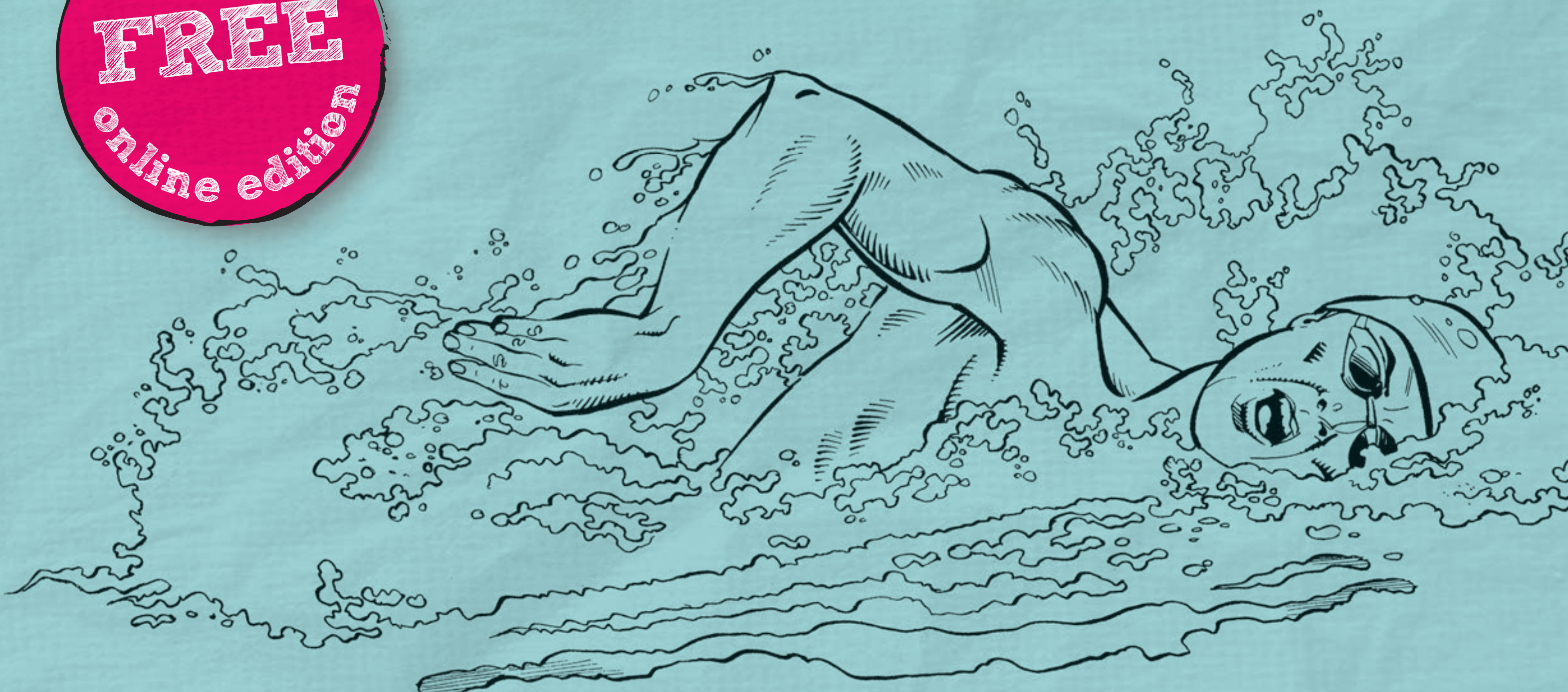
REVISE BTEC NATIONAL

Sport and Exercise Science

REVISION GUIDE

Includes FREE online edition



Pearson

REVISE BTEC NATIONAL
Sport and Exercise Science

REVISION GUIDE

Series Consultant: Harry Smith

Authors: Laura Fisher, Katie Jones, Stacey O'Donnell, Tracy Richardson, Louise Sutton and Danielle Toward

A note from the publisher

While the publishers have made every attempt to ensure that advice on the qualification and its assessment is accurate, the official specification and associated assessment guidance materials are the only authoritative source of information and should always be referred to for definitive guidance.

This qualification is reviewed on a regular basis and may be updated in the future. Any such updates that affect the content of this Revision Guide will be outlined at **www.pearsonfe.co.uk/BTECchanges**. The eBook version of this Revision Guide will also be updated to reflect the latest guidance as soon as possible.

Pearson

Introduction

Which units should you revise?

This Revision Guide has been designed to support you in preparing for the externally assessed units of your course. Remember that you won't necessarily be studying all the units included here – it will depend on the qualification you are taking.

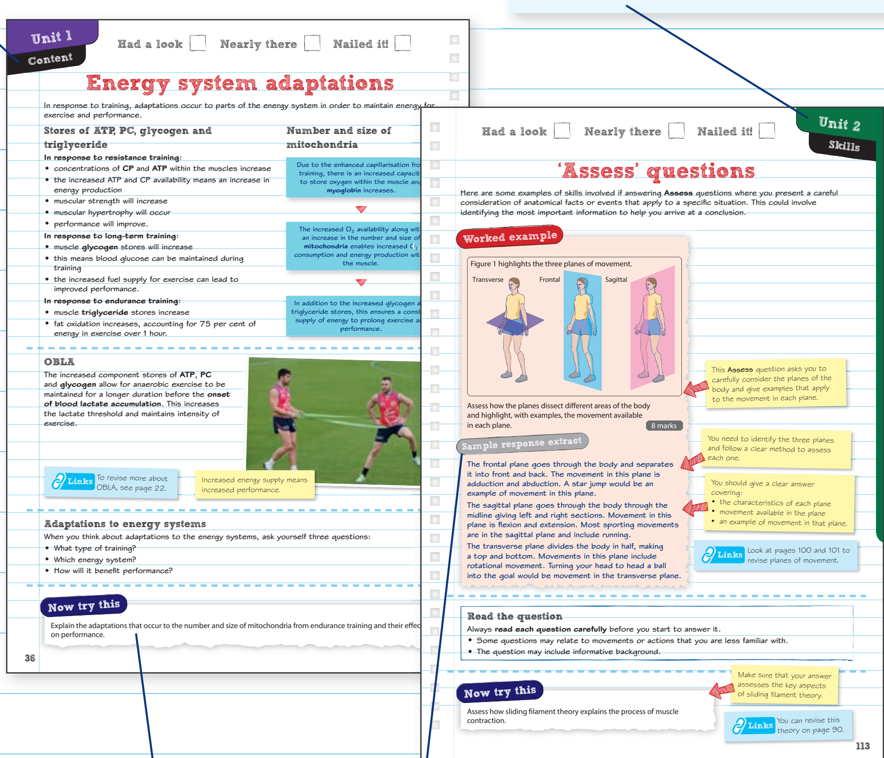
BTEC National qualification	Externally assessed units
For both: Extended Certificate Foundation Diploma	2 Functional Anatomy 3 Applied Sport and Exercise Psychology
Diploma	1 Sport and Exercise Physiology 2 Functional Anatomy 3 Applied Sport and Exercise Psychology
Extended Diploma	1 Sport and Exercise Physiology 2 Functional Anatomy 3 Applied Sport and Exercise Psychology 13 Nutrition for Sport and Exercise Performance

Your Revision Guide

Each unit in this Revision Guide contains two types of pages, shown below.

Content **pages** help you revise the essential content you need to know for each unit.

Skills **pages** help you prepare for your exam or assessed task. Skills pages have a coloured edge and are shaded in the table of contents.



Use the **Now try this** activities on every page to help you test your knowledge and practise the relevant skills.

Look out for the **sample response extracts** to exam questions or set tasks on the skills pages. Post-its will explain their strengths and weaknesses.

Contents

Workbook also available for externally assessed units
ISBN 9781292150437

Unit 1 Sport and Exercise Physiology

Unit 2 Functional Anatomy

Unit 3 Applied Sport and Exercise Psychology

Unit 13 Nutrition for Sport and Exercise Performance

A small bit of small print
Pearson publishes Sample Assessment Material and the Specification on its website. This should be the official content and this book should be used in conjunction with it. The questions in *Now try this* have been written to help you test your knowledge and skills. Remember: the real assessment may not look like this.

Osteoblast and osteoclast activity

There are two types of bone cells responsible for remodelling of bone. **Osteoblasts** are responsible for the building and growth of bone tissue in response to stress placed upon the bone. **Osteoclasts** are responsible for breaking down and removing old and weakened bone tissue, making way for stronger bones.

