolic blood pressure is experienced when the heart relaxes and fills with blood. Blood pressure can be measured using a sphygmomanometer. A typical reading at rest is 120 mmHg, 80 mmHg, where mmHg stands for millimetres of mercury.

**Blood flow through the heart**

The flow of blood from the heart and to the lungs and other body tissues through the cardiovascular system can be summarised as follows:

- Pulmonary circulation occurs when the right side of the heart receives de-oxygenated blood from most of the body and pumps it to the lungs. Blood is pumped through the superior and inferior vena cava (veins) into the right atrium.
  - The right atrium contracts, forcing the tricuspid valve open and the blood into the right ventricle. The tricuspid valve then closes, preventing the backflow of blood into the right atrium. Blood is then forced out of the right ventricle into the pulmonary artery to the lungs where it exchanges carbon dioxide and waste products for oxygen.
  - This oxygenated blood is pumped into the left side of the heart via the pulmonary vein into the left atrium. When the left atrium contracts, the bicuspid valve opens and blood is forced into the left ventricle. This valve then closes again, preventing backflow into the left atrium.
- Systemic circulation starts when the left ventricle contracts and pumps the blood into the aorta under high pressure. This blood is then pumped through the thousands of arteries to all parts of the body. As blood enters the capillaries, the pressure gradually drops.

The next section discusses how the respiratory system ensures a continuous supply of oxygen to the muscles and other body cells.
THINKING THINGS THROUGH

1. What are the major differences between the cardiovascular systems of males and females?
2. Why does systolic blood pressure show a greater increase than diastolic blood pressure during exercise?
3. Precapillary sphincters can save lives during major sporting accidents where major blood loss is likely to occur after serious injury. Discuss how this happens.

Respiratory system

Structure and function

The respiratory system comprises the mouth, nose, airways and lungs. Most of the system is encased by the ribs, sternum and vertebrae. External respiration involves air/gases moving into and out of the lungs whereas movement of gases from the lungs into the bloodstream is known as pulmonary diffusion.

The main parts of the respiratory system and their functions

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>Delivers large volumes of air into the airways quickly and more efficiently than the nose</td>
</tr>
<tr>
<td>Nose</td>
<td>Improves breathing as the cilia warm, filter and moisten the air, keeping the airways relaxed and open</td>
</tr>
<tr>
<td>Airways (including pharynx, larynx, trachea, bronchi and bronchioles)</td>
<td>The trachea directs air to the left and right bronchi. Bronchi branch into smaller bronchioles which enable air to pass into the alveoli where pulmonary diffusion occurs.</td>
</tr>
<tr>
<td>Lungs (including alveoli)</td>
<td>The body has more than 500 million alveoli, which have very thin walls to allow for the diffusion of gases. The surface of each alveoli has a rich blood supply to help with gaseous exchange.</td>
</tr>
</tbody>
</table>
Inspiration and expiration

We breathe in actively by contracting the intercostal muscles and the diaphragm. When the intercostals contract, the ribs move upwards and outwards and at the same time the diaphragm contracts downwards. Both of these actions increase the size of the thoracic cavity and the space within the lungs. This causes the pressure within the lungs (intrapulmonary pressure) to decrease to become less than that of air outside the body. Gases always move from areas of higher pressure to lower pressure so air moves into the lungs quickly. This is known as inspiration.

Expiration, on the other hand, is passive and occurs in response to the intercostal and diaphragm muscles relaxing. When this happens, the ribs drop and the diaphragm adopts its relaxed dome-like shape in the thoracic cavity. The space inside the lungs decreases, while air pressure increases until it exceeds that outside the body and air is exhaled or expired.

The amount of air inhaled and exhaled per breath is known as the tidal volume (TV). Men generally have a larger lung capacity than women, so their resting tidal volumes tend to also be greater. The average tidal volume for men is 600 mL and for women is 500 mL.

Pulmonary ventilation (or minute ventilation) refers to the volume of air moved into and out of the respiratory tract each minute and can be calculated from:

\[
\text{Minute ventilation (VE)} = \text{respiratory rate} \times \text{tidal volume}
\]

At rest, minute ventilation = \(12 \times 0.5 \text{L} = 6.0 \text{L/min}\).

