

AU: Please note that all figure & Table calls are not cited in text

INQUIRY QUESTION

Which acute body system responses may occur as a result of the movement as depicted in the image?



Acute physiological responses to exercise

Whenever an individual engages in exercise the body responds physiologically to meet the increased energy demands of the activity. These immediate short-term responses that last only for the duration of the activity are referred to as acute responses. This chapter examines the cardiovascular, respiratory and muscular systems and the roles of each in supplying oxygen and energy to the working muscles.

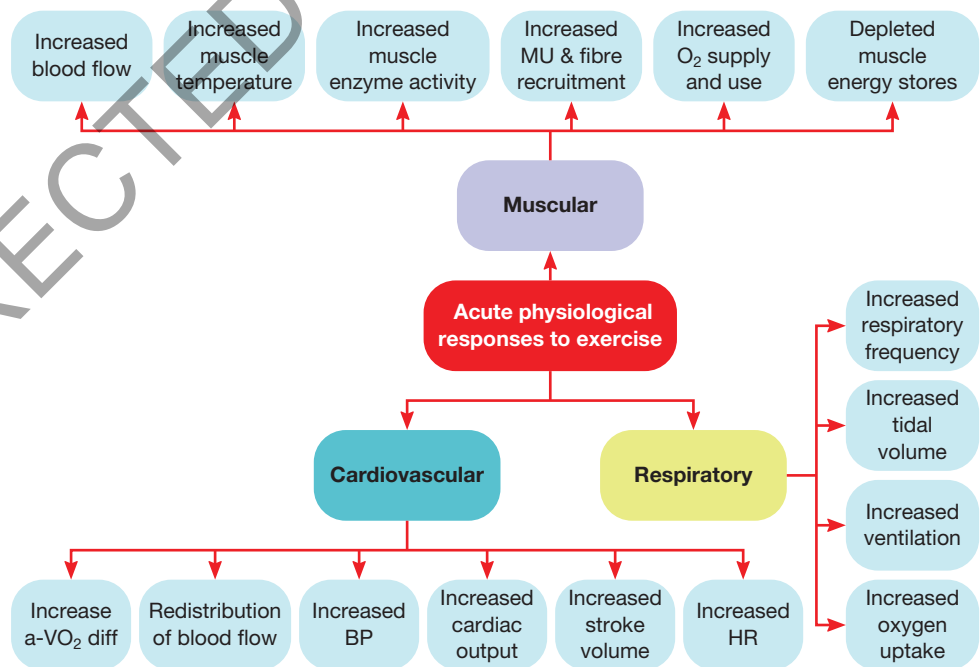
KEY KNOWLEDGE

- ▶ Oxygen uptake at rest, during exercise and recovery, including oxygen deficit, steady state, and excess post-exercise oxygen consumption
- ▶ Acute physiological responses to exercise in the cardiovascular, respiratory and muscular systems

KEY SKILLS

- ▶ Explain the changes in oxygen demand and supply at rest, during submaximal and maximal activity
- ▶ Participate in physical activities to collect and analyse data on the range of acute effects that physical activity has on the cardiovascular, respiratory and muscular systems of the body

CHAPTER PREVIEW



6.1 Acute responses of the cardiovascular system: heart rate, stroke volume and cardiac output



KEY CONCEPT When we engage in exercise, certain changes occur immediately within the cardiovascular system to meet the increased energy demands imposed on the body by the activity being undertaken. These are referred to as acute responses.

Acute responses are the body's immediate, short-term responses that last only for the duration of the training or exercise session and for a short time period (recovery) afterwards.

Heart rate (HR) is the number of times the heart contracts or beats per minute.

Resting heart rate (RHR) refers to the number of heartbeats per minute while the body is at rest — usually an average of 70 beats per minute for an adult.

Maximum heart rate (MHR) is the highest heart rate value achieved in an all-out effort to the point of exhaustion.

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Interactivity
Maximum heart rate calculator
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Numerous cardiovascular (heart, blood and blood vessels) responses occur when we start exercising. All are designed to facilitate the rapid and efficient delivery of increased amounts of oxygen to the working muscles in order to meet the body's increased demand for energy. **Acute responses** of the cardiovascular system to exercise include:

- ▶ increased heart rate
- ▶ increased stroke volume
- ▶ increased cardiac output
- ▶ increased blood pressure
- ▶ redistribution of blood flow to working muscles
- ▶ increased arteriovenous oxygen difference.

This section considers the first three of these cardiovascular responses as they all relate directly to the heart itself.

Increased heart rate

- ▶ **Heart rate (HR)** refers to the number of times the heart contracts or beats per minute (bpm).
- ▶ **Resting heart rate (RHR)** refers to the number of heartbeats per minute while the body is at rest and for an adult is usually somewhere between 60 and 80 beats per minute, with 70 beats per minute being about average.
- ▶ Once an individual begins to exercise, their heart rate increases as a response to the extra energy required by the body. The increase in heart rate helps to increase oxygen delivery to the working muscles and aids in the removal of waste products from the muscles and body.
- ▶ The heart rate increases directly in proportion (linearly) with increases in exercise intensity until near-maximal intensity is reached. The greater the intensity of exercise, the greater the increase in heart rate. For example, light or low-intensity exercise tends to produce heart rates of 100–140 beats per minute, while moderate intensity exercise typically results in heart rates of 140–160 beats per minute.
- ▶ High-intensity exercise produces even higher heart rates (see figure 6.1), although there is a maximum (ceiling) to which the heart rate can increase. This is referred to as the **maximum heart rate (MHR)** and it can be defined as 'the highest heart rate value achieved in an all-out effort to the point of exhaustion' (Wilmore et al.).
- ▶ An estimation of maximum heart rate can be calculated by subtracting the age of the individual from 220 (maximum heart rate = 220 – age in years). For example, a 17-year-old VCE student would have a maximum heart rate of $220 - 17 = 203$ beats per minute. However, it should be stressed that this method provides only a very rough estimation of an individual's maximum heart rate, and that considerable individual variation exists.

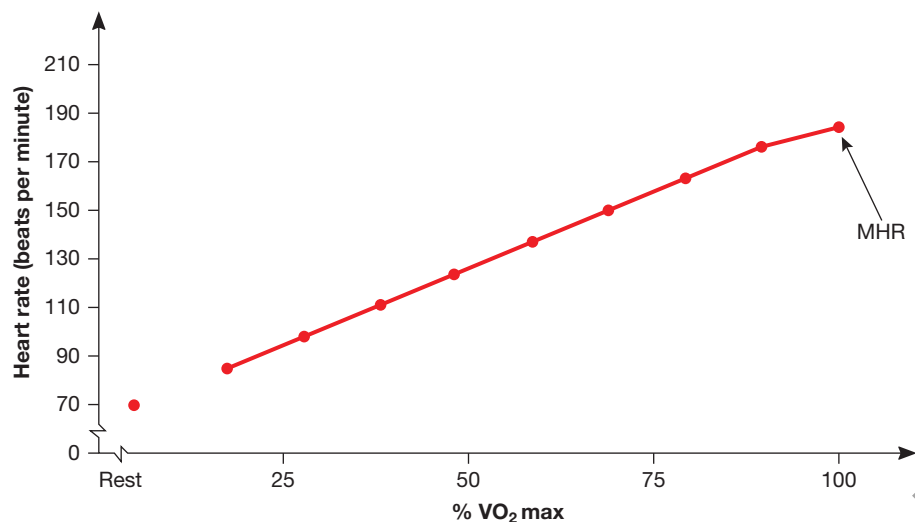


FIGURE 6.1 The heart rate increases directly in proportion (linearly) with increases in exercise intensity.

Source: Reprinted with permission, Wilmore, Costill & Kenney 2008.

Trained athletes have lower heart rates at rest and during all exercise intensities compared with untrained individuals. The heart rate actually rises above resting values just before the start of exercise. This is called an anticipatory response. The anticipatory increase in heart rate that occurs prior to beginning exercise is largely due to the release of epinephrine (adrenaline). [Figure 6.2](#) depicts the heart rate response to exercise before, during and after moderate-intensity exercise, further illustrating various aspects of the heart rate response to exercise.

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Heart rate response

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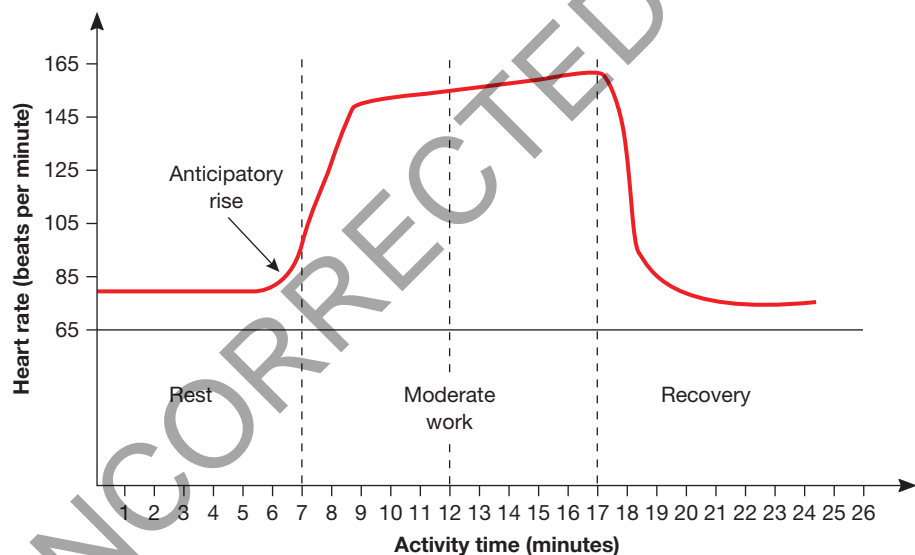


FIGURE 6.2 Heart rate response to exercise before, during and after moderate-intensity exercise

Increased stroke volume

Stroke volume (SV) is defined as the amount of blood ejected from the left ventricle with each beat (contraction) of the heart. Stroke volume increases during exercise; however, most researchers agree that while stroke volume increases with increasing exercise intensities, it does so only up to exercise intensities, for untrained athletes, somewhere between 40 and 60 per cent of maximal capacity (see [figure 6.3](#)). In untrained individuals stroke volume at rest is about 60–80 millilitres per beat. During exercise, stroke volume increases to average maximal values ranging from 110 to 130 millilitres per beat. At this point stroke volume typically plateaus and

Stroke volume (SV) is the amount of blood ejected from the left ventricle with each beat (contraction) of the heart.

