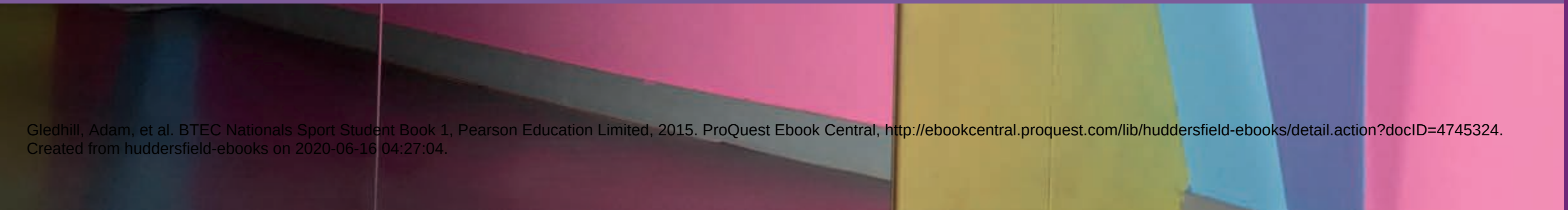
Anatomy and Physiology 1



Getting to know your unit

Assessment

This unit is assessed by an examination that is set and marked by Pearson.

To understand what happens during sport and exercise, you must know about body systems. This unit explains how the body is made up of a number of different systems, how these systems interact and work together, and why they are important to sports performance. You will:

- be introduced to the structures and functions of the five key systems and the effects that sport and exercise has on them
- investigate the structure and function of the skeletal and muscular systems and their role in causing movement in sport and exercise
- examine the structure and functions of the cardiovascular and respiratory systems
- understand why the heart works as it does and how it works with the lungs to allow sportspeople to cope with the demands of sport
- look at the three different energy systems and the sports in which they are predominantly used.

This is a mandatory unit and introduces knowledge that will link with all other units in the course.

How you will be assessed

This unit will be assessed by an examination set by Pearson. The examination will last 1 hour and 30 minutes and will contain a number of short answer and long answer questions. There will be a total of 90 marks available in the examination. You will be assessed for your understanding of the following topics in relations to sports performance:

- the skeletal system
- the muscular system
- the respiratory system
- the cardiovascular system
- the energy system.

During this examination you will need to show your knowledge and understanding of the interrelationships between these different body systems for sports performance.

Throughout this unit you will find assessment practice activities to help you prepare for the exam. Completing each of these activities will give you an insight into the types of question that will be asked and, importantly, how to answer them.

Unit 1 has five assessment outcomes (AO) which will be included in the external examination. Certain 'command words' are associated with each assessment outcome. Table 1.1 explains what these command words are asking you to do.

The assessment outcomes for the unit are:

- **AO1** Demonstrate knowledge of body systems, structures, functions, characteristics, definitions and other additional factors affecting each body system
  - Command words: identify, describe, give, state, name
  - Marks: ranges from 1 to 5 marks

- **AO2** Demonstrate understanding of each body system, the short- and long-term effects of sport and exercise on each system, and additional factors that can affect body systems in relation to exercise and sporting performance
  - Command words: describe, explain, give, state, name
  - Marks: ranges from 1 to 5 marks
- **AO3** Analyse exercise and sports movements, how the body responds to short-term and long-term exercise, and other additional factors affecting each body system
  - Command words: analyse, assess
  - Marks: 6 marks
- **AO4** Evaluate how body systems are used and how they interrelate in order to carry out exercise and sporting movements
  - Command words: evaluate, assess
  - Marks: 6 marks
- **AO5** Make connections between body systems in response to short-term and long-term exercise and sport participation. Make connections between muscular and all other systems, cardiovascular and respiratory systems, energy and cardiovascular systems
  - Command words: analyse, evaluate, assess, discuss, to what extent
  - Marks: 8 marks

Table 1.1: Command words used in the assessment outcomes

Command word	Definition – what it is asking you to do
Analyse	Identify several relevant facts of a topic, demonstrate how they are linked and then explain the importance of each, often in relation to the other facts.
Assess	Evaluate or estimate the nature, ability, or quality of something.
Describe	Give a full account of all the information about a topic, including all the relevant details of any features.
Discuss	Write about the topic in detail, taking into account different ideas and opinions.
Evaluate	Bring all the relevant information you have on a topic together and make a judgement (for example, on its success or importance). Your judgement should be clearly supported by the information you have gathered.
Explain	Make an idea, situation or problem clear to your reader by describing it in detail, including any relevant data or facts.
Give	Provide examples, justifications and/or reasons.
Identify	State the key fact(s) about a topic or subject. The word *Outline* is similar.
State/name	Give a definition or example.
To what extent	Review information and then bring it together to form a judgement or conclusion, after giving a balanced and reasoned argument.