Osteoblast activity

Osteoblast activity is increased in response to mechanical stress of weight-bearing exercise where the body is working against gravity, including weightlifting and running. This stimulates the bone and increases osteoblast activity, resulting in improved bone strength and density.

Non-weight-bearing activities such as swimming and rowing, where gravity does not influence the body, **do not** increase osteoblast activity.

Osteoblasts

Osteoblasts are the immature cells that **make** bone.

- They produce a matrix that then becomes **mineralised**.
- When loading bone during exercise, **calcium** in the blood is absorbed and encourages **bone formation**.

Osteoclast activity

Osteoclasts are cells that have the role of **breaking down** and removing old weakened bone.

- This is **reabsorbed** and makes way for new stronger bone tissue.
- Osteoclast activity **increases** in response to elevated calcium concentration within the blood (at rest).

Bone density

Bone mass is maintained by a **balance** between the activity of **osteoblasts**, forming bone, and the **osteoclasts**, breaking it down.

- Bone density **increases** as a result of placing stress on the bone when completing **weight-bearing exercise**. This can help to reduce the likelihood of osteoporosis. Exercise stimulates the bones to take up more minerals.
- **Osteoclast activity** will increase as a result of this, which will lead to an overall strengthening of the bone.

Now try this

Julie has returned to playing netball after a three-year break from sport. She needs to improve her fitness so takes part in a three-month fitness training programme. She joins a gym and is given the following weekly training programme:

Monday – 20 minutes continuous running

Tuesday – weight training (upper body)

Thursday – 15 minutes continuous rowing and 15 minutes continuous cycling

Friday – weight training (lower body)

Saturday – 20 minutes continuous running

Explain how this fitness training programme will increase the strength of Julie's bones.

Had a look ☐ Nearly there ☐ Nailed it! ☐

Synovial fluid

Synovial fluid **lubricates** the joints. This **reduces friction** between the hyaline cartilage of articulating bones during movement. The synovial membrane is the inner membrane of tissue that lines the joint and secretes the synovial fluid into the joint.

Synovial joints

There are **five** main joints where synovial fluid is found:

1. Knee
2. Elbow
3. Shoulder
4. Hip
5. Ankle

The act of exercise:

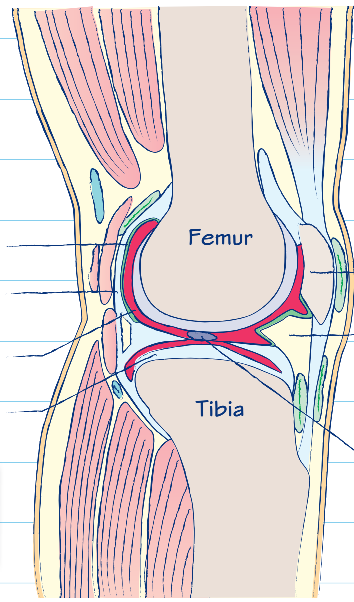
- **mobilises** the joints and is essential to maintain joint mobility and to avoid joint stiffness
- **increases** the production of **synovial fluid** within the joint, which is warmed and becomes less viscous (runnier), aiding joint mobility and range of movement
- **increases blood flow** to the tissues around the joint, which delivers nutrients and keeps the joint healthy.

Synovial fluid in the knee joint acts as a **shock absorber** during vigorous exercise.

Knee joint

The **structure** of a synovial joint can be seen in the knee joint. The **synovial fluid** within the joint capsule is viscous (thick) at rest, though when warmed, provides a friction-free environment allowing for ease of movement.

Knee joint



Structures common to synovial joints

Structure	Function
Hyaline cartilage	Hyaline articular cartilage covers the ends of articulating bones. It smooths and eases gliding movement between the bone ends.
Joint capsule	This is a fibrous tissue that encases the joint, forming a capsule.
Ligaments	Ligaments are white fibrous connective tissue, joining bone to bone. They restrict the amount of movement that can occur at the joint.
Synovial membrane	The synovial membrane acts as a lining to the joint capsule and secretes synovial fluid.
Synovial fluid	Synovial fluid fills the joint capsule; it nourishes and lubricates the articular cartilage.
Fat pad	Pads of fat act as cushions to protect the bones from wear and tear.

Now try this

Choose a sport or exercise and consider the role of synovial fluid in response to it. Using the same chosen sport, explain the importance of three roles of synovial fluid in your answer.

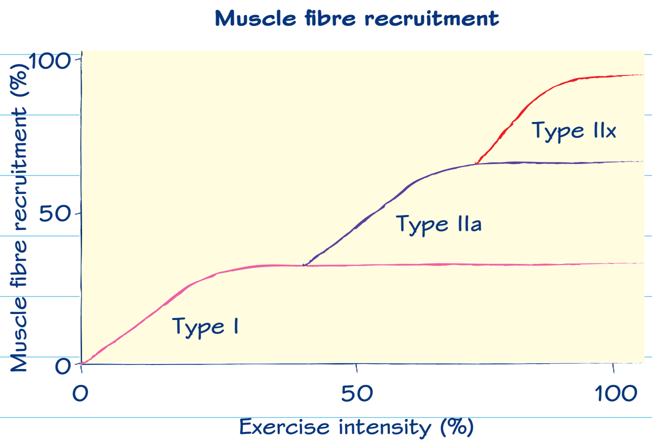
Muscle fibre recruitment

Recruitment of muscle fibres **alters**, depending on the **level of demand** on the muscle during exercise. Different sporting actions and exercises require varied amounts of muscle contraction and force production.

Muscle fibres and demand

The body recruits the minimum amount of muscle fibres to complete a task. Muscle fibres react to the demand made on them depending on the type of exercise.

- **Type I** muscle fibres are recruited first as they are the smallest, contract more slowly and generate less force.
- **Type IIa** muscle fibres are then recruited, and then **Type IIx**. Type II fibres are larger in size, able to contract more quickly and so generate greater force.

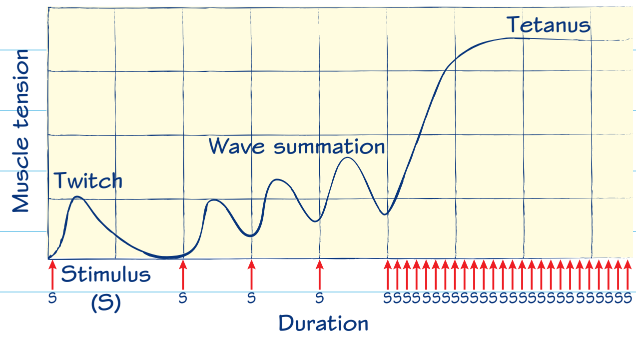


As intensity of exercise increases, muscle fibre recruitment moves from slow twitch (Type I) to fast twitch (Type IIa, then Type IIx).

Frequency of stimulation

Muscle contracts in response to a **stimulus**. The force production or duration of contraction is relative to the type of exercise.

- A **single contraction** in response to a stimulus is known as a **twitch**.
- **Repeated** stimulation (twitches) is known as **wave summation** and acts to increase muscular tension.
- **Tetanus** is when a muscle is in a complete sustained contraction due to rapid stimulation of the muscle.



The frequency of stimulation influences the relative tension within the muscle.

Muscular endurance

Where sport and exercise focus on muscular **endurance** such as long-distance running, cycling or swimming, the muscle develops the **Type I fibres**. This allows for efficient performance of repetitive slow isotonic contractions but a decrease in strength capacity.

Muscular strength

Where sport and exercise focus on muscular **strength** such as weightlifting and climbing, Type IIa and Type IIx fibres are recruited and act at a quicker and faster rate to produce the force required.

- **Type IIa** fibres help to produce sustained power.
- **Type IIx** fibres are faster, but fatigue more rapidly.

Now try this

Endurance athletes have a higher ratio of Type I muscle fibres and strength athletes have a higher ratio of Type II muscle fibres.

Explain which types of muscle fibres would be of greater use during sustained submaximal jogging or cycling, and explain the influence of the frequency of muscle stimulation in a 1RM barbell squat.

Remember that muscle fibres are stimulated into contracting, are recruited relative to size and that muscle fibre contraction and recruitment influence the performance of exercise.

Muscles: Exercise effects

Exercise leads to a number of **effects** and **adaptations** within working muscles. These may include alterations in blood flow and temperature of muscle, as well as micro-tears.

Blood flow to working muscle

During exercise the blood flow to the working muscle **increases**.

- Blood vessels dilate during exercise improving oxygen and nutrient supply to tissues and stimulating waste removal (lactic acid/CO_2).
- The increased blood flow also allows for oxygen demand to be met and enhanced aerobic performance.
- While blood flow is directed to working muscles, blood flow to the digestive system is reduced.