6.1 Acute responses of the cardiovascular system: heart rate, stroke volume and cardiac output

remains unchanged despite increases in exercise intensity. In elite trained athletes, stroke volume may increase from 80 to 110 millilitres per beat at rest up to 160 to 200 millilitres per beat during maximal exercise.

TABLE 6.1 Stroke volumes for untrained and trained athletes

Subjects	SV at rest (ml)	SV max (ml)
Untrained	60–80	110–130
Trained	70–90	110–150
Highly trained	80–110	160–220

- ▶ Females tend to have lower stroke volumes than males, both at rest and during exercise, as a result of their smaller heart size.
- ▶ Trained athletes (both male and female) have larger stroke volumes compared with their untrained counterparts.
- ▶ Some researchers have reported that stroke volume continues to rise with increasing exercise intensities, up to the point of exhaustion, although these studies mainly involve highly trained elite athletes.

Mechanisms responsible for increase in stroke volume

During exercise, there is an increase in venous blood return to the heart. As a result, the ventricle stretches as it fills more fully with blood, and subsequently contracts more forcefully as a result of the greater elastic recoil. The ventricle's force of contraction is further enhanced by an increase in neural stimulation.

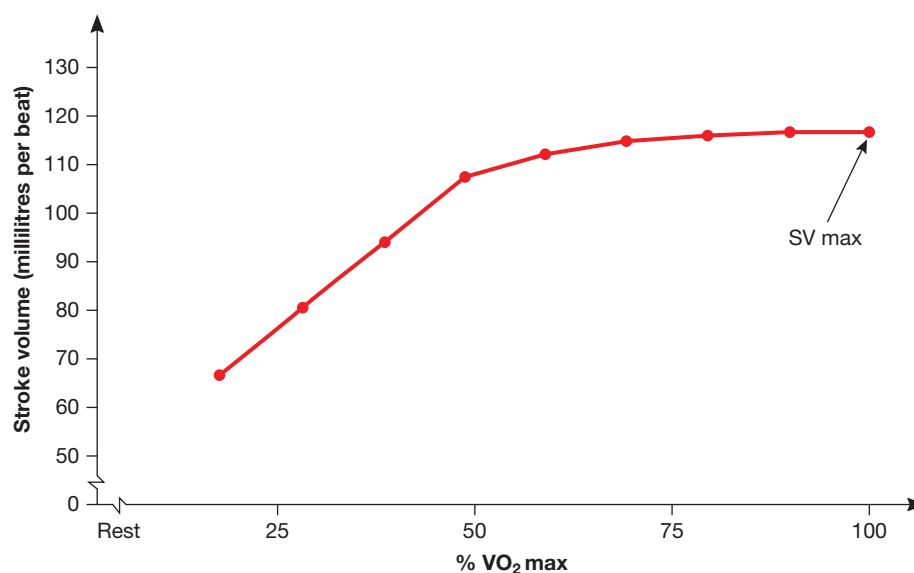
There is a decrease in peripheral resistance as a result of **vasodilation** of the vessels supplying blood to the exercising skeletal muscles. This decrease in resistance facilitates a greater emptying of the blood from the ventricle.

As to why stroke volume tends not to increase further at exercise intensities beyond 40–60 per cent of maximal capacity, the most likely explanation for this is the reduced amount of time available for the ventricle to fill. As heart rate increases with increasing exercise intensity, the filling time is reduced significantly, thereby limiting the amount of blood within the ventricle. Studies have shown that the filling time may be reduced from 500–700 ms (milliseconds) at rest to as little as 150 ms at higher heart rates.

Vasodilation is the process whereby blood vessels increase their internal diameter as a response to an increased demand for oxygen delivery to muscle tissue.

FIGURE 6.3 Stroke volume responses to exercise. The stroke volume increases as exercise intensity increases up to approximately 40–60 per cent of VO_2 max, then plateaus and remains essentially unchanged despite increases in exercise intensity.

Source: Reprinted with permission, Wilmore, Costill & Kenney 2008

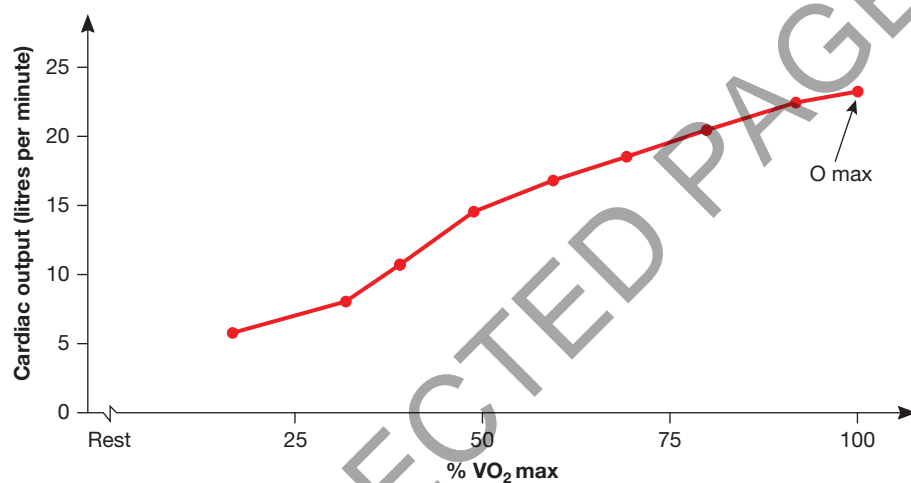


Increased cardiac output

Cardiac output (\dot{Q}) usually refers to the amount of blood ejected from the left ventricle of the heart per minute. It is the product of heart rate multiplied by stroke volume:

$$\begin{aligned}\dot{Q} &= \text{heart rate (HR)} \times \text{stroke volume (SV)} \\ \dot{Q} &= \text{HR} \times \text{SV}\end{aligned}$$

Given this, cardiac output predictably increases during exercise. Under resting conditions the average adult male's cardiac output is about 4–6 litres per minute; but this varies in proportion to the size of the individual. During exercise, cardiac output increases as a result of increases in both heart rate and stroke volume. This increase in cardiac output is designed to bring about an increase in oxygen delivery to the working muscles and heart. During maximal exercise intensities, average cardiac output can be 20–25 litres per minute, although among highly trained endurance athletes cardiac output may be as high as 35–40 litres per minute, giving these athletes a major physiological advantage (see figure 6.4).



Cardiac output (\dot{Q}) is the amount of blood ejected from the left ventricle of the heart per minute. It is the product of heart rate multiplied by stroke volume. \dot{Q} = heart rate (HR) \times stroke volume (SV).

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Cardiac output calculator

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FIGURE 6.4 Cardiac output responses to exercise: cardiac output increases in direct proportion to increasing exercise intensity.

Source: Reprinted with permission, Wilmore, Costill & Kenney 2008

The integrated cardiac response to exercise

To summarise the cardiac response to exercise, let us consider how heart rate, stroke volume and cardiac output vary as an individual (average adult male aged 20) transitions from rest to exercise of increasing intensities.

At rest, the individual's heart rate will be around 70 beats per minute, with their stroke volume approximately 70 millilitres per beat. This gives them a cardiac output (HR \times SV) of roughly 5 litres per minute (70 beats per minute \times 70 millilitres per beat = 4900 millilitres per minute).

As they transition from rest to walking, their heart rate will increase to about 90 beats per minute, and their stroke volume will also increase, resulting in an increase in cardiac output.

Moderate-paced jogging will see their heart rate increase to approximately 140 beats per minute, with stroke volume peaking at about 120 millilitres per beat, giving them a cardiac output of approximately 16–17 litres per minute.

Fast-paced running will see heart rate reach maximal values of near 200 beats per minute. During high-intensity exercise, it will be this increase in heart rate that contributes primarily to the further increases in cardiac output, since stroke volume tends to plateau when exercise intensity reaches around 40–60 per cent of the individual's maximal exercise capacity.

6.1 Acute responses of the cardiovascular system: heart rate, stroke volume and cardiac output

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TABLE 6.2 Effect of heart rate, stroke volume and cardiac output at rest, moderate exercise and strenuous exercise

Intensity	Heart rate (beats per minute)	Stroke volume (millilitres per beat)	Cardiac output (litres/minute)
Rest	70	70	4.9
Submaximal	140	120	16.8
Maximal	200	120	24



TEST your understanding

- 1 Explain what is meant by 'acute responses to exercise'.
 - 2 Define what is meant by the terms *heart rate*, *stroke volume* and *cardiac output*.
 - 3 Outline the method for estimating the maximum attainable heart rate.
 - 4 Explain why females tend to have lower stroke volumes than males.
 - 5 (a) Explain the mechanisms that are responsible for the increase in stroke volume that accompanies exercise.
(b) Explain why stroke volume plateaus at exercise intensities approaching 40–60 per cent of maximum exertion levels. Discuss why this might not be the case with highly trained athletes.
 - 6 (a) Calculate the cardiac output of an individual who has a heart rate of 80 beats per minute and a stroke volume of 75 millilitres per beat.
(b) Calculate the heart rate of an individual who has a cardiac output of 12 litres per minute and a stroke volume of 120 millilitres per beat.
- 7 Heart rate and stroke volume responses to exercise**
- Refer to figures 6.1 and 6.3 and answer the following questions:
- (a) Figure 6.1 shows a linear relationship between heart rate and exercise intensity, as indicated by the straight line. Explain what is meant by a linear relationship between heart rate and exercise intensity.
 - (b) At what intensity of exercise does stroke volume reach maximum levels? Explain your answer.
 - (c) Explain why trained athletes have higher stroke volumes than untrained individuals.