Getting started

Anatomy and **physiology** are essential ingredients in all sport and exercise performance. List the changes that your body experiences when you take part in sport or exercise. When you have done this, consider each change and try to identify which body system is being affected.

A The effects of exercise and sports performance on the skeletal system

Key terms

Anatomy – study of the structure of the body such as the skeletal, muscular or cardiovascular systems.

Physiology – study of the way that the body responds to exercise and training.

Structure of the skeletal system

Before we look at the functions of the skeletal system, it is important to understand which bones make up the skeleton and how they are used to perform the vast range of techniques and actions required in sport. Without bones, you would be a shapeless mass of muscle and tissue, unable to move. The skeletal system is made up of bones, cartilage and joints.

Your skeleton is made up of 206 bones which provide a framework that supports your muscles and skin and protects your internal organs.

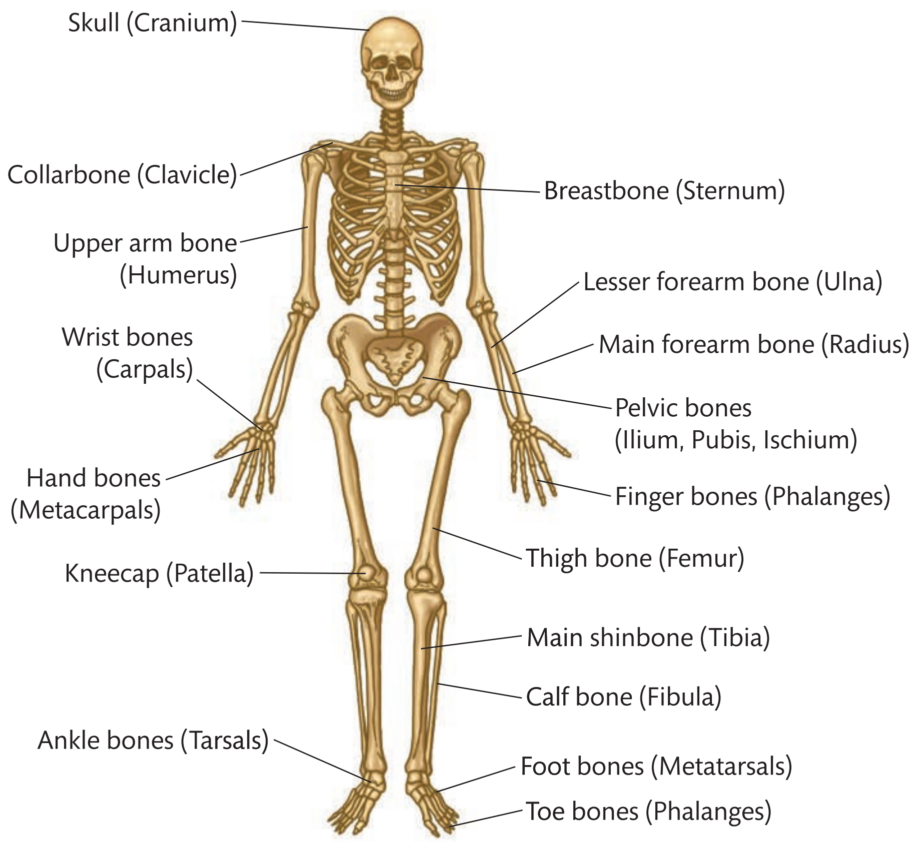


Figure 1.1: Bones of the human skeleton; Latin names are shown in brackets

Many terms are used to describe the location (or anatomical position) of bones. These are described in Table 1.2. You might find it useful to make a note of them.