Temperature

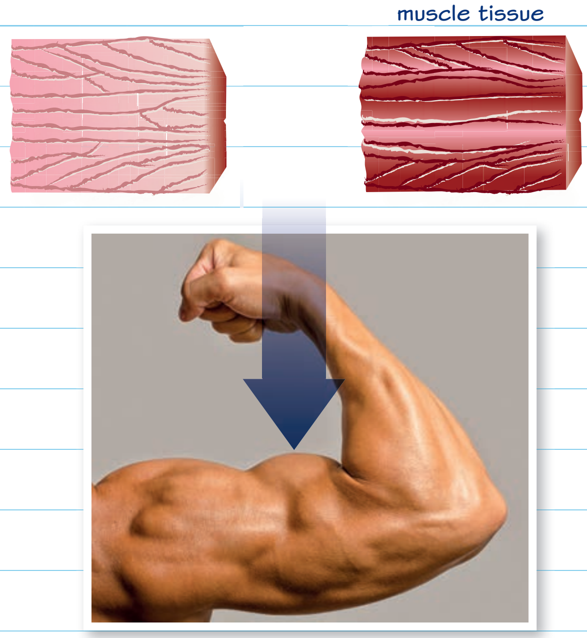
The temperature of muscle **alters** during exercise which has various **effects**:

- When muscles contract they produce heat.
- Increased blood flow also increases the temperature and pliability of muscles, which in turn helps to improve flexibility and range of motion.
- Improved elasticity of muscle aids performance and recovery, and reduces delayed onset muscle soreness (DOMS).

Micro-tears

Overload from strength and endurance exercise creates **stress** on muscles.

- The excess stress creates micro-tears within the muscles.
- When micro-tears repair, the muscle rebuilds.
- This process is normal and increases strength and muscular hypertrophy.
- Training improvements, such as increased muscle strength and size, are made if the body has sufficient rest to repair.



Minor localised swelling and discomfort may occur following exercise. This is worse following eccentric training (if you push your muscles beyond their normal point of failure).

How can micro-tears in muscle affect sports performance?

Micro-tears from training sessions do not fully repair when recovery is insufficient. If there is not enough rest between training sessions the body does not fully repair the muscles. This may happen because of:

- overtraining
- high volume of training
- poor scheduling.

Now try this

Tommy attends the gym three times a week, in addition to training for and competing as a mixed martial artist twice a week. His primary goal in the gym is to improve his strength so that his punches and kicks are more powerful when he competes.

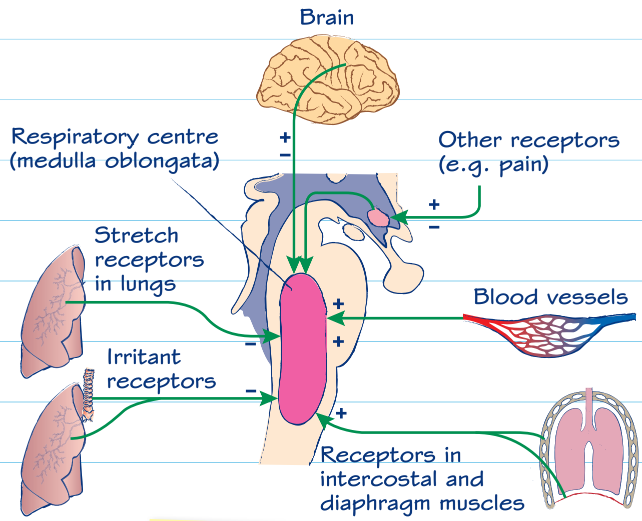
Explain the main exercise effects that will occur within Tommy's muscles when completing a strength training session.

Remember:
- supply
- repair
- heat.

Control of breathing rate

In response to different sports activities the rate of breathing needs to change in order to provide a sufficient supply of oxygen. As **oxygen** (O_2) consumption increases, so too does **carbon dioxide** (CO_2) production, hence the rate of breathing will alter in response to this. The body has two control mechanisms for this – the rate of breathing is under **chemical** and **neural** control.

Breathing control mechanisms



Breathing rate is under chemical and neural control.

How does breathing rate affect sports performance?

When you exercise:

- you need to take in more O_2 to help produce energy for the working muscles, so your breathing rate alters subconsciously in response to the increased demand for O_2
- you need to breathe more quickly in order to maintain performance, not only to take in more O_2, but to exhale more CO_2
- if the supply of oxygen is insufficient this will cause a build-up of CO_2 and a decrease in blood pH.

Chemical control of breathing rate

Breathing may also be controlled by peripheral sensors (**chemoreceptors**) within the aorta and carotid arteries.

- Chemical changes, including the concentration of O_2 and CO_2 and the blood **pH** are monitored.
- If there is a low **pressure** (below 60 mmHg) and **saturation** (below 90 per cent) of O_2 within the blood, information is sent to the medulla oblongata to increase the breathing rate.
- Breathing control is closely linked to cardiovascular control.

Neural control of breathing rate

The **pons** in the brain is the control centre and the **medulla oblongata** subconsciously controls the breathing rhythm.

- In response to increased CO_2 in the blood and a subsequent decrease in **pH**, the body will increase the rate of breathing to draw in more oxygen.
- Nerve impulses are sent to the intercostal muscles and diaphragm to stimulate contraction and increase **breathing rate**.
- Stretch receptors in the lungs prevent over inflation.

Now try this

Dionne is a long-distance runner. To ensure that she has an adequate supply of oxygen during her races, her rate of breathing will need to change.

Explain the changes that occur to Dionne's breathing rate in response to exercise.

Be sure to mention:
- carbon dioxide
- oxygen
- pH
- chemical control
- neural control.

Respiratory muscles

Respiratory muscles contribute to **inhalation** (breathing in) and **exhalation** (breathing out). The main muscles involved are the **intercostal muscles** (internal and external) and the **diaphragm**. They act to enlarge and decrease the thoracic cavity in the chest area, which contains the lungs.

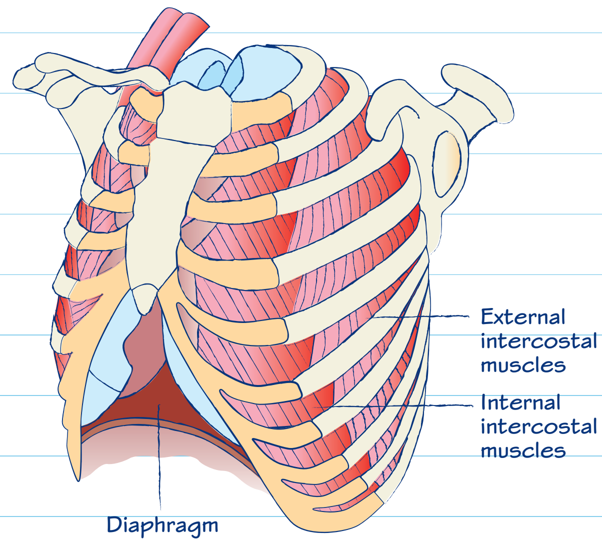
Respiratory muscles

The diaphragm

- A dome shaped muscle separating the thoracic and abdominal cavities
- Flattens when it contracts, increasing the thoracic cavity for lung expansion, upon inhalation

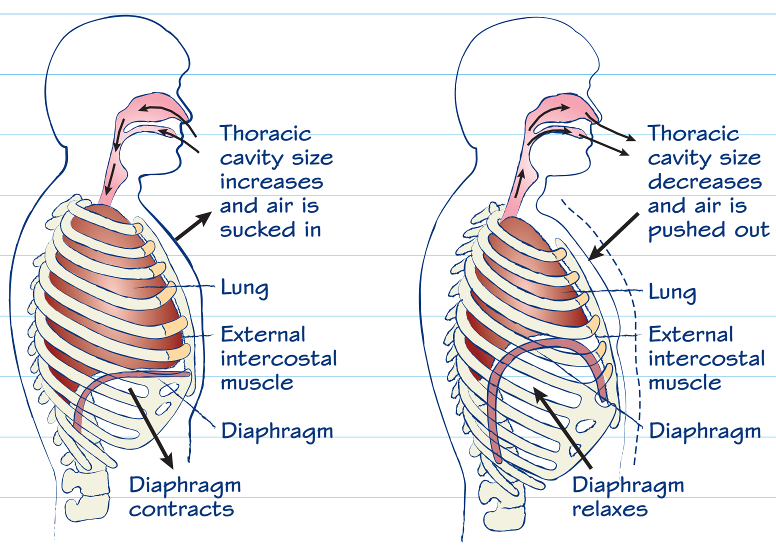
The intercostal muscles

- Contract to move the ribcage during breathing
- Located on the inner side (**internal**) and outer side (**external**) of the ribcage



Location of main respiratory muscles

Inhalation and exhalation



Muscle action movement during inhalation and exhalation

Inhalation

When breathing in:

- the **diaphragm** contracts and flattens
- the **external intercostal** muscles move the ribs upwards and outwards
- the size of the thoracic cavity increases and the lungs **expand**
- the pressure in the lungs decreases and so air is **sucked into** the lungs.