<table>
<thead>
<tr>
<th>State</th>
<th>Respiratory rate (breaths/min)</th>
<th>Tidal volume (L/breath)</th>
<th>Minute ventilation (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>12</td>
<td>0.5</td>
<td>6.0</td>
</tr>
<tr>
<td>40–50% max HR exercise</td>
<td>25</td>
<td>2.5</td>
<td>62.5</td>
</tr>
<tr>
<td>85–95% max HR exercise</td>
<td>50</td>
<td>3.0</td>
<td>150</td>
</tr>
</tbody>
</table>
During exercise, the frequency and depth of breathing increases in order to supply more oxygen to working muscles. If an athlete works submaximally, this will level off and they will experience **steady state**. This occurs when oxygen supply can meet oxygen demand and is commonly experienced when jogging or walking at a steady pace. When exercise intensity increases, a point is reached where oxygen supply can no longer meet demand. This is because there is a maximum amount of oxygen that can be taken in, transported and utilised – this is known as VO₂ maximum. So this intense exercise cannot be sustained for extended periods as the body will not be able to supply sufficient oxygen.

**THINKING THINGS THROUGH**

1. Endurance athletes train to achieve improved cardiovascular and respiratory functions. List as many cardiovascular or respiratory benefits such training would bring to a triathlete.

2. a. What are the two most important muscles that bring about respiration? Briefly discuss how they work together to bring about inspiration and expiration.
   
   b. Explain how being ‘winded’ affects the mechanics of breathing.

3. Aerobic training increases the alveolar-capillary surface area at the lungs. Briefly discuss how this improves oxygen uptake.

---

**Heart rate and blood pressure**

**AIM**

To investigate heart rate and blood pressure response during rest and exercise for different class members.

**EQUIPMENT**

Exercise bike (Repco, Monarch or similar), blood-pressure monitor (preferably electronic) or sphygmomanometer, heart-rate monitor (manual readings are acceptable)

**METHOD**

1. Divide the class (wherever practical) into three groups:
   - Group 1 – students involved in no training
   - Group 2 – students involved in aerobic training
   - Group 3 – students involved in anaerobic training

2. Work in pairs. One student takes a comfortable seated position on the exercise bike and has their resting blood pressure and heart rate recorded by the other student. The student on the bike starts pedalling. Once they have reached 75 watts workload, they maintain an even pace for 3 minutes. Their heart rate and blood pressure are recorded over the last 15 seconds of this 3-minute period. Then over the next minute, the student should slow their pedalling rate down to stationary.

3. Record the heart rate and blood pressure at the end of the first minute of ‘cool-down’ and then again at the 3-minute mark of rest/recovery.

4. Repeat steps 2 and 3 for a workload of 300 watts.
5 Use a table similar to the following to record your results.

<table>
<thead>
<tr>
<th></th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75 watts</td>
</tr>
<tr>
<td>Heart rate</td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td></td>
</tr>
<tr>
<td>End of 3-minute exercise period</td>
<td></td>
</tr>
<tr>
<td>First minute of recovery</td>
<td></td>
</tr>
<tr>
<td>Third minute of recovery</td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td></td>
</tr>
<tr>
<td>End of 3-minute exercise period</td>
<td></td>
</tr>
<tr>
<td>First minute of recovery</td>
<td></td>
</tr>
<tr>
<td>Third minute of recovery</td>
<td></td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td></td>
</tr>
<tr>
<td>End of 3-minute exercise period</td>
<td></td>
</tr>
<tr>
<td>First minute of recovery</td>
<td></td>
</tr>
<tr>
<td>Third minute of recovery</td>
<td></td>
</tr>
</tbody>
</table>

6 Share the heart/pulse rates for the class. Construct two graphs, one for each workload, showing the effect exercise has on both heart rate and blood pressure for each member of the different groups.

**DISCUSSION**

1 What is the relationship between systolic blood pressure and exercise intensity?
2 Are there any differences in either heart rate or blood pressure response to the different workloads from students in each of the three groups?
3 Are there any advantages in having blood pressure increase minimally in response to exercise?
4 During recovery, which group took longest for heart rates and blood pressure to return to resting levels?