APPLY your understanding

8 Learning activity: laboratory test on heart rate responses to exercise

In pairs, measure and record your and your partner's resting heart rate. Your teacher will show you how to do this manually or with a heart rate monitor. Then perform the following physical activities with your partner, taking and recording your and your partner's heart rate immediately after you both complete each activity. Allow your heart rates to return to their resting values before undertaking the next activity.

- Walking for 2 minutes
 - Jogging for 2 minutes
 - Performing stepups on a bench for 2 minutes
 - Performing bent-knee situps for 2 minutes
- (a) Graph the results you obtained for both yourself and your partner.
 - (b) Identify the exercise that resulted in the highest heart rate. How do you account for this?
 - (c) Discuss the relationship between your heart rate and the intensity of the exercise.

EXAM practice

- 9 Describe how heart rate, stroke volume and cardiac output respond during exercise of increasing intensity. Ensure that you explain how these three variables are interrelated.

6.2 Acute responses of the cardiovascular system: blood pressure, redistribution of blood flow, arteriovenous oxygen difference



KEY CONCEPT In addition to the acute cardiac responses to exercise, other acute cardiovascular responses occur in relation to changes in blood pressure, distribution of blood flow and the arteriovenous oxygen difference.

Increased blood pressure

Blood pressure is the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: **systolic blood pressure** and **diastolic blood pressure**. Systolic blood pressure is the pressure recorded as blood is ejected during the contraction phase of the heart beat. Diastolic blood pressure is the value recorded during relaxation of the heart.

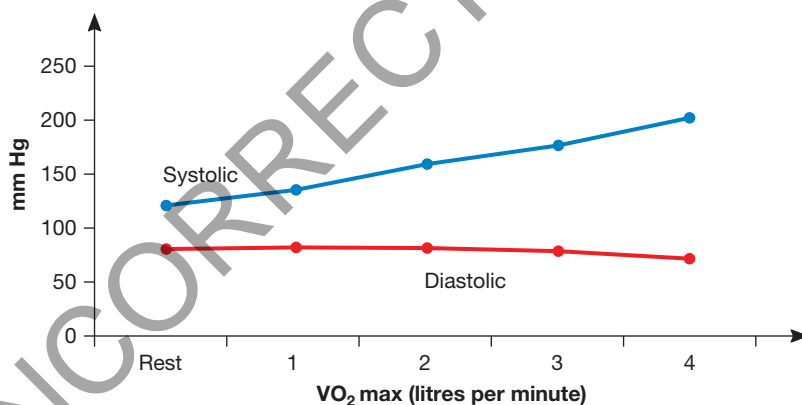
Blood pressure is usually expressed as:

$$\text{Blood Pressure} = \frac{\text{systolic}}{\text{diastolic}} \text{ mmHg}$$

$$\text{Normal Blood Pressure} = \frac{120}{80} \text{ mmHg}$$

During dynamic whole-body exercise such as jogging or cycling, blood is pumped more forcefully and quickly out of the heart, increasing pressure on the artery walls. This results in an increase in systolic blood pressure — it may reach levels as high as $\frac{180}{200}$ mm Hg during the heaviest workloads (see figure 6.5) — although the decrease in peripheral resistance caused by vasodilation of the blood vessels of the exercising muscles (see section opposite) offsets or buffers this rise in systolic pressure. Diastolic blood pressure changes little during exercise, with increases of more than 10 mm Hg considered abnormal. The minimal change in diastolic blood pressure is accounted for by the decrease in peripheral resistance.

less space



Blood pressure (BP) is the pressure exerted by the blood against the arterial walls as it is forced through the circulatory system by the action of the heart. It has two components: systolic blood pressure and diastolic blood pressure.

Systolic blood pressure is the blood pressure recorded as blood is ejected during the contraction phase of the heart cycle. It is the higher of the two blood-pressure values.

Diastolic blood pressure is the blood pressure recorded during the relaxation phase of the heart cycle. It is the lower of the two blood-pressure values.

FIGURE 6.5 Blood pressure responses to progressive endurance exercise

Source: Reprinted with permission, Hoffman J 2002.

During resistance-type exercise (e.g. lifting weights), large increases in both systolic and diastolic blood pressure are evident. With high-intensity resistance training, blood pressure can reach values as high as 480 over 350 mm Hg. This increase is the result of a compression of the vasculature within the contracting muscles and the use of a **Valsalva manoeuvre** during the performance of the exercise. The Valsalva manoeuvre occurs when an individual attempts to exhale while the mouth, nose and glottis (part of the larynx) are closed. This results in a large increase in the intrathoracic (chest cavity) pressure, which in turn results in an increase in both systolic and diastolic blood pressure as the body attempts to overcome the high internal pressure created during the Valsalva manoeuvre. The Valsalva manoeuvre is considered dangerous and should be avoided.

The **Valsalva manoeuvre** occurs when an individual attempts to exhale while the mouth, nose and glottis (part of the larynx) are closed.

6.2 Acute responses of the cardiovascular system: blood pressure, redistribution of blood flow, arteriovenous oxygen difference

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Systemic blood flow

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Systemic blood flow is the blood flow around the body. Blood leaves the left ventricle of the heart via the aorta, and then travels via the arteries and capillaries to the body, returning to the right atrium of the heart via the superior and inferior vena cava.

Vasodilation is the process where blood vessels increase their internal diameter as a response to an increased demand for oxygen delivery to muscle tissue.

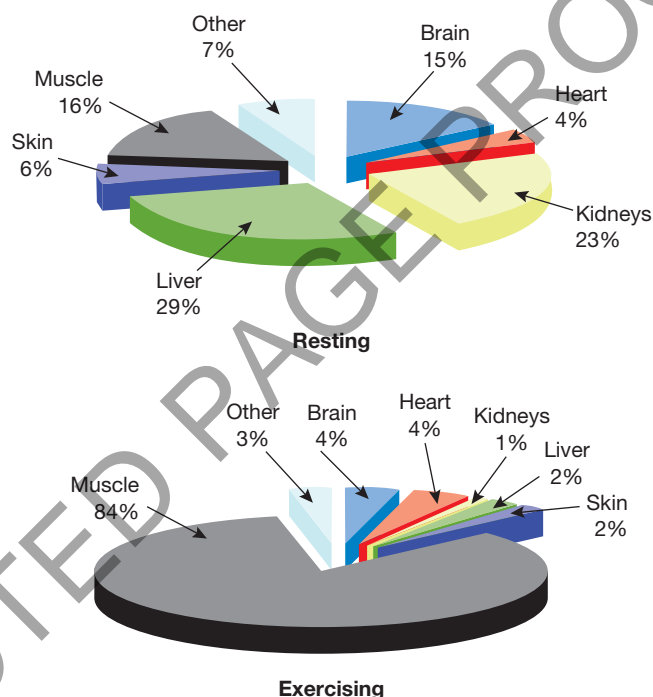
Vasoconstriction is the process where blood vessels narrow or constrict as a response to a decreased demand for oxygen delivery to muscle tissue.

FIGURE 6.6 Distribution of cardiac output while resting and exercising

Source: Reprinted with permission, Hoffman J 2002.

Redistribution of blood flow to working muscles

Under resting conditions only about 15–20 per cent of total **systemic blood flow** is directed to the skeletal muscles. The majority of the remaining 80–85 per cent is distributed to the organs (e.g. heart, liver, kidneys, intestines, brain) of the body. However, under exercise conditions the majority of the blood (80–90 per cent) may be redirected to the working muscles (see figure 6.6). This is achieved by the capillaries and arterioles supplying the working muscles expanding in diameter (a process known as **vasodilation**). At the same time, blood flow to the organs of the body is reduced by the **vasoconstriction** (narrowing) of the capillaries and arterioles that supply blood to these organs.



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Interactivity

Redistribution of blood flow during exercise

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Arteriovenous oxygen difference (a-VO₂ 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.

Increased arteriovenous oxygen difference

The **arteriovenous oxygen difference (a-VO₂ 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. This is measured in millilitres per 100 millilitres of blood. At rest, the arteries contain an oxygen concentration of approximately 20 millilitres per 100 millilitres of blood (200 millilitres of oxygen per litre of blood), while at rest the veins typically contain about 15 millilitres per 100 millilitres. Thus the arteriovenous oxygen difference at rest is about 5 millilitres per 100 millilitres of blood.

$$a\text{-VO}_2 \text{ diff.} = \frac{20 \text{ mL}}{100 \text{ mL}} - \frac{15 \text{ mL}}{100 \text{ mL}}$$

$$a\text{-VO}_2 \text{ diff.} = \frac{5 \text{ mL}}{100 \text{ mL}}$$

The amount of oxygen extracted from the arterial blood at rest is therefore about 25 per cent. However, during exercise working muscles extract much more of the available oxygen from the blood that passes through them (as much as 75 per cent of the available oxygen is extracted). As a result, the arteriovenous oxygen difference increases and can be as high as 15–18 millilitres per 100 millilitres of blood — almost a threefold increase over the value at rest (see figures 6.7 and 6.8).

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a-VO₂ diff.