Exhalation

When breathing out:

- it is a passive process when breathing out **at rest**
- the **external intercostal** muscles relax moving the ribcage downwards and inwards
- the **diaphragm** returns to its dome shape
- the size of the thoracic cavity decreases and the lungs **recoil**
- the pressure in the lungs **increases** and air is **pushed out** of the lungs.

Now try this

During breathing the respiratory muscles will need to work to ensure an adequate oxygen supply.

Explain the different functions of the respiratory muscles at rest and how the air gets into the lungs when a person inhales and exhales.

In your answer, discuss:

- intercostal muscles
- diaphragm
- thoracic cavity
- pressure.

Respiratory skeletal muscles

During intense physical exercise, where oxygen demands are increased, **additional muscles** assist the diaphragm and the intercostal muscles during the breathing cycle. This enables **maximal** flow of breath during inhalation and exhalation.

Additional skeletal muscles aid breathing during inhalation

During intense physical exercise, additional muscles assist the diaphragm and the intercostal muscles (**primary muscles**) during inhalation due to the greater oxygen demands.

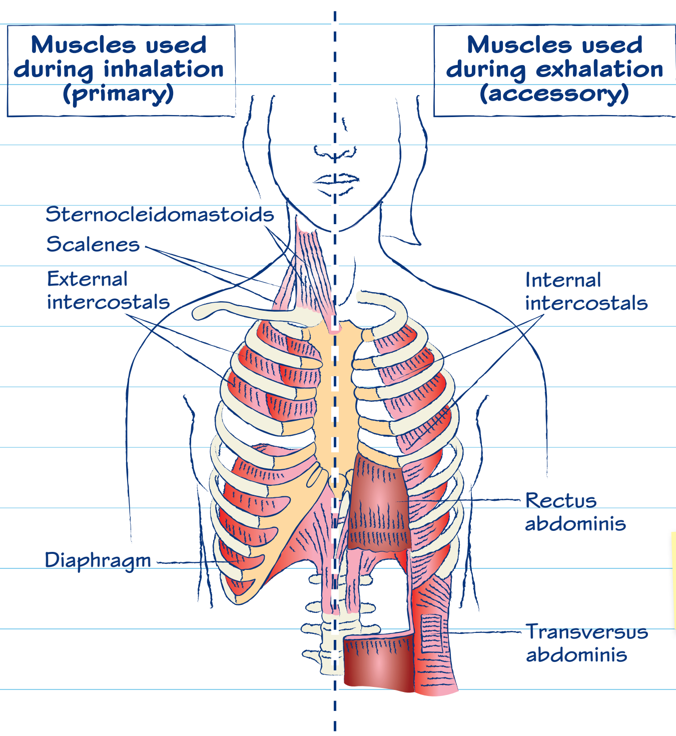
- The extent of their involvement depends on the degree of respiratory effort required. As **breathing rate** increases, so too does their contribution.
- During inhalation, in addition to the diaphragm and intercostal muscles, the **sternocleidomastoid** and **scalene** muscles (anterior, mid and posterior – **accessory muscles**) act to help lift the top portion of the ribcage.
- This increases the thoracic cavity size and further **decreases** pressure within the lungs.

Additional skeletal muscles aid breathing during exhalation

Due to the increased breathing rate during exercise, other (**accessory**) muscles contribute to exhalation.

- Due to the increased demand for oxygen, rather than being a passive process as happens at rest, it requires **forcible exhalation**.
- In addition to the internal **intercostal muscles** pulling the ribcage downwards and inwards during exhalation, the **rectus abdominis** and **transverse abdominis** (**accessory muscles**) pull the lower portion of the ribcage downwards.
- This forces exhalation and **increases** the pressure within the lungs.

Muscles used during inhalation and exhalation



Primary and accessory respiratory muscles

Now try this

Kim is a tennis player. During intense exercise, her respiratory muscles need to work harder than when they are at rest to ensure adequate oxygen supply.

Explain the functions of the accessory respiratory muscles during exercise and how air gets into the lungs when Kim inhales and exhales.

Include in your answer:
- accessory muscles – inhalation
- accessory muscles – exhalation
- breathing rate
- forced exhalation
- thoracic cavity
- pressure.

Respiratory volume

Although breathing rate increases in response to exercise, the amount of air taken in per breath (**tidal volume**) and hence per minute (**minute ventilation**) also needs to increase to help accommodate this increased demand.

Tidal volume

Tidal volume is the amount of air you breathe in and out within a normal breath.

- The average tidal volume in a healthy adult is around **500** ml per inhalation.
- During exercise this increases as the breaths become deeper to help accommodate the increased oxygen demands.

Minute ventilation

Minute ventilation (V_E) is the volume of gas you breathe in and out per minute.

- At rest the average breathing rate is **12** breaths per minute.
- To **calculate minute ventilation** you can use the following calculation:

  V_E = Frequency of breaths × Tidal volume

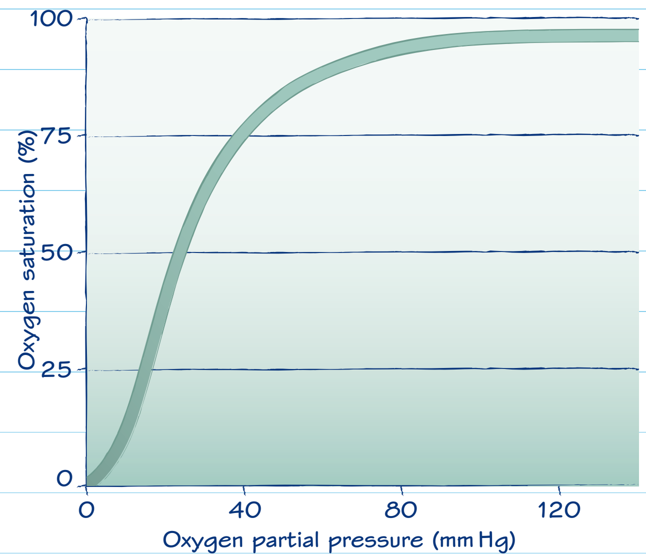
Therefore the average V_E is:

V_E = 12 × 500 = 6000 ml OR 6 litres

Oxygen dissociation curve

This curve plots the **saturation** of oxygen-rich haemoglobin (%) within the blood against the partial **pressure** of oxygen in the blood (PO_2).

- Each molecule of **haemoglobin** (Hb) has the ability to carry 4 molecules of O_2. The amount filled with O_2 is known as saturation.
- As more molecules bind to the haemoglobin the **partial pressure** increases.
- The curve flattens above 60 mm Hg – this indicates the O_2 content is stable.



The oxygen dissociation curve

The Bohr effect

The **Bohr effect** states:

- that the attraction of oxygen to bind to haemoglobin is inversely related to increased CO_2 and decreased pH
- hence during exercise when body temperature increases along with an increased level of CO_2 and a decreased pH, O_2 is more easily released from Hb due to the increased demand
- the curve will shift to the right.

Now try this

Gina is a triathlete who trains and competes regularly. Due to the duration of her sport, she obviously needs to increase the amount of oxygen within her working muscles.

Explain the changes that occur to Gina's tidal volume and minute ventilation in response to exercise, including details of what happens to the oxygen dissociation curve.

During exercise, consider:

- breathing depth
- breathing frequency
- haemoglobin
- Bohr effect.

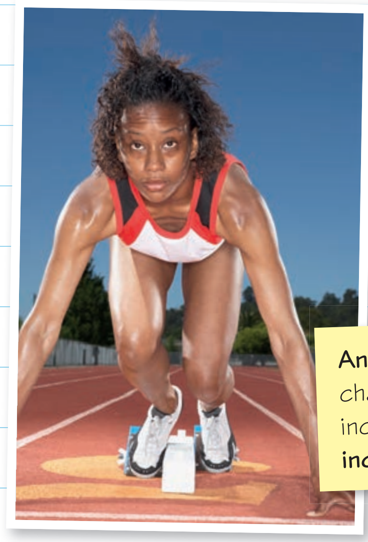
Heart rate, cardiac output and stroke volume

The **cardiovascular system**, composed of the heart and blood vessels, pumps blood around the body to ensure an adequate supply of O_2 and nutrients, as well as removing waste products. During exercise, heart rate needs to increase to ensure the supply to the working muscles is maintained.