Table 1.2: Terms used to describe the location of bones

Term	Meaning
Anterior	To the front or in front
Posterior	To the rear or behind
Medial	Towards the midline or axis, an imaginary line down the centre of the body
Lateral	Away from the midline or axis
Proximal	Near to the root or origin (the proximal of the arm is towards the shoulder)
Distal	Away from the root or origin (the distal of the arm is towards the hand)
Superior	Above
Inferior	Below

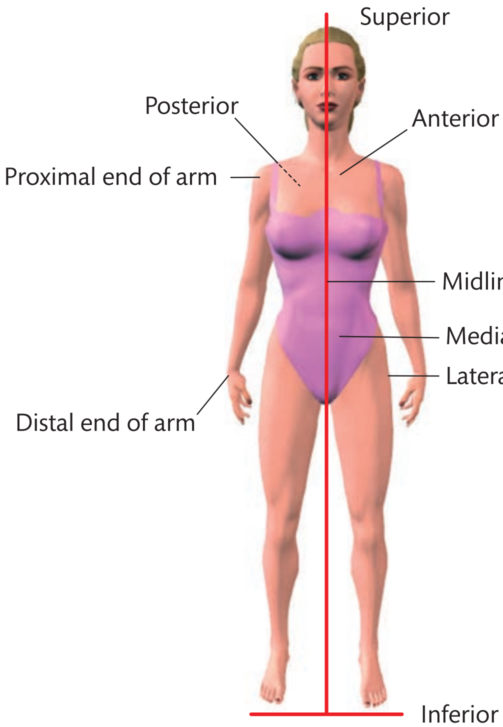


Figure 1.2: Anatomical positions

Types of bone

The skeleton has five main types of bone according to their shape and size. These can be classified as:

- **long bones** – the bones found in the limbs. They have a shaft known as the **diaphysis** and two expanded ends known as the **epiphysis**.
- **short bones** – small, light, strong, cube-shaped bones consisting of **cancellous bone** surrounded by a thin layer of compact bone. The carpals and tarsals of the wrists and ankles (introduced later in this section) are examples of short bones.
- **flat bones** – thin, flattened and slightly curved, with a large surface area. Examples include the scapulae, sternum and cranium.
- **irregular bones** – have complex shapes that fit none of the categories above. The bones of the spinal column are a good example.
- **sesamoid bones** – have a specialised function and are usually found within a tendon. These bones provide a smooth surface for the tendon to slide over. The largest sesamoid bone is the patella in the knee joint.

Key term

Cancellous bone – light and porous bone material that has a honeycomb or spongy appearance.

Areas of the skeleton

The skeleton can be divided into two parts: 80 bones form your **axial skeleton** – the long **axis** of your body; the other 126 bones form your **appendicular skeleton** – the bones that are attached to this axis.

Key term

Axis – a centre line through any body or object. The body or object to either side of the line should be symmetrical (a mirror image).

Axial skeleton

The axial skeleton is the main core or axis of your skeleton and consists of:

- the skull (including cranium and facial bones)
- the thoracic cage (sternum and ribs)
- the vertebral column.