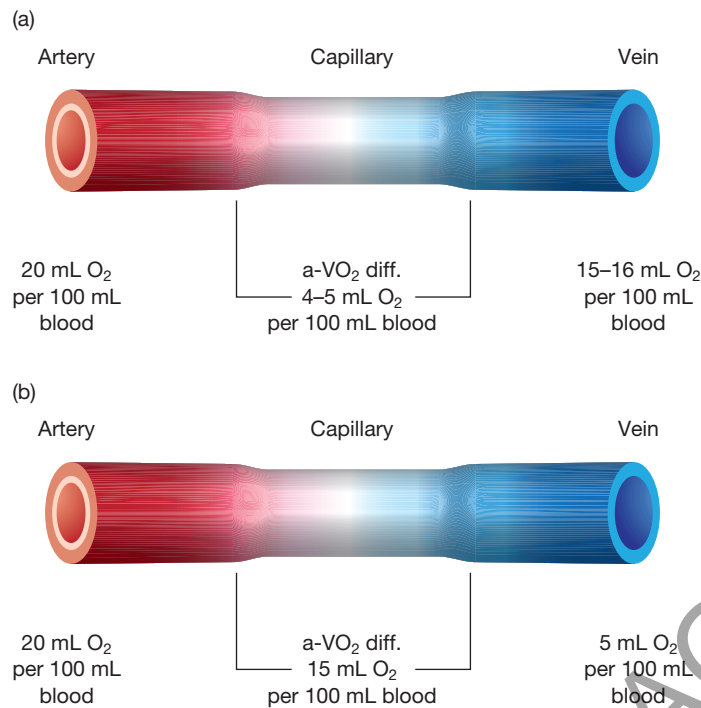


FIGURE 6.7 The arteriovenous oxygen difference (a) at rest and (b) during intense aerobic exercise

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Interactivity

Arteriovenous oxygen difference at rest and during intense exercise

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TEST your understanding

- 1 State the component of blood pressure that is most affected by exercise. Explain why this is the case.
- 2 Explain the difference between vasodilation and vasoconstriction. Explain how these processes result in increased blood flow and oxygen delivery to working muscles.
- 3 Explain what is meant by the arteriovenous oxygen difference. Explain why this increases during exercise.

APPLY your understanding

4 Learning activity: laboratory test on measuring blood pressure

Working in small groups of three or four, measure and record the blood pressure of one member of your group while they undertake the activities listed below. Record the blood pressure each minute (i.e. at 1 minute, 2 minutes, 3 minutes).

- Sitting at rest
- Standing at rest
- Lying at rest
- Cycling for 10 minutes on an exercise bike at a moderate intensity

In order to complete this laboratory test you will need to be proficient in the use of either a sphygmomanometer or a digital blood pressure reader. Your teacher will show you how to use this equipment to measure blood pressure.

- (a) Graph the blood pressure data you obtained. Make sure both systolic and diastolic values are shown on the one graph.
- (b) What effect did different body positions have on blood pressure when the participant was at rest? Explain how you account for any differences observed.
- (c) What happened to the participant's blood pressure during exercise? At what point in the exercise bout did blood pressure reach its maximum value? Did blood pressure plateau at any point?
- (d) Did the changes in the participant's blood pressure during exercise match what you expected to happen based on your understanding of blood pressure responses to exercise? Explain.
- (e) Explain what might happen to the participant's blood pressure if they had been asked to perform a maximum bench press test? How would this blood pressure response differ to that experienced during the 10 minutes of moderate-intensity cycling? Explain why this difference occurs.

EXAM practice

- 5 Anna Meares won the 2015 Women's Keirin in France at the Track Cycling World Championship. The Keirin consists of eight laps around a 250-metre velodrome: a total of 2000 metres. State an acute cardiovascular response and explain how this response assisted with Anna's performance.

6.3 Acute responses of the respiratory system



KEY CONCEPT When we engage in exercise, certain changes occur immediately in the respiratory system. These acute responses are designed to meet the increased energy demands imposed on the body by the activity being undertaken.



Acute responses of the respiratory system to exercise are designed to facilitate an increase in the availability of oxygen and the removal of carbon dioxide. These responses include:

- increased respiratory frequency (breathing rate)
- increased tidal volume
- increased ventilation
- increased pulmonary diffusion
- increased oxygen uptake.

Respiratory frequency is the number of breaths taken per minute. At rest, the average respiratory frequency is around 10–12 breaths per minute. When exercise begins, breathing rates rise sharply and can increase to as high as 35–50 breaths per minute.

Increased respiratory frequency (breathing rate)

Respiratory frequency or breathing rate refers to the number of breaths taken per minute. At rest, the average respiratory frequency is around 12 breaths per minute. When exercise begins, breathing rates rise sharply and can increase to as high as 35–50 breaths per minute. This increase in respiratory frequency is triggered by the increase in carbon dioxide concentrations in the blood, which stimulates the respiratory control centre in the brain.

Tidal volume is the amount of air breathed in and out in one breath.

Increased tidal volume

The depth of breathing (**tidal volume**) increases from around 0.5 litres per breath at rest to as high as 3–5 litres per breath at maximal workloads.

Ventilation is the amount of air inspired or expired per minute by the lungs. It is a product of respiratory frequency multiplied by tidal volume. Ventilation (V) = respiratory frequency × tidal volume.

Increased ventilation

Ventilation is the amount of air inspired or expired per minute by the lungs. It is a product of respiratory frequency multiplied by tidal volume.

$$\text{Ventilation (V)} = \text{respiratory frequency} \times \text{tidal volume}$$

At rest, ventilation is around 5–6 litres per minute. During maximal exercise, it may increase beyond 180 and 130 litres per minute (for males and females respectively). This is 25 to 35 times as great as resting values. It should be noted that both tidal volume and ventilation for males are generally greater because of larger lung volumes in males.

TABLE 6.3 Comparison of respiratory frequency, tidal volume and ventilation at rest and during exercise

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	Respiratory ratio (breaths/minute)	Total volume (L/breath)	Ventilation (L/min)
Rest	12	0.5	6
Submaximal exercise	30	2.5	75
Maximal exercise	45	4.0	180

Increased pulmonary diffusion

Pulmonary diffusion is where the gaseous exchange takes place within the lungs. Pulmonary diffusion has two major functions:

- ▶ to replenish oxygen supply through diffusion from alveolar to pulmonary capillaries
- ▶ to remove carbon dioxide from returning venous blood.

At rest, the oxygen diffusion capacity is about 21 ml of oxygen per minute. During maximal exercise, the oxygen diffusion capacity may increase by up to three times the resting rate.

Mechanisms responsible for increased ventilation

Because of its rapid onset, the initial ventilation adjustment to the increased oxygen demands of exercise is without doubt neural in nature, controlled by respiratory control centres in the brain, although neural input can also be provided by receptors within the exercising muscles. As exercise progresses, further adjustments in ventilation are controlled primarily by changes in the chemical status of arterial blood. Increased muscle metabolism due to exercise results in the production of greater levels of carbon dioxide and hydrogen ions. The increased levels of carbon dioxide and hydrogen ions within the blood are sensed by chemoreceptors located in the brain and lungs, which in turn stimulate the respiratory control centres resulting in an increase in both the rate and depth of breathing (in other words, an increase in ventilation).

Increased oxygen uptake

Oxygen uptake (VO_2) refers to the amount of oxygen transported to, taken up by and used by the body for energy production. At rest, the body consumes oxygen at a rate of approximately 0.25 litres per minute. When exercise begins, oxygen uptake increases as the working muscles use more of the oxygen made available by the combined efforts of the circulatory and respiratory systems. In fact, there is a linear relationship between oxygen uptake and exercise intensity (see figure 6.9), similar to that between heart rate and exercise intensity. That is, as exercise intensity increases, oxygen uptake increases in direct proportion because the body requires more oxygen to perform at higher intensities. This linear increase continues until a maximum level of oxygen uptake is attained — the **maximum oxygen uptake (VO_2 max)**. No further increase in oxygen uptake can be achieved beyond this maximal value, which is usually around 2–3.5 (absolute value) litres per minute.

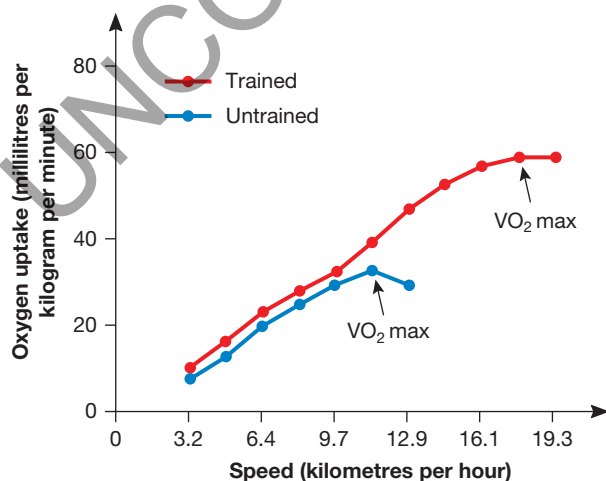


FIGURE 6.9 The relationship between exercise intensity and oxygen uptake

Source: Reprinted with permission, Wilmore, Costill & Kenney 2008.

Pulmonary diffusion is the process whereby oxygen is taken in via the lungs to the blood, and carbon dioxide is diffused from the blood to the lungs.

Oxygen uptake (VO_2) is the amount of oxygen transported to, taken up by and used by the body for energy production.

Maximum oxygen uptake (VO_2 max) is the maximum amount of oxygen per minute that can be transported to, taken up by and used by the body for energy production.

6.3 Acute responses of the respiratory system



TEST your understanding

- 1 Define the terms *respiratory frequency*, *tidal volume*, *ventilation*, *pulmonary diffusion*, *oxygen uptake*, *maximum oxygen uptake*.
- 2 An individual sets out on a 3-kilometre run. Indicate the likely respiratory system responses to this exercise bout.
- 3 Using your prior knowledge of the respiratory system, explain the mechanics of inspiration (inhalation) and expiration (exhalation), and how gases diffuse into and out of the lungs and blood vessels.
- 4 Calculate the ventilation of an individual who has a respiratory frequency of 15 breaths per minute and a tidal volume of 0.5 litres per breath.

APPLY your understanding

5 Learning activity: laboratory test on acute respiratory responses to exercise

Measure your resting respiratory frequency by counting the number of breaths you take in 1 minute. Then perform the following activities, measuring your respiratory frequency for 10 seconds immediately after you complete each activity. Allow your breathing rate to return to your resting value before undertaking the next activity.