Anticipatory rise in heart rate

Before you even start to exercise your body begins to prepare you by increasing your **heart rate** (beats per minute).

- This happens because your **sympathetic nervous system** is stimulated and releases **adrenaline**.
- This increase in heart rate is known as an **anticipatory rise** in heart rate.
- The heart beats faster in order to help circulate a **greater volume** of blood to the working muscles.



Adrenaline and heart rate

Adrenaline is a hormone released at times of stress, sometimes known as your 'fight or flight' hormone.

Andrenaline causes a number of changes to take place in the body, including causing the **heart rate to increase** before participation in sport.

Cardiac output

Cardiac output (Q) is the **volume of blood** pumped from the heart **per minute**.

- For the average person, at rest, this is around **5 litres per minute** (l/min).
- The heart has the ability to **adjust** the strength of its contraction dependent upon how full the ventricle chamber is.
- As more blood enters the heart during exercise, the muscle contracts with greater force to push out a larger blood volume per beat (**stroke volume**).

Calculating cardiac output

To calculate cardiac output you can use the following equation:

Cardiac output = Heart rate × Stroke volume

Q	HR	SV
(l/min)	(bpm)	(litres)

Generally:

- **stroke volume** at rest is around 70–90 millilitres (ml)
- the average **heart rate** is around 60–100 bpm
- for example, if your SV is 0.08 l and your HR is 70 bpm, your Q is 5.6 litres per minute.

Variations in heart rate

Sometimes you can experience variations in heart rate including:

- **bradycardia** – slow heart rate less than 60 bpm (common in athletes)
- **tachycardia** – heart rate more than 100 bpm (normal during exercise)
- **sinus arrhythmia** – variation in heart rate due to increased breathing rate (normal).

Now try this

Bradley is a 400-metre hurdler and although he is not nervous, when he is on the starting line before a race, he experiences a pounding sensation in his chest and it feels as though his heart is quickening.

Explain the reason for Bradley experiencing this sensation and explain what factors it affects and the influence upon his performance.

Think about the effects of adrenaline.

Starling's law

In order to supply the working muscles with sufficient amounts of oxygen during exercise, the heart needs to increase its **cardiac output**. To do this the **heart rate (HR)** and volume per beat – **stroke volume (SV)** – increases, in addition to the volume of blood filling the heart.

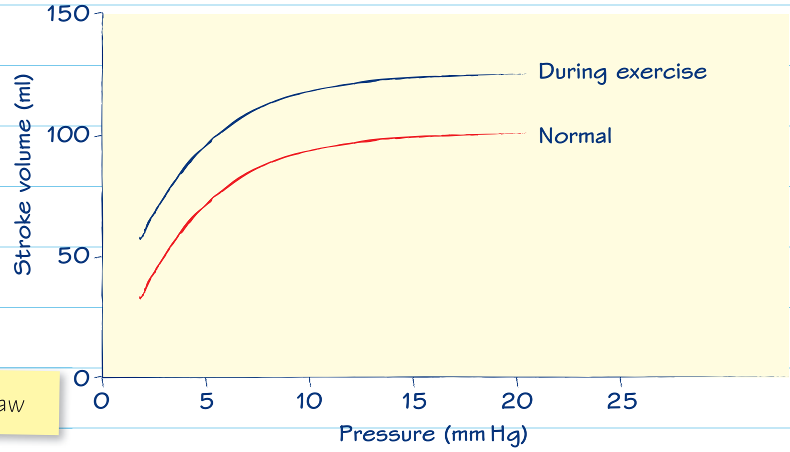
Starling's law

Starling's law indicates the relationship between the stretch of **cardiac muscle** or pressure and the **stroke volume**.

- As more blood fills the heart, the **ventricle walls** are stretched.
- This stretching of the cardiac muscle causes it to contract more **forcibly** and hence increase the stroke volume.
- The more blood squeezed into the ventricles, the more can be **pumped out** with each contraction.
- The amount a muscle can **shorten** depends on the degree to which it is **stretched** (without over extension).
- Greater stretch of the ventricles means increased cardiac muscle shortening and a more **powerful** contraction.

Starling's law illustrated

- An increase in blood volume would cause an increase in pressure and a shift along the *x* (horizontal) axis.
- As the volume of blood is greater, the stroke volume increases and there is a shift along the *y* (vertical) axis.



Starling's law

How does this relate to exercise?

Stroke volume is an important contributing factor of **cardiac output** and consequently **blood pressure**.

- During exercise, as the pressure within the ventricle rises and increases the stretch of the cardiac muscle, a greater contraction will occur, pumping a greater volume of blood out of the heart per beat – meaning an increased SV.
- As SV is increased, so too is *Q*.
- An athlete's heart provides greater ventricular filling and a longer diastole phase allowing stretch to be increased and therefore an increase in SV too.

Now try this

As a crossfit athlete, Frank's heart is used to working harder to help him maintain his performance. When he competes, he has to complete a number of different exercises within the quickest time possible.

Explain the changes that occur relative to Frank's cardiac output in response to exercise.

Remember to include in your answer:
- stretch
- filling
- contracting
- stroke volume
- pressure.

Blood pressure

Blood pressure allows for the flow of blood around the body. It is a measure of the arterial pressure exerted upon the walls of the blood vessels (mm Hg) as a result of the heart contracting and pumping out blood.

Blood pressure

Blood pressure is most commonly taken using the brachial artery in the arm. When blood pressure is taken, **two values** are given. A typical measure for the average adult is **120/80**.

- The **upper value** is the **systolic pressure**. This occurs during heart muscle contraction.
- The **lower value** is the **diastolic pressure**. This occurs during relaxation of the heart muscle.

Taking blood pressure using a sphygmomanometer and stethoscope

Calculating blood pressure

Cardiac output (**Q**) is the volume of blood pumped from the heart per minute. **Blood pressure** (**BP**) is determined by **cardiac output** and the **resistance to the blood flow (R).**

$$BP = Q \times R$$

Blood pressure changes if the resistance to flow is altered.

- This is caused by the diameter of the blood vessel and the viscosity of the blood. Smaller blood vessels and thicker blood increases **resistance**.
- **Baroreceptors** detect changes in blood pressure and stimulate the central nervous system (CNS) so appropriate response can occur.
- The involuntary smooth muscle that lines the arterioles may either relax, causing **vasodilation,** or contract, causing **vasoconstriction**.

Links To revise vasodilation and vasoconstriction, see page 13.

Blood pressure and exercise

When aerobic exercise or strength training commences:

- **blood pressure** increases
- the **baroreceptors** detect this and stimulate the sympathetic nervous system (SNS) branch of the autonomic nervous system (ANS) to increase BP and vasodilate arterioles
- aerobic exercise and strength training increase HR, which increases Q.
- strength training leads to temporarily increased blood pressure, due to isometric contraction of muscles.

Variations in heart rate

- If Q increases and R does not change then BP will automatically increase.
- If R increases, then Q and blood flow will decrease and BP will increase.

Now try this

Sally has just joined a gym. She wants to start getting fitter so that she can participate in a 5-km charity run. At her induction, the instructor measured her blood pressure as 120/80.

Explain to Sally what will happen to her blood pressure when she exercises and the additional effects that will take place in order for this to occur.

Remember that:

- vasodilation leads to a decrease in resistance
- vasoconstriction leads to an increase in resistance
- decreased viscosity leads to decreased resistance
- increased viscosity leads to increased resistance.

Had a look ☐ Nearly there ☐ Nailed it! ☐

Cardiac cycle

The cardiac cycle includes the contraction and relaxation of cardiac muscle during a heartbeat. The frequency of the **cardiac cycle** is known as the **heart rate**, which is typically expressed as beats per minute.

The cardiac cycle

The active phase of the cycle is called **systole** (contracting) and the resting period **diastole**. At rest, one heartbeat or **cardiac cycle** takes 0.8 seconds.

- The contraction phase begins with both **atria** pushing blood into the ventricles. Their contractions are not powerful but help to improve the heart's efficiency by forcing blood into **ventricles.** Atrial contraction is complete at the time the ventricle contraction begins.
- A **resting phase** begins in the atria at the same time that a **contraction** phase begins in the ventricles. After the ventricles have contracted, all chambers relax for a short period as they fill with blood.