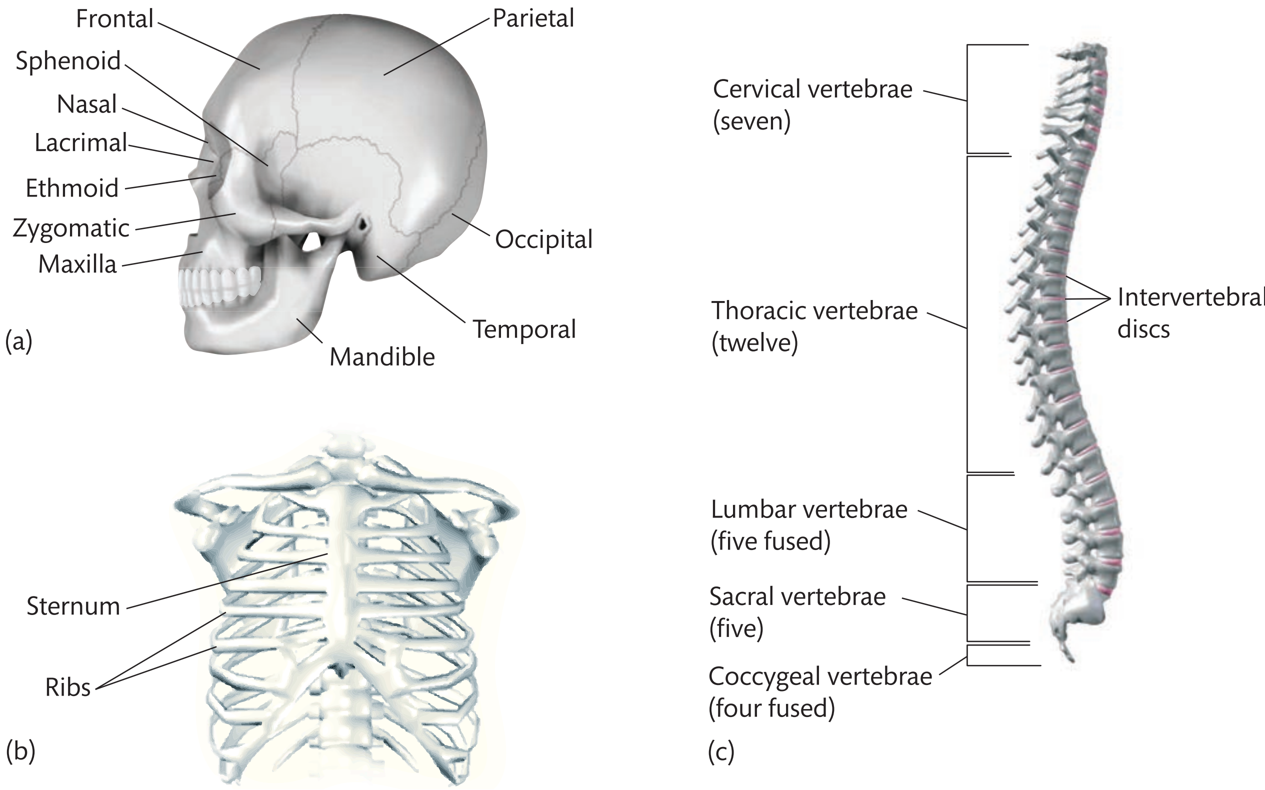


Figure 1.3: The axial skeleton: (a) the skull, (b) the thorax and (c) the vertebral column

Appendicular skeleton

The appendicular skeleton consists of the bones that are attached to the axial skeleton. These bones will be introduced in more detail later in this section, but the appendicular skeleton consists of the following parts.

- The upper limbs consist of 60 bones (30 in each arm) including the humerus, radius, ulna, carpals, metacarpals and phalanges.
- The lower limbs consist of 60 bones (30 in each leg) including the femur, tibia, fibula, patella, tarsals, metatarsals and phalanges.
- The shoulder girdle consists of four bones – two clavicles and two scapulae – which connect the limbs of the upper body to the thorax.
- The pelvic girdle is made of three bones: the ilium, pubis and ischium. These fuse together with age and are collectively known as the innominate bone. The main function of the pelvic girdle is to provide a solid base through which to transmit the weight of the upper body. It also provides attachment for the powerful muscles of the lower back and legs, and protects the digestive and reproductive organs.