- Standing still for 2 minutes
- Lying down for 2 minutes

- Walking for 2 minutes
 - Jogging for 2 minutes
 - Performing stepups on a bench for 2 minutes
 - Resting for 1 minute after the bout of stepups
 - Resting for 2 minutes after the bout of stepups
 - Performing bent-knee situps for 2 minutes
- (a) Record and graph your results. To determine your respiratory frequency immediately after each activity, multiply the 10-second breathing-rate measurement by 6 to calculate your heart rate per minute.
 - (b) Which activity resulted in the highest respiratory frequency? How do you account for this?
 - (c) Did standing still or lying down result in the highest respiratory frequency? Explain.
 - (d) Explain why respiratory frequency increases so much during exercise.
 - (e) Explain why your respiratory frequency remains elevated above normal resting values for a period after the cessation of strenuous exercise.

EXAM practice

- 6 List two acute respiratory responses to exercise which enable higher levels of oxygen to be diffused at the skeletal muscles.

6.4 Maximum oxygen uptake



KEY CONCEPT Maximum oxygen uptake refers to the maximum capacity for oxygen consumption by the body during maximum exertion.

ts

Maximum oxygen uptake or VO_2 max represents the maximum amount of oxygen able to be taken up by, transported to and used by the body for energy production. This value is commonly used to determine an athlete's capacity to perform in aerobic (endurance) activities.

Around 3.5 litres of oxygen per minute is the average maximum oxygen uptake for males. This figure is lower for females, who have an average oxygen uptake of around 2.3 litres per minute.

Factors affecting maximum oxygen uptake

Maximum oxygen uptake is affected by a number of factors including body size, gender, genetics, age and training status (aerobic or cardio-respiratory fitness levels).

Body size

Oxygen uptake is related to body size — a larger, heavier person requires more oxygen than a smaller person. It is for this reason that VO_2 max is usually expressed relative to body size in mL/kg/min — so that individuals can be compared, particularly in relation to their aerobic fitness levels, irrespective of differences in body size.



FIGURE 6.10 Oxygen uptake is related to body size.

Gender

Females tend to have lower oxygen uptake values compared with males of similar age and athleticism. Maximum oxygen uptake values for untrained female individuals can be as great as 20–25 per cent lower than for untrained male individuals. However, when comparing trained athletes, the gap tends to close to about 10 per cent.

Several factors contribute to females having a lower maximum oxygen uptake than males, including:

- ▶ Females typically have a higher percentage of body fat and lower percentage of muscle mass. Body fat does not consume oxygen, unlike muscle tissue.
- ▶ Females have lower blood volumes and lower levels of red blood cells and haemoglobin compared with males. This reduces the oxygen-carrying capacity of females as compared with males, as oxygen binds to haemoglobin when being transported around the body.
- ▶ Females typically have a smaller lung size and volume and a smaller heart size and volume (due to their on-average smaller body size) than males, thereby reducing their oxygen intake and transport capacity.



FIGURE 6.11 Females generally have a lower maximum oxygen uptake than males.

ts

6.4 Maximum oxygen uptake

Genetics

There is significant evidence to suggest that aerobic capacity is largely genetically determined, with some studies suggesting that heredity may account for up to 25–50 per cent of the variance seen between individuals. Training, however, can result in substantial improvement in maximum oxygen uptake values.

Age

Maximum oxygen uptake tends to decline with increasing age. It peaks during late adolescence and early adulthood and then declines from that point. The average rate of decline is generally accepted to be about 1 per cent per year or 10 per cent per decade after the age of 25. However, training and/or maintaining a physically active lifestyle can both increase maximum values as well as decrease the rate of decline that occurs with increasing age. Usually, the age-related decline in maximum oxygen uptake can be accounted for by a reduction in maximum heart rate, maximal stroke volume and maximal a-VO₂ difference.



FIGURE 6.12 Maximum oxygen uptake declines with age.

Training status (aerobic or cardio-respiratory fitness level)

Aerobic training can substantially increase maximum oxygen uptake values for both males and females. Average maximum oxygen uptake relative values for untrained male and female adults aged 20–29 are 43–52 mL/kg/min and 33–42 mL/kg/min respectively. Trained endurance athletes on the other hand may have values as high as 60–85 mL/kg/min for male athletes and 50–70 mL/kg/min for female athletes. **Table 6.4** presents a range of maximum oxygen uptake values for various population groups.

The extent to which maximum oxygen uptake can improve also appears to be dependent on the initial fitness level (starting point) of the individual. The greater the level of an individual's fitness to begin with, the less potential there is for further increases. There also seems to be a genetic upper limit beyond which further increases in either intensity or volume of training have no effect on increasing maximum oxygen uptake, although other benefits may be gained from such training; for example, an improvement in the athlete's capacity to perform at a higher percentage of their maximum oxygen uptake for longer periods of time.



FIGURE 6.13 Oxygen uptake levels can be increased in an individual through aerobic training.

The highest ever recorded and documented maximum oxygen uptake values are 94 mL/kg/min for a male and 77 mL/kg/min for a female. Both were elite-level cross-country skiers.

TABLE 6.4 Maximum oxygen uptake values (mL/kg/min) for various population groups

Group	Age	Males	Females
Non-athletes	10–19	47–56	38–46
	20–29	43–52	33–42
	30–39	39–48	30–38
	40–49	36–44	26–35
	50–59	34–41	24–33
	60–69	31–38	22–30
	70–79	28–35	20–27
Baseball/softball	18–32	48–56	52–57
Basketball	18–30	40–60	43–60
Bicycling	18–26	62–74	47–57
Canoeing	22–28	55–67	48–52
Gymnastics	18–22	52–58	36–50
Racquetball	20–35	55–62	50–60
Rowing	20–35	60–72	58–65
Skiing, alpine	18–30	57–68	50–55
Skiing, Nordic	20–28	65–94	60–75
Soccer	22–28	54–64	50–60
Speed skating	18–24	56–73	44–55
Swimming	10–25	50–70	40–60
Track and field, discus	22–30	42–55	–
Track and field, running	18–39	60–85	50–75
	40–75	40–60	35–60
Track and field, shot put	22–30	40–46	–
Volleyball	18–22	–	40–56
Weight-lifting	20–30	38–52	–

Source: Reprinted with permission, Wilmore, Costill & Kenney 2008.

6.4 Maximum oxygen uptake



TEST your understanding

- 1 Define the term *maximum oxygen uptake*. Explain why it is best expressed relative to body weight.
- 2 List and briefly summarise the factors that can affect maximum oxygen uptake.
- 3 Discuss the relationship between oxygen uptake (consumption) and energy production.
- 4 Explain why Nordic (cross-country) skiers would have higher maximum oxygen uptake values than weight-lifters of a similar age (see table 6.4).

APPLY your understanding

5 Learning activity: estimating maximum oxygen uptake

As a class, undertake a test designed to provide an estimation of VO_2 max.

After completing the test, obtain the results for all members of the class and calculate the average estimated VO_2 max for males and females. Graph these results alongside your own personal results and then answer the following questions.

- (a) How did your personal result compare with the group average result? (If you are a male student compare your result with the male class average; if you are a female student compare your result with the female class average.)
- (b) How would you account for your performance relative to the class average? Think about your activity levels and the sports and activities you participate in.
- (c) Which group obtained the higher group average — males or females? How do you account for this?
- (d) Explain the influence of genetics and training status on maximum oxygen uptake.

6 Learning activity: laboratory testing of VO_2 max

As a class, visit an organisation that conducts laboratory testing of VO_2 max. A number of universities and other organisations offer such facilities to school groups (your teacher will have details).

After attending and witnessing a laboratory VO_2 max test, complete the following questions.

- (a) Outline the basic protocols involved in a laboratory test of VO_2 max.
- (b) Why are laboratory tests more accurate than field tests designed to measure VO_2 max?
- (c) What are the disadvantages of laboratory testing of VO_2 max as compared with field tests?

EXAM practice

7 Australia's Michael Shelley, 31 years of age, powered to victory in the men's marathon at the Glasgow 2014 Commonwealth Games in a time of 2 hours, 11 minutes and 15 seconds.

- (a) Estimate the VO_2 max result of an international level male marathon runner such as Michael Shelley.
- (b) Estimate the VO_2 max result of a 31-year-old female competing in the local marathon. Explain your reasons.

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VO_2 test

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6.5 Oxygen uptake at rest, oxygen deficit, steady state and excess post-exercise oxygen consumption



KEY CONCEPT Oxygen uptake at rest, oxygen deficit, steady state and excess post-exercise oxygen consumption are important factors in the efficient delivery of oxygen to working muscles during exercise performance.

Oxygen uptake at rest

When at rest, the body's need for ATP is relatively small, requiring minimal oxygen consumption. At rest the average person consumes about 0.3L of oxygen per minute and will usually utilise a mixture of carbohydrates and fats for energy. The body stores minimal amounts of oxygen. This means that the amount of oxygen entering your bloodstream is directly proportional to the amount used by your tissues for oxidative metabolism. As exercise intensity increases, the consumption of oxygen increases to allow greater levels of ATP to be produced at the muscle level.

Oxygen deficit

As we have discovered in the previous sections, when exercise begins, oxygen uptake increases as the body attempts to meet the increased oxygen demand of the working muscles that results from their need to produce more energy for ATP resynthesis. The respiratory and cardiovascular systems play the major role when increasing oxygen uptake and transport to the working muscles.

However, during the transition from rest to exercise, particularly high-intensity exercise, and at any time during exercise performance when exercise intensity increases, there is a period of time where there is a discrepancy between the amount of oxygen required for a given exercise intensity and the amount actually supplied and used. This discrepancy is referred to as the **oxygen deficit** (see figure 6.14). Because of this discrepancy (shortfall) between supply and demand, anaerobic sources must be involved in providing energy during these periods of time.