**Transfer and transport of gases**

Pulmonary diffusion explains the gaseous exchange that occurs in the lungs. This has two main functions:

- To provide the blood with oxygen before being transported to muscles and other cells within the body
- To remove carbon dioxide from the blood returning from the muscles and other cells

At the alveoli, a two-way movement of gases results in oxygen moving from the alveoli into the blood and carbon dioxide moving from the blood to the alveoli. The pulmonary capillaries...
surrounding the alveoli contain blood that is oxygen poor and therefore has a low oxygen pressure because it has been used by working muscles. The pressure difference causes oxygen to move from the alveoli into the blood. At the same time, carbon dioxide is present at a higher pressure and concentrations than in the pulmonary capillaries and it moves from the blood into the alveoli to then be expired.

Most oxygen is transported by the red blood cells combined with haemoglobin (Hb); when the two combine they form oxyhaemoglobin:

\[
\text{haemoglobin} + \text{oxygen} \rightarrow \text{oxyhaemoglobin}
\]

\[
\text{Hb} + \text{O}_2 \rightarrow \text{HbO}_2
\]

The amount of oxygen that can be transported thus depends on haemoglobin levels. The amount of haemoglobin may be increased along with blood volumes in response to long-term aerobic training. It can also be increased by illegal means such as the use of blood doping or EPO (erythropoietin) (see Chapter 9).

Only 20 per cent of carbon dioxide produced at cells and muscles is transported via haemoglobin. Most of it (70 per cent) travels in the blood as a bicarbonate ion and is non-gaseous, and a small amount is dissolved in blood plasma (7 per cent). Once again, carbon dioxide is removed via concentration and pressure gradients and it moves from areas of high pressure and concentration such as the tissues/muscles to the blood to be transported to the alveoli to then be expired.

### Arteriovenous oxygen difference

The arteriovenous oxygen difference (a-vO\(_2\) diff) is an indication of the difference in oxygen concentration between arterial and venous blood. At rest, the a-vO\(_2\) diff is approximately 5 mL of oxygen per 100 mL of blood and this reveals the amount of oxygen exchanged or used. Once again, blood arriving at the muscles in the arterioles is higher in oxygen than in the capillaries so it moves into the capillaries and then the muscle cells by attaching to myoglobin.

At rest, the blood retains a large amount of oxygen, about 15 mL O\(_2\)/100 mL blood, in reserve for when demands suddenly increase, for example when exercise intensity increases. As exercise intensity increases and the muscles extract more oxygen from blood flowing through them, the a-vO\(_2\) diff will increase as well.

### Arteriovenous oxygen difference in various people

<table>
<thead>
<tr>
<th>State</th>
<th>a-vO(_2) diff (mL/100 mL blood)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untrained</td>
</tr>
<tr>
<td>Rest</td>
<td>4.5</td>
</tr>
<tr>
<td>Moderate exercise</td>
<td>8.0</td>
</tr>
<tr>
<td>Maximal exercise</td>
<td>13.5</td>
</tr>
</tbody>
</table>
Investigating exercise intensity

AIM
To investigate any relationship between exercise intensity and both heart and respiratory rates.

EQUIPMENT
Bench, metronome, heart rate monitor

METHOD
1. Form groups of three students. One student will perform bench steps while the other members of their group record heart rates and respiratory rates (rise and fall of chest or number of breaths per minute). The roles should be swapped to allow everyone to experience first hand what occurs during varied exercise intensities.

2. Students should keep up with the metronome for each of the four different rates:
   - Rate 1 – 30 beats/min
   - Rate 2 – 45 beats/min
   - Rate 3 – 60 beats/min
   - Rate 4 – 90 beats/min
   The student performing the task should step up on one beat of the metronome and step down on the next beat.

3. One partner records the heart rate and another records the respiratory rate for the last 10 seconds of each minute.

4. Use a table similar to the following to record your results.

<table>
<thead>
<tr>
<th>Rest/rate</th>
<th>Heart rate</th>
<th>Respiratory rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 beats/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 beats/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 beats/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 beats/min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Share your results with at least two other groups and plot your results on a clearly labelled graph.