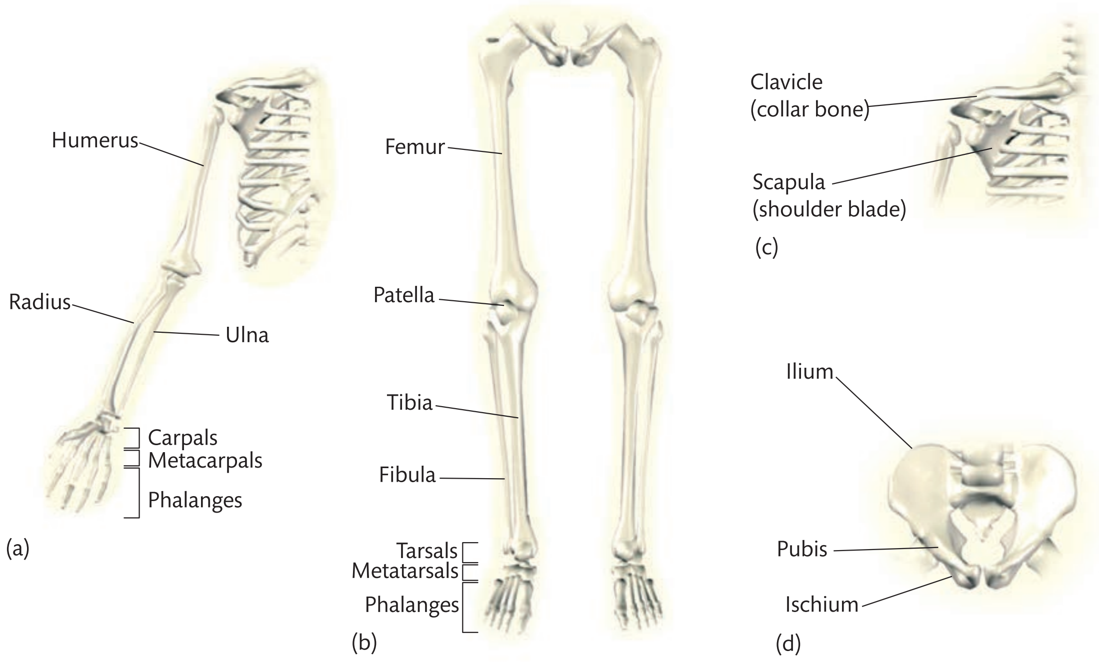


Figure 1.4: The appendicular skeleton: (a) the upper limbs, (b) the lower limbs, (c) the shoulder girdle and (d) the pelvic girdle

The spine or vertebral column

The vertebral column is commonly known as the spine or backbone and extends from the base of the cranium to the pelvis, providing a central axis for the body. It is made up of 33 irregular bones called **vertebrae**.

The vertebral column accounts for around 40 per cent of a person's overall height. The vertebrae are held together by powerful **ligaments**. These allow little movement between adjacent vertebrae but a considerable degree of flexibility along the spine as a whole.

The vertebral column can be classified into five sections or regions (see Figure 1.3(c)):

- **cervical vertebrae** – the seven vertebrae of the neck. The first two are known as the atlas (C1) and the axis (C2). They form a pivot joint that allows the head and neck to move freely. They are the smallest and most vulnerable vertebrae of the vertebral column.
- **thoracic vertebrae** – the 12 vertebrae of the mid-spine, which articulate with the ribs. They lie in the thorax, a dome-shaped structure that protects the heart and lungs.
- **lumbar vertebrae** – the five largest of the movable vertebrae, situated in the lower back. They support more weight than other vertebrae and provide attachment for many of the muscles of the back. The discs between these vertebrae produce a **concave** curve in the back.
- **sacral vertebrae** – the five sacral vertebrae are fused together to form the **sacrum**, a triangular bone located below the lumbar vertebrae. It forms the back wall of the pelvic girdle, sitting between the two hip bones. The upper part connects with the last lumbar vertebra and the bottom part with the coccyx.
- **coccygeal vertebrae** – at the bottom of the vertebral column there are four coccygeal vertebrae, which are fused together to form the **coccyx** or tail bone.

Key terms

Ligaments – short bands of tough and fibrous flexible tissue that hold bones together.

Concave – having an outline or surface that curves inwards.

Key term

Intervertebral discs – fibrocartilaginous cushions that act as the spine's shock absorbing system and prevent injury to the vertebrae and brain.

The vertebral column has many functions. It protects the spinal cord and supports the ribcage. The larger vertebrae of the lumbar region support a large amount of body weight. The flatter thoracic vertebrae offer attachment for the large muscles of the back. These, along with the **intervertebral discs**, receive and distribute impact associated with sporting performance, reducing shock.

Postural deviations

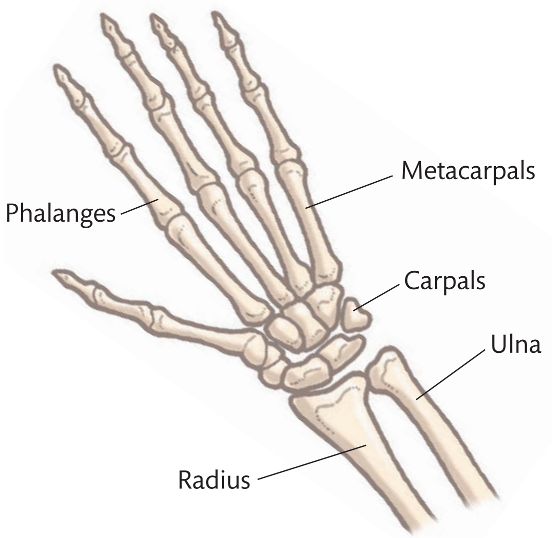
The 33 vertebrae of the spine have a distinctive shape when stacked on top of one another. The normal shape consists of a curve in the cervical (neck), thoracic (mid back) and lumbar (low back) regions when viewed from the side. A **neutral spine** refers to a good posture with the correct position of the three natural curves. When viewing the spine from the front (anterior), it should be completely vertical. Occasionally the spine may suffer from disorders which can cause the natural curves to change.