The oxygen deficit occurs because the respiratory and circulatory systems take some time to adjust to the new oxygen demand (even at low exercise intensities) and, consequently, the amount supplied lags behind the amount needed until these systems make the necessary adjustments required to increase oxygen supply. These adjustments involve such things as:

- ▶ increased respiratory frequency (breaths per minute)
- ▶ increased tidal volume (depth of breathing)
- ▶ increased heart rate (number of times the heart beats per minute)
- ▶ increased stroke volume (amount of blood ejected from the heart per beat).

Steady state

It may take anywhere between a few seconds and 1 minute or more, depending on the intensity of the exercise, for oxygen supply or uptake to have increased sufficiently to meet the oxygen demands of the exercise. If and when oxygen supply does equal the oxygen demand of the exercise, an aerobic **steady state** (see figure 6.14) has been attained. Steady state occurs when virtually all of the required ATP to maintain the current exercise intensity is being supplied aerobically, so that there is no need for further increases in oxygen uptake and there is little reliance on the anaerobic pathways to supply energy for ATP resynthesis. This steady state in oxygen uptake also coincides with a plateau in heart rate and ventilation.

However, if the exercise intensity increases again, the demand for ATP resynthesis and oxygen also increases. Once again, during the short delay before oxygen uptake increases sufficiently for supply to equal demand, the anaerobic pathways must

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Oxygen deficit

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Oxygen deficit is the state in which there is a discrepancy (shortfall) between oxygen supply and demand and the oxygen required to meet the energy requirements of the activity. Under these conditions the anaerobic pathways must supplement the energy demands of the activity.

Steady state is the state in which oxygen supply equals oxygen demand so that virtually all of the required ATP to maintain the current exercise intensity is being supplied aerobically.

6.5 Oxygen uptake at rest, oxygen deficit, steady state and excess post-exercise oxygen consumption

supplement the energy supply. As the oxygen uptake increases to the required level, a second aerobic steady state is achieved. The process of increasing oxygen uptake and reaching a new steady state can only occur when lactate removal is greater than production. A steady state can only be held up to and including the lactate inflection point. It should be noted that in trained endurance (aerobic) athletes, the oxygen deficit is reduced due to these athletes attaining steady state sooner than untrained individuals.

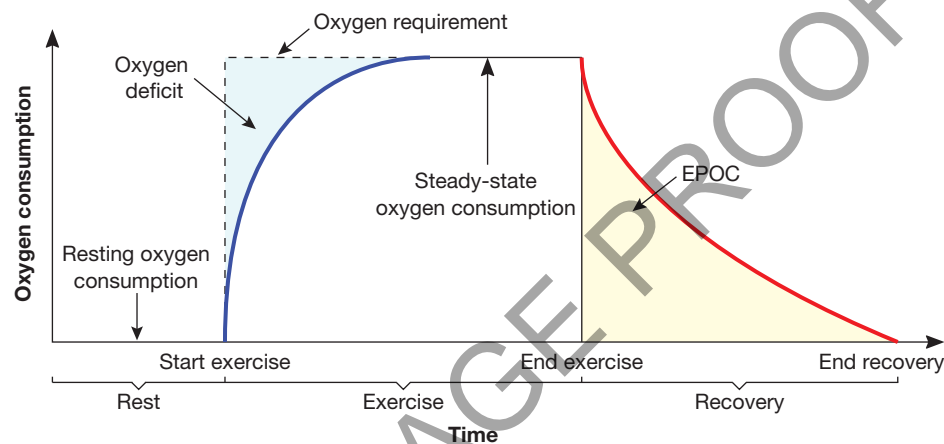


FIGURE 6.14 Oxygen deficit, steady state and EPOC

Source: Reprinted with permission, Wilmore, Costill & Kenney, 2008.

Excess post-exercise oxygen consumption (EPOC)

Oxygen can be viewed as the ‘currency’ the body uses in order to ‘purchase’ (resynthesise) ATP. In other words, oxygen must be used in order for ATP to be produced. During the time period where an oxygen-deficit condition prevails, the muscles are able to continue contracting by obtaining the required energy for ATP resynthesis via the two anaerobic pathways (i.e. without sufficient oxygen).

Even though these two anaerobic systems do not rely directly on oxygen, they should not be viewed as producing ‘free’ ATP. After the cessation of exercise, oxygen uptake or consumption does not immediately return to resting levels, despite the fact that the demand for ATP resynthesis decreases dramatically. Rather, oxygen consumption remains temporarily elevated. This elevated oxygen consumption, which exceeds that normally experienced at rest, is referred to as **excess post-exercise oxygen consumption (EPOC)** (see figure 6.14).

Factors responsible for elevated EPOC

There are a number of factors associated with EPOC and they can only be understood by focusing on how the chemical and physical changes occur in muscle cells during exercise. Chemical and physical changes occurring in contracting muscle cells that increase levels of oxygen consumption and ATP will continue for some time after exercise has ceased. These changes continue into the recovery phase as oxygen consumption remains elevated.

Some of the factors of EPOC are:

- ▶ Temperature is the most important factor. Elevated muscle temperature after exercise is closely associated with elevated levels of EPOC and account for the slow component of oxygen consumption.
- ▶ Increased mitochondrial respiration during exercise to produce aerobic energy. Mitochondria are the site of aerobic energy production. Calcium ions stimulate mitochondrial respiration, influencing EPOC levels

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Interactivity

Oxygen deficit, steady state and EPOC

Searchlight ID: int-6800

Excess post-exercise oxygen consumption (EPOC) is the amount of oxygen consumed during the recovery period after the cessation of an exercise bout that is over and above the amount usually required during rest.

- ▶ Increased use of mitochondria, which may be controlled by concentrations of ADP, ATP, inorganic phosphates and creatine phosphate
- ▶ Resynthesising creatine phosphates after exercise exhibiting a fast and slow recovery component
- ▶ The size of EPOC is determined by re-phosphorylation of creatine and ADP.
- ▶ Elevated concentration levels of catecholamine, which stimulate energy-requiring processes in cells
- ▶ Increased ATP production
- ▶ Changes in sodium (Na^+), potassium (K^+) and hormone levels interact to change EPOC levels.
- ▶ Lipolysis and release of fatty acids increases EPOC after exercise.
- ▶ If previous exercise was primarily aerobic, EPOC recovery would be completed within several minutes (fast component).
- ▶ If previous exercise was strenuous, where lactate and body temperature have increased considerably, EPOC recovery would be slow (slow component). EPOC recovery may take several hours, depending on intensity and duration, before returning to pre-exercise oxygen consumption levels.



TEST your understanding

- 1 Explain why an oxygen deficit accrues at the beginning of any exercise bout.
- 2 Discuss the factors that could determine the size of the oxygen deficit that accrues.
- 3 When is a steady state achieved during an exercise bout? What does this signify in terms of energy supply to the working muscles?
- 4 Explain the factors responsible for the elevated levels of EPOC.
- 5 Explain what is meant by the expression 'oxygen is the body's exercise currency'.
- 6 Explain the changes in oxygen demand and supply during submaximal exercise.

EXAM practice

- 7 A female VCE PE student completes a 3-km cross-country course in 12 minutes on a 20°C day.

She wears a heart rate monitor and holds a steady pace until the final minute where she increases her pace until she crosses the finish line.

She notices that her heart rate reaches a plateau after about three minutes from the start. She also notices that her heart rate returns to pre-race levels about four minutes after her race is completed.

Draw and label a graph that illustrates oxygen uptake for the female student for the 12 minutes of the race and 4 minutes of recovery. On your graph, label and include:

- (a) any periods of rest
- (b) any periods of oxygen deficit
- (c) any periods of steady state
- (d) any periods of EPOC.
- (e) Explain why the heart rate plateaued at the three-minute mark.

6.6 Acute responses of the muscular system



KEY CONCEPT When we engage in exercise, acute responses also occur in the muscles themselves as the body responds to the increased energy demands imposed by the activity undertaken.

Acute muscular system responses to exercise are those that occur in the working muscles themselves. These responses vary according to the type, intensity and duration of the exercise performed, and may differ according to the type of muscle fibre recruited (fast-twitch as opposed to slow-twitch fibres). However, basically these responses include:

- increased motor unit and muscle fibre recruitment
- increased blood flow to the muscles
- increased arteriovenous oxygen difference
- increased muscle temperature
- increased muscle enzyme activity
- increased oxygen supply and use
- decreased muscle substrate levels (ATP, creatine phosphate, glycogen and triglycerides).

Increased motor unit and muscle fibre recruitment

When an individual engages in any physical activity there is a need for muscular contractions to take place. When exercise begins, an increase in motor unit recruitment must take place so that more muscle fibres are activated to contract. The greater the force or effort required, the greater the number of motor units recruited and the greater the number of muscle fibres activated.

Increased blood flow in the muscles

The extra demand of the muscles for oxygen during exercise leads to vasodilation of the capillaries and redistribution of blood flow from the internal organs to the working skeletal muscles.

Increased arteriovenous oxygen difference

During exercise, working muscles extract much more of the available oxygen from the blood, via myoglobin and mitochondria. As much as 75 per cent of the available oxygen is extracted and, as a result, the arteriovenous oxygen difference increases.

Increased muscle temperature

Increased blood flow to the muscles, coupled with the heat generated as a by-product of the increased production of ATP during exercise, results in an increase in muscle temperature.

Increased muscle enzyme activity

Enzyme activity increases during exercise to produce the increased amounts of ATP required by the muscles. Enzymes are involved in all of the chemical processes that produce energy via the three energy pathways.

Increased oxygen extraction and utilisation

The muscle cells extract and use more oxygen from the blood during exercise because of the increased demand for ATP. This greater extraction and use of oxygen by the exercising muscle contributes to the increase in the arteriovenous oxygen difference that has been previously referred to.

Decreased muscle substrate levels

Muscular stores of ATP, creatine phosphate, glycogen and triglycerides begin to deplete during exercise because they are sources of fuel for the production of ATP. The depletion of these energy stores, particularly creatine phosphate and glycogen, contributes to the fatigue experienced during exercise and physical activity.