During exercise the cycle speeds up, increasing the heart rate. The volume of blood filling the atria and ventricles also increases along with systolic blood pressure in order to meet the demands of exercise by transporting sufficient oxygen and nutrients to the working muscles and removing carbon dioxide.

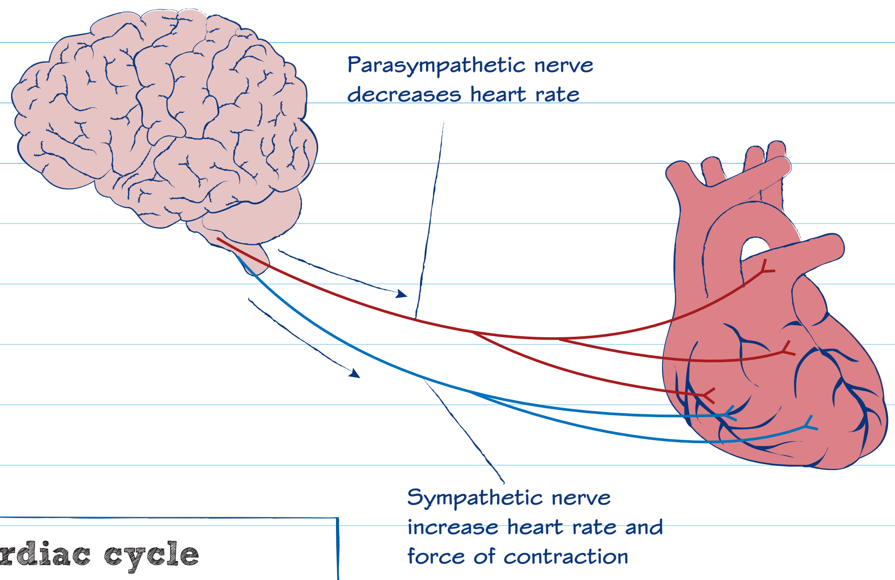
Additionally, **vasodilation** occurs within the arterioles, resulting in increased blood flow to the working muscles. Conversely, **vasoconstriction** occurs to other regions of the body, such as the digestive system, decreasing blood flow.

Control of heart rate

Heart rate is controlled by the **SAN** – sinoatrial node – the heart's internal **pacemaker**. This will increase or decrease relative to the information received from the nervous system.

When you exercise:

- the sympathetic nerve will signal to increase the heart rate and noradrenaline will be secreted
- the parasympathetic nerve will decrease the heart rate and acetylcholine will be selected.



Nervous control of the heart

Neural control of the cardiac cycle

The heart's electrical system is made up of three main parts:

- Sinoatrial node (SAN) revised on this page
- Atrioventricular node (AVN) revised on page 71
- Bundle of His and Purkinje fibres, revised on page 71.

Now try this

A single heart beat is where the cardiac muscle relaxes and contracts. Your heart rate is the number of heart beats over one minute. When you exercise, your heart rate increases.

Explain what happens to the cardiac cycle when you exercise.

Changes in blood

To accommodate the increased oxygen needed during exercise, blood is redistributed in response to chemical changes. Oxygen can reach the relevant areas to allow for increased exchange and uptake of oxygen.

Redistribution of blood flow

As exercise commences:

- Blood is redistributed and directed to the exercising muscles – known as **shunting**.
- Primarily this is controlled by **vasoconstriction** and **vasodilation** of the smooth muscle lining arterioles in response to chemical changes in local tissues.

The **sympathetic nervous system:**

- Increases vasodilation to skeletal muscle and respiratory system.
- Decreases vasoconstriction to skin and digestive organs.

The **parasympathetic nervous system:**

- Decreases vasoconstriction to skeletal muscle and respiratory system.
- Increases vasodilation to skin and digestive organs.

Changes in blood pH

The pH of your blood is normally **7.35–7.45**. If this drops below it is termed **acidosis**, if it rises above, it is termed **alkalosis**.

- As you exercise, in the absence of O_2, blood becomes more **acidic** because the amount of CO_2 produced increases and **bicarbonate** (HCO_3) and **hydrogen** (H^+) ions are produced and accumulate – this lowers the pH.
- Exhaling CO_2 acts to lower the pH. The bicarbonate acts as a **buffer** to prevent sharp increases in H^+ and to maintain the pH between 7.35–7.45.
- When exercising, if there is insufficient O_2, a build-up of H^+ ions occurs, which may impair muscle contraction.

Diffusion rate

- **Diffusion** is the movement of molecules from an area where they are in a high concentration to an area where they are in a low concentration.
- **Diffusion rate** is the rate at which O_2 diffuses from the blood stream (high concentration) into tissue (low concentration).

During exercise, CO_2 is produced and O_2 demand increases. The body's response is to increase breathing rate and cardiac output to ensure supply meets demand, maximising potential for gaseous exchange and diffusion.

Arteriovenous oxygen difference

The **arteriovenous oxygen difference** (a-VO_2 diff) is a comparison of the difference between the concentration of oxygen in **arterial blood** and **venous blood**, measured in ml of oxygen per 100 ml of blood (ml/100 ml).

- It provides an indication of how much oxygen is removed from the capillaries and circulating within the body at any one time and is a factor contributing to total **oxygen consumption**.
- As you exercise, your muscles use oxygen and this results in an increased a-VO_2 diff. This is enhanced in trained athletes and increased capillarisation allows for **increased diffusion** and an enhanced ability to extract O_2 from the blood.

Now try this

When you exercise you need more oxygen to sustain your performance.

Explain how the body is able to redistribute, exchange and extract oxygen for use and how it ensures a suitable environment for transporting oxygen.

Motor unit recruitment

To produce a muscle action, nerve impulses from the central nervous system, the brain and spinal cord stimulate skeletal muscle fibres.

Motor units

- Signals travel from the central nervous system through nerve cells called **motor neurons** as motor impulses. A motor neuron has its main body within the **central nervous system (CNS)** and then branches (**axons**) carry signals to the effectors in the muscle fibres to produce muscular contractions.
- A single motor neuron and the fibres it stimulates make up a **motor unit**, which may **innervate** many muscle fibres. Smaller motor units are used in fine movements and larger motor units for gross movements.
- The point at which a neuron contacts a muscle is known as the **neuromuscular junction**. A chemical **neurotransmitter** called **acetylcholine** (Ach) is released from the neuron to stimulate the muscle cell.

Innervate

To **innervate** means to supply an organ or other body part with nerves.

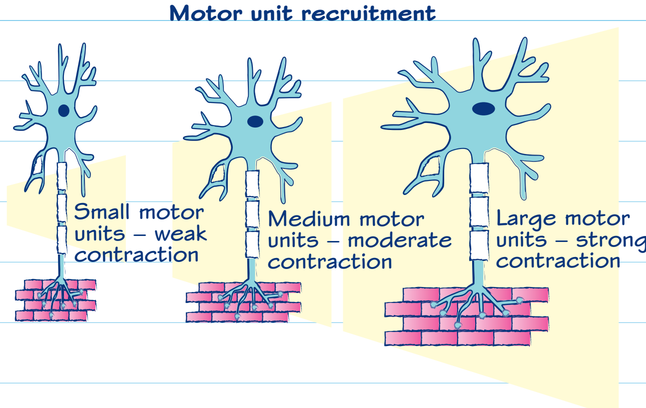
- This neurotransmitter travels across the **synaptic cleft** (the space between neuron and muscle) and is received by the motor end plate in the muscle. The electrical impulse spreads rapidly along the muscle membrane creating an **action potential** (AP).
- A muscle can undergo **many APs** in the duration of a single muscle twitch. However, if an AP arrives before a twitch has been completed, the twitches overlap. APs arriving repeatedly before the end of a twitch produces greater force (summation), e.g. concentric biceps curl.
- If the APs are constant and fired rapidly, tension within the muscle rises smoothly and gradually **plateaus** (tetanus), e.g. holding a handstand.

Motor unit recruitment and exercise

When a motor neuron is activated, all of the muscle fibres it innervates are stimulated to contract.

- **Motor unit** recruitment is relative to the **force production** required. The more motor neurons activated, the more muscle fibres are stimulated and therefore the stronger the muscle contraction (**size principle**).
- The motor units will only be recruited **as needed** and motor units are generally recruited smallest to largest. If the initial force production is insufficient, further motor units are recruited.
- During exercise the motor units produce muscle contraction at **different rates**. Different parts of the muscle contract at different times to produce a smooth contraction.

Motor unit recruitment



The strength of a muscle contraction is dependent upon the number of motor units recruited.

Now try this

When you lift a load, you are contracting your muscles to move the resistance.