DISCUSSION
1. Is there a relationship between exercise intensity and heart rate and respiratory rate?
2. How is it possible for heart rate to keep increasing but respiratory rate to level off?
3. Account for any differences in the results obtained from different class members.
CHAPTER 2: The cardiovascular and respiratory systems

CHAPTER Summary

- The heart is made up of four chambers – two atria and two ventricles – separated by one-way valves.
- The heart has its own blood supply via the coronary arteries.
- The cardiac cycle is made up of four distinct stages – atrial diastole and systole, and ventricular diastole and systole.
- Stroke volume is a measure of how much blood is squeezed out of the heart into the aorta each time it beats, i.e. per systole.
- Cardiac output is the volume of blood pumped out of the heart per minute volume: Cardiac output = stroke volume (mL per ventricular systole) × heart rate (beats per min). As you start to exercise, your heart pumps more forcefully and more blood is squeezed out per beat and hence both the stroke volume and cardiac output increase to cater for increased muscle contractions.
- The vascular system consists of the blood vessels (arteries, arterioles, capillaries, venules and veins) and the blood that flows in them.
- Blood has three main functions: transportation of gases, fuels, and minerals; protection; and maintaining the body’s state of equilibrium (homeostasis) via enzyme and hormone regulation.
- The network of blood vessels is known as the circulatory system, which is made up of the pulmonary circuit and the systemic circuit. Arteries carry blood away from the heart, and veins carry blood back to the heart. Blood returning to the heart in veins is assisted by muscular and respiratory contractions.
- Precapillary sphincters regulate the distribution of blood through capillaries. During exercise, they direct more blood to working muscles and less to major organs thereby transporting more oxygen and fuels to muscles and facilitating removal of wastes.
- Blood pressure is the force exerted by the blood against the blood vessel walls. It is greatest during ventricular systole (systolic blood pressure) and lowest during ventricular diastole (diastolic blood pressure).
- Inspiration (inhaling) is an active process in which the ribs lift upwards and outwards, the intercostal muscles contract and the chest cavity is further increased when the diaphragm simultaneously contracts and lowers.Expiration (exhaling) is a passive process that occurs when the respiratory muscles relax and air is forced out of the lungs.
- Oxygen leaves the alveoli and enters the blood through diffusion. It is transported as oxyhaemoglobin.
- Gaseous exchange occurs all around the body as a result of concentration differences.
- The amount of air inhaled and exhaled per breath is known as the tidal volume (TV). During exercise, tidal volume increases. If a person works submaximally this will level off and the athlete will experience steady state. This occurs when oxygen supply meets oxygen demand.
- VO2 maximum is the maximum amount of oxygen that can be taken in, transported and used.
- The arteriovenous oxygen difference (a-vO2 diff) is an indication of the difference in oxygen concentration between arterial and venous blood. As exercise intensity increases and the muscles extract more oxygen from the blood flowing through them, the a-vO2 diff will increase.
Multiple choice

1. During maximal exercise:
   A. the cardiac output is also at maximum levels
   B. it is likely VO₂ max has been reached
   C. the pressure of carbon dioxide at the lungs would be greatly increased.
   D. All of the above.

2. In the heart, the tricuspid valve:
   A. operates in a bidirectional plane
   B. is inferior to the superior vena cava
   C. is located on the left side
   D. sometimes links up with the septum to increase cardiac contractions.

3. The blood vessel that supplies blood to most of the body is the:
   A. superior vena cava
   B. pulmonary vein
   C. pulmonary artery
   D. aorta.

Short answer

4. Why is the arteriovenous oxygen difference greater when someone is jogging than when they are walking?

5. Joggers often jog on the spot while they wait for pedestrian lights to change. Suggest a reason for this. Your answer must focus on heart and respiratory rates.

6. Explain how it is possible for athletes to achieve multiple ‘steady states’ during the running of a marathon.

7. Carry out some research to explain how vasoconstriction and vasodilatation occur in the body and the effect they have on the performance of an athlete.

8. Draw a diagram to show the movement of gases between the systemic capillaries and muscles they surround.

9. Draw a simple flow chart or diagram to demonstrate an understanding of the movement of blood between the heart and lungs. Draw oxygenated blood as red and deoxygenated blood as blue and use arrows to show direction of flow.

10. Describe the effect asthma sprays have on the respiratory system and the performance of athletes. You may need to carry out some research to answer this question.