FIGURE 6.15 During high-intensity exercise, muscular stores of ATP and creatine phosphate deplete as they provide energy for the production of ATP.



TEST your understanding

- 1 Draw a simple diagram (using appropriate icons to represent each muscular system change) that summarises the major acute muscular system responses to exercise.

APPLY your understanding

- 2 Using your knowledge of different types of muscle fibre, explain how each of the muscle fibre types might respond to different types of exercise (anaerobic and aerobic).

EXAM practice

- 3 State three acute muscular responses that will occur during a 100-metre sprint.

KEY SKILLS ACUTE PHYSIOLOGICAL RESPONSES TO EXERCISE

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

STRATEGIES TO DECODE THE QUESTION

- **Identify the action word:**
Describe — provide a detailed account of
- **Key terminology** — changes in oxygen demand from rest to submaximal exercise and relationship between oxygen uptake and exercise intensity
- **Key concept** — oxygen demand and supply at various exercise intensities — understanding how oxygen demand and supply changes from rest (supply = demand) to submaximal intensity (oxygen supply > oxygen demand)
- **Marking scheme** — 4 marks — always check marking scheme for the depth of response required, linking to key information highlighted in the question

HOW THE MARKS ARE AWARDED

- **1 mark:** describing that energy demand equals energy supply at rest as the oxygen uptake meets all energy requirements
- **1 mark:** describing that this is a linear relationship between oxygen uptake and exercise intensity
- **1 mark:** describing that as exercise intensity increases, there is a period where oxygen demand is greater than supply (oxygen deficit)
- **1 mark:** describing oxygen demand and supply at submaximal intensity and reaching steady state

KEY SKILLS

- Explain the changes in oxygen demand and supply at rest, during submaximal and maximal activity
- Participate in physical activities to collect and analyse data relating to the range of acute effects that physical activity has on cardiovascular, respiratory and muscular systems of the body

UNDERSTANDING THE KEY SKILLS

To address these key skills, it is important to remember the following:

- At rest, oxygen uptake is low as the body's need for ATP is relatively small
- As the body shifts from rest to exercise, the demand for ATP increases
- At the onset of exercise, the respiratory and cardiovascular systems are unable to immediately meet the oxygen demand of the task
- Because of this lag time, oxygen demand by the working muscles is greater than the oxygen supplied so the body incurs oxygen deficit
- Oxygen deficit occurs as soon as exercise commences
- Oxygen deficit is calculated as the difference between the oxygen required for a given rate of work and the oxygen actually supplied
- During oxygen deficit, ATP will be resynthesised using the anaerobic pathways
- During submaximal exercise intensities, steady state occurs where oxygen supply equals oxygen demand
- When exercise intensity is increased, oxygen demand will be greater than supply as the working muscles produce additional ATP through the anaerobic pathways creating a larger oxygen deficit
- The range of acute responses (cardiovascular, respiratory and muscular) that occur due to various exercise intensities

PRACTICE QUESTION

- 1 **Describe** the changes in oxygen demand and supply from rest to submaximal exercise and the relationship between oxygen uptake and exercise intensity. (4 marks)

SAMPLE RESPONSE

At rest, energy demand equals energy supply as the body's oxygen uptake meets all energy requirements.

When exercise begins, oxygen uptake increases as the working muscles use more of the oxygen made available by the combined efforts of the circulatory and respiratory systems.

There is a linear relationship between oxygen uptake and exercise intensity.

However, from rest to exercise there is a period of time when there is a discrepancy between the amount of oxygen required for a given exercise intensity and the amount actually supplied and used. This is referred to as oxygen deficit where there is a shortfall between supply and demand.

For submaximal intensities, it may take only a few seconds for oxygen supply or uptake to meet the demands of the exercise and reach steady state.

CHAPTER REVIEW ACUTE PHYSIOLOGICAL RESPONSES TO EXERCISE

CHAPTER SUMMARY

Table 6.5 summarises the acute cardiovascular, respiratory and muscular system responses to exercise that have been discussed in this chapter.

TABLE 6.5 Summary of acute responses to exercise

Body system	Acute response	Nature of response
Cardiovascular system	<ul style="list-style-type: none"> Increased heart rate Increased stroke volume Increased cardiac output Increased blood pressure Redistributed blood flow to working muscles Increased arteriovenous oxygen difference 	<ul style="list-style-type: none"> Increases linearly with increasing exercise intensity up to approximate maximum that is calculated by subtracting the individual's age (years) from 220 Maximal value reached during submaximal exercise Increases from 5–6 L/min at rest to 20–25 L/min or more during maximal exercise Increased systolic pressure At rest 15–20 per cent of total blood flow directed to working muscles; during exercise 80–90 per cent of total blood flow directed to working muscles Increases can be almost threefold over the value at rest
Respiratory system	<ul style="list-style-type: none"> Increased respiratory frequency (breathing rate) Increased tidal volume Increased ventilation Increased oxygen uptake Increased pulmonary diffusion increase by up to three times the resting rate 	<ul style="list-style-type: none"> Increases from 12 breaths per minute to as many as 35–40 per minute Increases from around 0.5 litres per breath at rest to as high as 5 litres per breath at maximal workloads Increases from around 5–6 L/min at rest to beyond 108 and 130 L/min during exercise (for males and females respectively) Increases from 0.3–0.4 L/min at rest to maximal values of 2.0–3.5 L/min during exercise
Muscular system	<ul style="list-style-type: none"> Increased motor unit and muscle fibre recruitment Increased blood flow in the muscles Increased muscle temperature Increased muscle enzyme activity Increased oxygen extraction and utilisation Decreased muscle substrate levels 	<ul style="list-style-type: none"> More motor units recruited and muscle fibres activated Increases from 15–20 per cent of total blood flow at rest up to 80–90 per cent during exercise As a result of increased blood flow and ATP production In order to produce the increased amounts of ATP required by the muscles during exercise Muscle cells extract and use more oxygen during exercise ATP, creatine phosphate, glycogen and triglycerides

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Interactivity

Understanding acute response terms

Searchlight ID: int-6801

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Interactivity

Acute responses to exercise

Searchlight ID: int-6802

EXAM PREPARATION

MULTIPLE-CHOICE QUESTIONS

- 1 State the major body systems that respond immediately to the transition from rest to exercise.
 - (A) Cardiovascular, skeletal and muscular
 - (B) Respiratory, skeletal and muscular
 - (C) Cardiovascular, respiratory and muscular
 - (D) Cardiovascular, digestive and nervous
- 2 State which two factors, when multiplied, result in cardiac output.
 - (A) Heart rate and stroke volume
 - (B) Blood volume and heart rate
 - (C) Tidal volume and heart rate
 - (D) Stroke volume and blood volume
- 3 Cardiac output at rest and during maximal exercise would be approximately
 - (A) 1 to 2 L/min and 4 to 5 L/min respectively.
 - (B) 1 to 2 L/min and 40 to 45 L/min respectively.
 - (C) 11 to 12 L/min and 24 to 35 L/min respectively.
 - (D) 5 to 6 L/min and 20 to 25 L/min respectively.
- 4 Which two factors, when multiplied, result in ventilation?
 - (A) Tidal volume and maximal oxygen uptake
 - (B) Respiratory frequency and total lung capacity
 - (C) Respiratory frequency and tidal volume
 - (D) Residual volume and respiratory volume
- 5 The relationship between exercise intensity and oxygen uptake is
 - (A) exponential until maximal uptake is obtained.
 - (B) linear until maximal uptake is obtained.
 - (C) non-linear.
 - (D) non-linear until maximal uptake is obtained.
- 6 From rest to submaximal exercise, the arteriovenous difference
 - (A) increases.
 - (B) remains the same.
 - (C) decreases.
 - (D) is close to zero.
- 7 At the start of exercise, the body's oxygen transport systems do not immediately supply the required quantity of oxygen to the active muscles. This is known as
 - (A) steady state.
 - (B) oxygen debt.
 - (C) oxygen deficit.
 - (D) EPOC.
- 8 During exercise, capillaries and arterioles
 - (A) vasoconstrict to increase oxygen to the working muscles.
 - (B) vasodilate to decrease oxygen to the non-essential organs.
 - (C) remain the same to increase oxygen to the non-essential organs.
 - (D) vasodilate to increase oxygen to the working muscles.
- 9 An elite female alpine skier would have a VO_2 max of approximately
 - (A) 65 to 70 mL/kg/min.
 - (B) 50 to 55 mL/kg/min.
 - (C) 50 to 55 L/min.
 - (D) 50 to 55 mL/min.
- 10 An acute muscular response during high intensity exercise could be
 - (A) decreased stores of ATP and creatine phosphate.
 - (B) increased tidal volume.
 - (C) increased cardiac output.
 - (D) decreased muscle enzyme activity.

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Interactivity

Acute physiological responses to exercise quiz

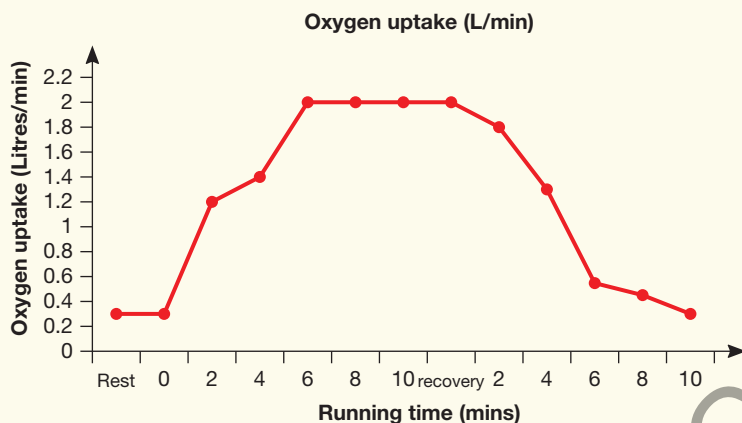
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TRIAL EXAM QUESTIONS

Question 1

(ACHPER Trial Exam 2009, question 8a, b, c, f, g)

The graph shows the oxygen uptake of a male athlete running on a treadmill for 12 minutes at 22 degrees C.



a. Explain why the athlete's oxygen uptake has increased at the 2 and 4 minute marks of exercise.

b. State what would happen to the athlete's heart rate and stroke volume at the 2 and 4 minute marks of the exercise bout.