Explain the motor unit recruitment for a powerlifter performing a 1RM bench press, and a Pilates instructor performing a plank for 1 minute.

Sensory receptors

Fluctuations within the body's internal environment are monitored by **muscle spindles**, **Golgi tendon organs** and other sensory receptors, which serve as a means of communication between an organ and the central nervous system (CNS).

Muscle spindles

A **muscle spindle** is an organ within a muscle belly, which acts as a **proprioceptor** to sense **changes in muscle length**, primarily when a muscle is contracting.

- When a muscle is contracted the muscle spindle senses a change in length, which is communicated via signals to the CNS. This helps to **regulate** muscle contraction in order to increase the strength of a contraction or to relax the muscle.
- In addition, when the muscle lengthens, the muscle spindle is stretched, which sends signals to the CNS. This triggers **action potentials** and results in increased motor unit recruitment and greater force of **contraction** in order to decrease the speed at which the muscle is being stretched.
- This is a protective response to avoid overstretching known as the **stretch reflex**.

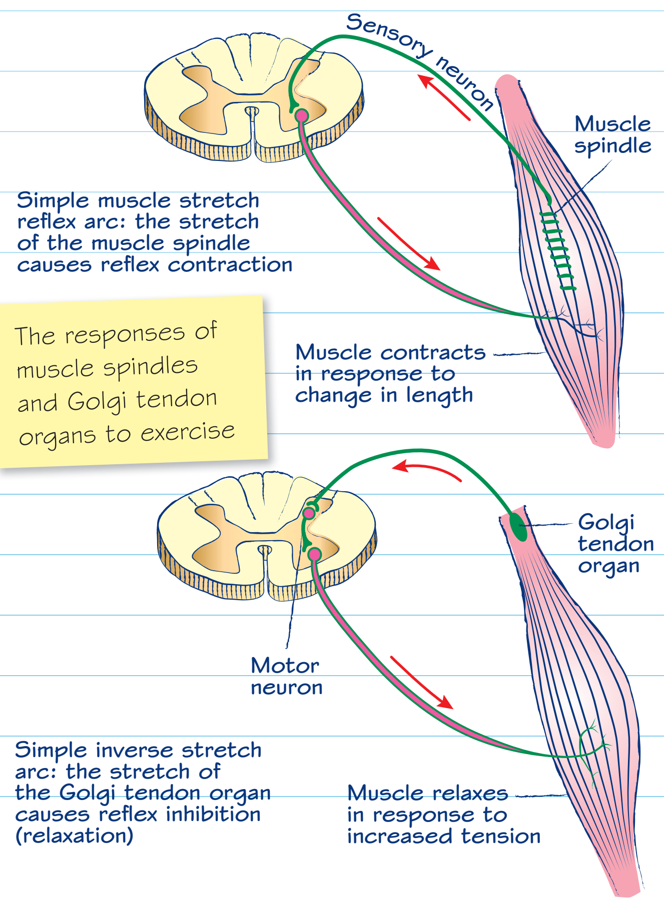
CNS

Baroreceptors, located in the walls of blood vessels, respond to changes in blood pressure. When the blood vessel walls are stretched, they signal the CNS and firing of action potentials is increased. This influences cardiac output and peripheral resistance in the form of vasoconstriction and vasodilation.

Thermoreceptors respond to changes in temperature and are located in the skin. They transmit signals to the CNS when the environmental temperature changes and predict a change in core body temperature, acting to cool or warm the body.

Chemoreceptors respond to changes in the blood pH and levels of O_2. In response to exercise, the CNS signals the diaphragm and intercostal muscles to increase the rate and depth of breathing. This helps regulate short-term responses to exercise.

Muscle spindles and Golgi tendon organs



The responses of muscle spindles and Golgi tendon organs to exercise

Golgi tendon organs (GTO) are located at the points where skeletal muscle fibres meet their tendons and act as another type of proprioceptor, providing information about **changes in muscle tension**.

- When a muscle is under great **tension** a signal from the GTO is sent to the CNS. This causes the motor neuron to relax and so the muscle tension is released.
- This is a protective response to avoid overstretching known as the **inverse myotatic reflex**. It acts to regulate the tension in a muscle causing relaxation before the tension in the tendon becomes too great and causes tissue damage.

Now try this

When Ella exercises, several variations occur within her body systems. One of these is the stretch reflex.

Explain the stretch reflex and how it prevents injury.

Adrenaline, noradrenaline and cortisol

The **endocrine system** consists of a group of glands that produce **hormones**. The endocrine system and nervous system work together to regulate and coordinate the body's responses. Although the effects of the endocrine system occur more slowly, they are longer lasting.

Adrenaline and noradrenaline are hormones secreted from the adrenal glands located above the kidneys

- Stimulated by the sympathetic nervous system (SNS)
- Primary secretion is adrenaline (80%)
- Noradrenaline is mainly secreted by the SNS and acts more as a neurotransmitter.
- Responsible for changes to the cardiovascular system function
- Often referred to as the '**fight or flight**' hormones

Blood concentration

The blood concentration of **adrenaline** and **noradrenaline** increases as exercise intensity increases.

When released into the bloodstream adrenaline and noradrenaline act to:

- increase **heart rate** – stimulating cardiac muscle contraction, increasing cardiac output
- increase **glycogenoylsis** – where glycogen in the liver is transformed into glucose, to be released into the blood
- increase **peripheral resistance** of blood vessels – stimulating involuntary smooth muscle in walls of arterioles
- increase **dilation of bronchioles** – smooth involuntary muscle relaxation

The above contributes to an **increase** of blood flow and oxygen to working muscles during exercise and a **decrease** to the urinary and digestive systems. When exercise stops, acetylcholine is released to lower adrenaline and noradrenaline concentration, and return the body back to normal.

Cortisol

The adrenal cortex releases glucocorticoids. One is called **cortisol,** also known as hydrocortisone.

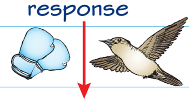
- It acts to raise the level of nutrients in the blood and maintain carbohydrate reserve by stimulating the liver to convert amino acids and fatty acids (FAs) into glucose (gluconeogenesis).
- It also has anti-inflammatory effects.

As exercise duration increases:

- More liver glycogen is utilised.
- There is an increase in muscle glucose uptake and an increase in liver glucose release.
- As glycogen stores decrease glucagon levels increase.

Hormone response to exercise

Exercise starts → Fight or flight response



→ Adrenaline, noradrenaline and cortisol released → Physical responses

Exercise stops → Acetylcholine released → Adrenaline, noradrenaline and cortisol levels lower → Body returns to normal

Physical responses

- ↑ heart rate and cardiac output
- ↑ peripheral resistance of blood vessels
- ↑ glycogenolysis
- ↑ dilation of bronchioles
- ↑ liver glycogen utilised
- ↑ muscle glucose uptake
- ↑ liver glucose release
- as glycogen stores are reduced ↓ glucagon levels increase. ↑

The hormonal response to exercise can be described as 'fight or flight'.

Now try this

Tara has just started training at the gym and has noticed that her heart beats faster and her breathing quickens. She has been told this is a normal response, though she wants to know why this happens.

As part of your answer for Tara, explain the responses of the adrenal glands to exercise and how they act to help Tara during exercise.

Testosterone, human growth hormone and oestrogen

The amount of a hormone secreted can be influenced by exercise, as by as to a number of variations of the exercise.

Human growth hormone (HGH)

Exercise stimulates the release of **human growth hormone** into the circulation, which stimulates other growth in different tissues around the body.

Hypertrophy means an increase in muscle size.

Human growth hormone

- Produced in the anterior lobe of the **pituitary gland**
- Acts to promote growth of tissues, stimulating protein production for **hypertrophy** and cellular **maintenance and repair**
- Acts on metabolism, stimulating the liver to **release fatty acids** for energy in times of stress

HGH and resistance exercise

HGH secretion is relative to load and frequency.

It increases:

- as load increases
- as rest intervals decrease
- with an increase in training frequency
- with large muscle group exercises.

HGH and endurance exercise

HGH secretion depends on intensity, duration, frequency and mode of endurance exercise.

It increases:

- when intensity is above lactate threshold
- with duration over 10 minutes.

Oestrogen

Oestrogen is produced by the ovaries and affects the skeletal system. Its main role is within the menstrual cycle.

- Although bone mass increases as a result of physical activity, highly trained women may experience **amenorrhoea** (when their periods stop) when training intensity or volume increases.
- The variations in menstrual cycle may affect **bone density**.

When women experience **menstrual disruption** this can:

- decrease oestrogen production
- decrease osteoclasts activity
- decrease bone reabsorption
- decrease bone density
- increase risk of osteoporosis.

As bone density decreases with **age**, this may also contribute to decreased strength, bone and muscle mass. So **resistance exercise** may preserve bone density, strength and muscle mass as the body ages.

Testosterone

Testosterone is a hormone that is derived from cholesterol, produced in men and women (mainly in the testes in males). It affects the muscular system.

- It diffuses into surrounding fluids and is absorbed into the bloodstream.
- Its main roles are to **increase** protein anabolism – muscle synthesis – and **decrease** protein breakdown.

Testosterone secretion will increase and improve muscle size, strength and power in response to:

- heavy resistance training (85–100% 1RM)
- large muscle group exercises (squat)
- moderate–high training volume – multiple sets/ multiple exercises
- short rest interval (30 sec–1 min).

Production of testosterone decreases with **age**, so **resistance exercise** for older adults may help raise levels.

Now try this

Grant and Sally are 21 and attend the gym together 5 days a week. Grant is a powerlifter. He usually trains at 85–100%1RM and likes to complete at least 8 sets for each lift. Sally is an Olympic qualified steeplechaser and usually trains at 60-80%1RM for 5 sets, and has recently increased her training volume from 3 days to 5 days a week.

Explain the response to exercise of HGH, testosterone and oestrogen for Grant and Sally.

Energy sources

Sources used to supply the energy needed by muscles to perform include adenosine triphosphate (ATP), phosphocreatine, blood glucose, glycogen and fatty acids. They are used within the three **energy systems**: ATP-PC, lactate and aerobic systems.

ATP and PC

Adenosine triphosphate (ATP)

1. Source of energy for muscle activation and the energy currency of the body
2. Contains one adenosine molecule and three phosphate molecules linked with high energy bonds
3. When ATP is broken down to **adenosine di-phosphate** (ADP) and **phosphate** (P), it releases energy for muscular contraction
4. Stored within the sarcoplasm of the muscle and the immediate source for muscular actions

Phosphocreatine (PC)

1. Similar to ATP as it is stored within the muscle sarcoplasm and contains high energy bonds, although it is composed of one P and one creatine (Cr) molecule
2. Aids in the reformation of ATP
3. When PC is broken down to P and Cr, the energy released is used to reform ATP from ADP and P

Energy sources for a single exercise session

ATP or PC or blood glucose or glycogen → Anaerobic → ATP
During maximal activity

Carbohydrates or fatty acids or protein → Aerobic → ATP and carbon dioxide and water
Carbohydrates or fatty acids or protein → Anaerobic → ATP and lactic acid
During submaximal activity

Fuel sources during maximal and submaximal activity

Blood glucose and glycogen

Blood glucose refers to the concentration of glucose that is transported within the blood to supply energy to the body. It is derived from the diet and acts as the primary source of energy.

Glycogen Is primarily stored in the muscles with an additional store within the liver, which can be broken down to glucose, and used to produce energy in the lactic acid system. Its release from the liver is stimulated by glucagon from the pancreas and helps to maintain blood glucose levels. Glucose provides approximately 4 kcal of energy per gram.

Fatty acids (FA)

Fat is stored in adipose (fat) tissue in the form of triglycerides.

- Fat contains three **fatty acid** (FA) chains connected by glycerol and is broken down by **lipase**.
- In muscle, fat can be broken down and enter the Krebs cycle via gluconeogenesis.
- FAs have a lot of high energy bonds, so when they enter the cycle more energy is released to provide ATP. However, it requires roughly 15 per cent more oxygen to break down than glycogen, so when oxygen is limited glycogen will be broken down.
- Lactic acid inhibits the breakdown of fat.

Now try this

Explain the energy sources available to maintain energy production and blood glucose levels.

Different activities will demand different contributions from the energy sources depending upon the physiological demand placed on the muscles for exercise.

ATP-PC system

Adenosine triphosphate (ATP) and phosphocreatine (PC) are stored within the muscle in limited amounts, which restricts the amount of energy they can produce.

ATP-PC system

The ATP-PC system is the primary source used for resistance exercises which are:

- short duration
- high power
- high force.

ATP:

- is stored within the muscle
- is broken down to release energy for use in muscular contraction
- lasts for approximately 8–10 seconds.

The system does not rely on the presence of oxygen and is used exclusively for the first 5 seconds of high-intensity exercise.

Creatine kinase is the enzyme involved, which breaks down PC.

ATP-PC system stages – coupled reaction

1. Eat food
2. Energy stored in the muscle as ATP
3. ATPase (enzyme) breaks phosphate bonds
4. ADP + P + Energy released for use
5. Creatine phosphate (CP) stored in sarcoplasm
6. Creatine kinase (enzyme) activated
7. Creatine kinase breaks creatine and phosphate bond
8. Energy released for reforming ATP
9. P + ADP = ATP + C

ATP and exercise

- Training to improve the use of this system involves high intensity and short duration exercise.
- The training should be specific to the actions required by the athlete.
- This will improve the metabolic capacity of the muscle tissue, and enhance neuromuscular adaptation.

Advantages and disadvantages of the ATP-PC system

👍 The energy is immediately available for use by the muscle.

👍 Has a large power capacity.

👍 Supplies large amounts of energy per second to support muscular contraction.

👎 As exercise continues there is an imbalance between use and resynthesis of ATP, leading to fatigue.

👎 Stores must be fully replenished to continue further intense bouts of training.

Now try this

Raj is completing a sprint training session of 6 × 60 metre sprints, with a 3-minute rest in between sprints.

Explain the process of energy production relative to Raj and why it is appropriate for energy production for a sprinter.

Lactate system (anaerobic glycolysis)

The breakdown of glycogen occurs when energy demands are increased and oxygen is not required to function.

Lactate system

The process is as follows.

Carbohydrate stored in muscles and liver as glycogen is converted into glucose by the enzyme glycogen phosphorylase.

▼

The glucose is then broken down by the enzyme phosphofructokinase (PFK) to pyruvic acid.

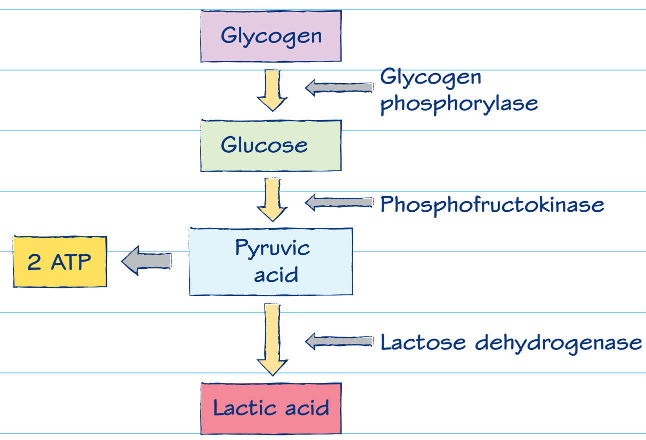
▼

Energy is released at this point and 2 ATP molecules are resynthesised.

▼

Due to the lack of oxygen, pyruvic acid is converted by the enzyme lactose dehydrogenase (LDH) into lactic acid.

Energy production in the lactate system



The anaerobic energy system

Advantages and disadvantages of the lactate system

- 👍 No delay waiting for oxygen to be supplied from the lungs for glycogen breakdown as oxygen is not required.
- 👍 Relatively large amounts of glycogen stored in our bodies and so this system can provide more ATP than PC system.
- 👍 Relatively few chemical reactions taking place so ATP can be provided for high intensity activities that last anywhere from 15 to 90 seconds.
- 👎 The by-product, lactic acid, reduces the pH of the muscle, making it more acidic.
- 👎 This prevents the enzymes from functioning properly, causing muscle fatigue.

Resistance versus endurance exercise

During endurance exercise, muscle glycogen stores decrease, in contrast to the response after resistance training.

- Bodybuilders may have up to 50 per cent greater glycogen concentration than untrained people. Endurance athletes also have high levels of glycogen in their muscle tissue.
- Skeletal muscle glycogen content increases as a result of resistance training and blood glucose levels do not decrease during resistance training.
- Therefore, unlike within endurance exercise, carbohydrate availability is not a limiting factor to performance during a training session.

Now try this

George trains at the gym. When he exercises for more than 10–15 seconds and wants to maintain his performance, his body needs to produce more energy.

Explain the process of energy production in George's lactate energy system.

- Describe the process of fuel utilisation.
- State the number of ATP molecules produced.
- Mention the by-products of the energy system.
- Give examples of activities that are fuelled by this energy system.