Heart rate _____

Stroke volume _____

2 marks

c. Does the athlete achieve steady state during their run? Use data from the graph to justify your answer.

2 marks

d. On the graph, shade in the area of excess post oxygen consumption (EPOC).

1 mark

e. Outline **three** reasons why EPOC occurs.

Reason 1 _____

Reasons 2 _____

Reason 3 _____

3 marks

<keyed text>

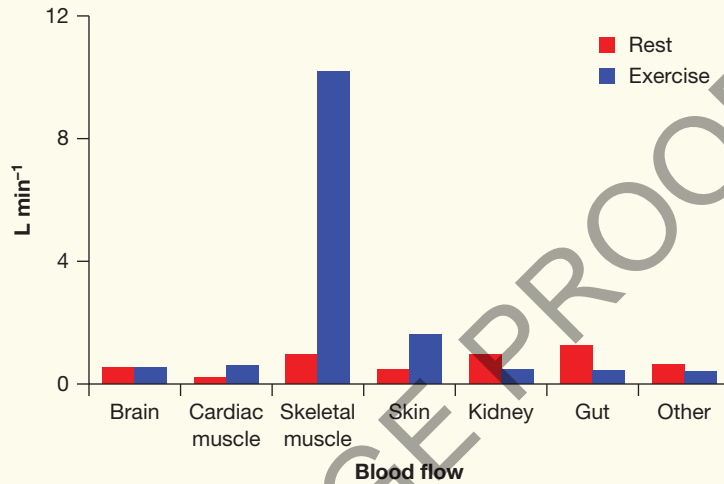
AU: How much mark contains the Question 1 (a) is not mention in msp, please check and suggest.

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Question 2

(ACHPER Trial Exam 2009, question 12a, b, c)

The graph below indicates blood flow to various organs of the body at rest and during exercise.



a. Approximately how much blood is redistributed to the skeletal muscles during exercise?

1 mark

b. Other than skeletal muscle indicate **two** areas where blood flow increases during exercise and outline the reason for this redistribution in blood flow for each area.

Area 1 _____

Reason _____

Area 2 _____

Reason _____

2 + 2 marks

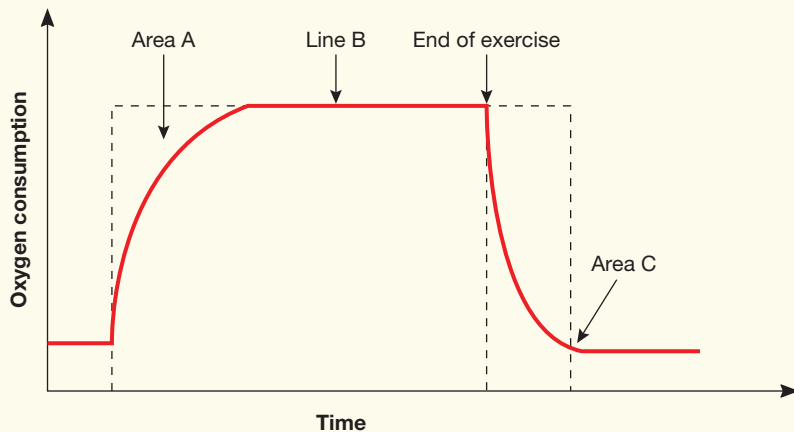
c. Explain the physiological response that allows the increase in blood flow to skeletal muscle during exercise.

2 marks

Total 7 marks

Question 3

(ACHPER Trial Exam 2010, Question 4)



<keyed text>

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a. What do the following areas of the graph represent?

Area A: _____

Line B: _____

Area C: _____

3 marks

b. Why does Area 'A' occur at the beginning of exercise?

1 mark

c. Describe the circumstances that allow Line 'B' to occur

2 marks

d. Name one strategy that an athlete can undertake in order to reduce the size of Area 'A'

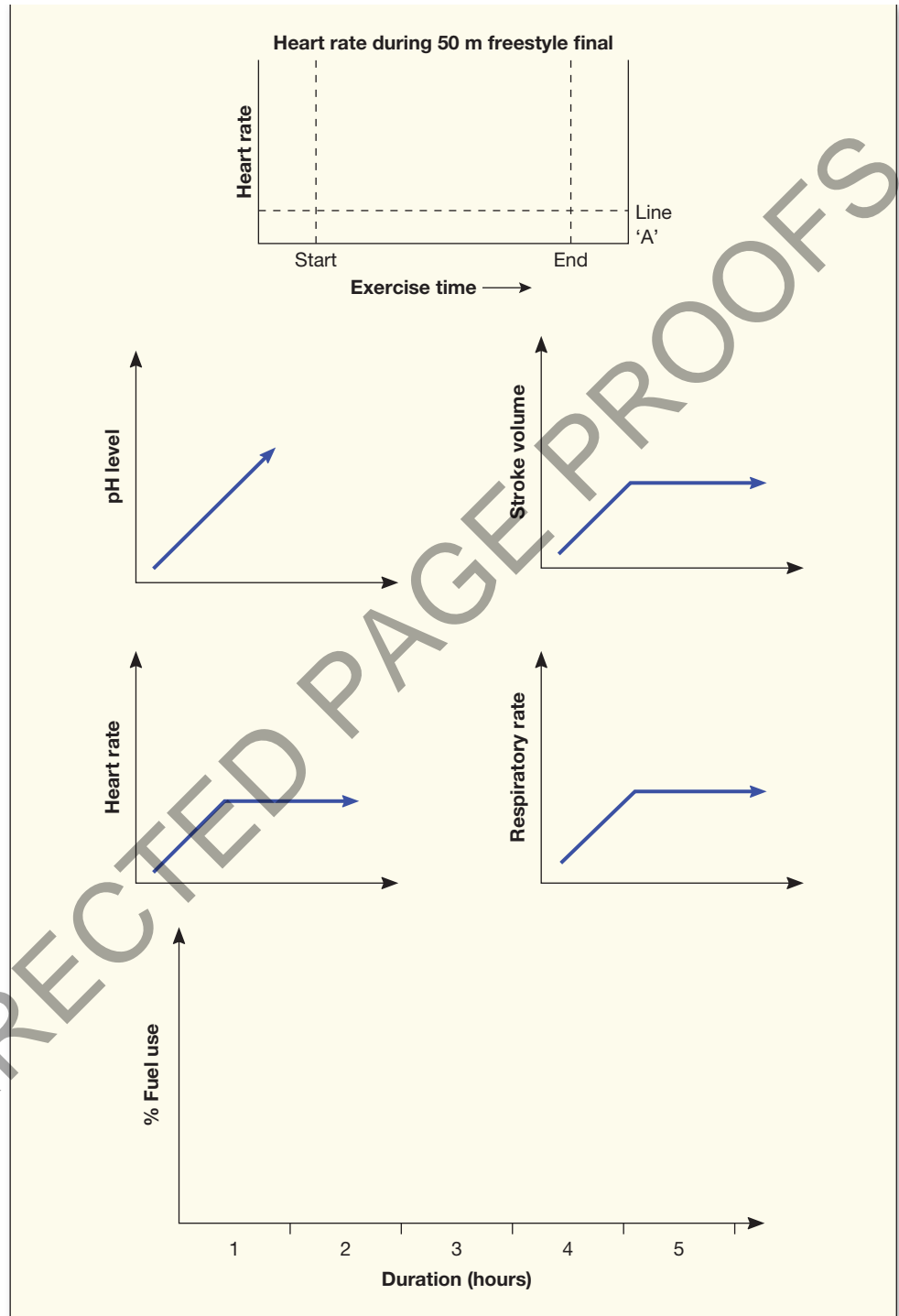
1 mark

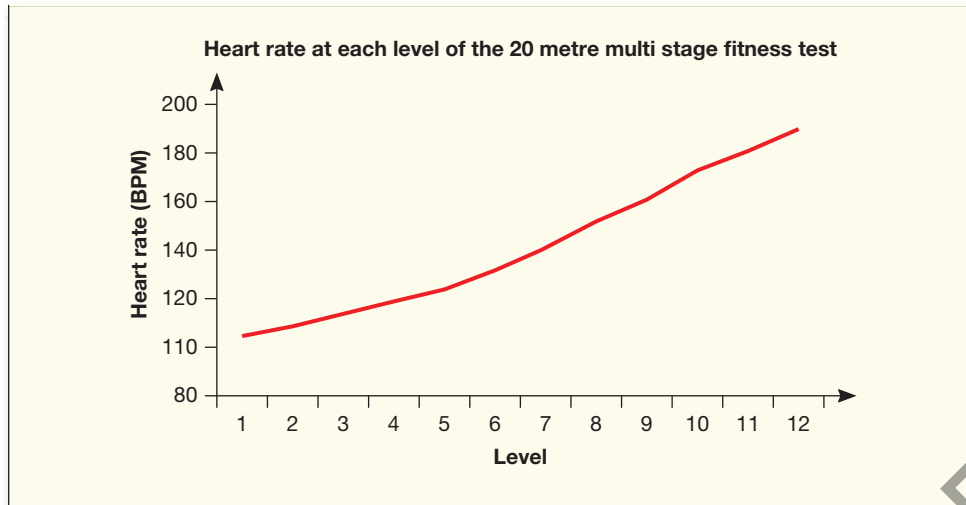
e. Explain why the strategy listed in **part d**, above can reduce the size of Area "A"

2 marks

Total 9 marks

CHAPTER REVIEW ACUTE PHYSIOLOGICAL RESPONSES TO EXERCISE





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