- **Kyphosis** – the excessive outward curve of the thoracic region of the spine resulting in a 'hunchback' appearance. This is often caused by poor posture but can be caused by deformities of the vertebrae.
- **Scoliosis** – the abnormal curvature of the spine either to the left or to the right (lateral curvature). Most likely to occur in the thoracic region. Often found in children but can be found in adults. This condition is not thought to be linked to bad posture and the exact reasons for it are unknown, although it seems to be inheritable.

Major bones of the skeletal system

The skeletal system includes the following bones.

- **Cranium** – this box-like cavity (space) consists of interlinking segments of bone that are fused together. The cranium contains and protects the brain.
- **Clavicles** – these are commonly known as the collar bones and are the long, slim bones that form the anterior part of the shoulder girdle. This provides a strong attachment for the arms.
- **Ribs** – there are 12 pairs of ribs and they form part of the **thoracic cage**. The first seven pairs are attached to the sternum (see below) and are known as true ribs; the remaining five pairs are known as false ribs as they do not attach to the sternum. The ribs are long, flat bones.
- **Sternum (breast bone)** – this is the elongated, flat bone that runs down the centre of the chest and forms the front of the thoracic cage. Seven pairs of ribs are attached to the sternum, which provides protection and muscular attachment.
- **Scapula** (plural: scapulae) – commonly known as the **shoulder blades**, these large, triangular, flat bones form the posterior part of the shoulder girdle.
- **Humerus** – this is the long bone of the upper arm and is the largest bone of the upper limbs. The head of the humerus articulates (joins) with the scapula to form the shoulder joint. The distal end articulates with the radius and ulna to form the elbow joint.
- **Radius and ulna** – the ulna is the longer of the two bones of the forearm. The ulna and radius articulate distally (see Table 1.2) with the wrist.
- **Carpals** – these are the eight small bones that make up the wrist. They are irregular, small bones arranged in two rows of four. They fit closely together and are kept in place by ligaments.

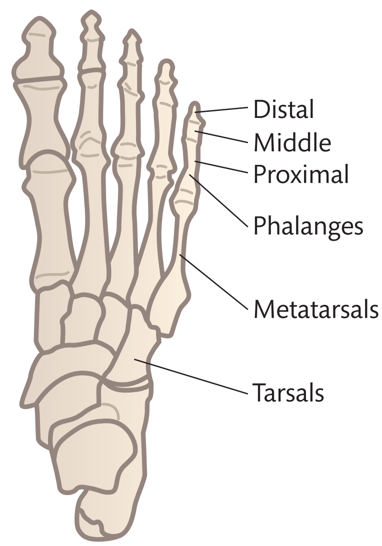


▶ **Figure 1.5:** The bones of the wrist and hand

- **Metacarpals** – five long bones in the palm of the hand, one corresponding to each digit (finger or thumb). These run from the carpal bones of the wrist to the base of each digit in the hand.
- **Phalanges** – the bones that make up the thumbs, fingers and toes. Most fingers and toes have three phalanges, but the thumbs and big toes have two.
- **Pelvis** – the pelvis is made up of two hip bones which in turn consist of three sections (**ilium**, **ischium** and **pubis**) which fuse together during puberty to form one bone. The ilium structure provides the socket for the ball and socket joint (see Figure 1.8) of the femur, allowing the legs to be attached to the main skeleton.
- **Femur** – the longest and strongest bone in the body, sometimes referred to as the **thigh bone**. The head fits into the socket of the pelvis to form the hip joint; the lower end joins the tibia to form the knee joint.
- **Patella (kneecap)** – the large, triangular sesamoid bone found in the quadriceps femoris **tendon**. It protects the knee joint.
- **Tibia and fibula** – the long bones that form the lower leg. The tibia is the inner and thicker bone, also known as the **shin bone**. The upper end of the tibia joins the femur to form the knee joint, while the lower end forms part of the ankle joint. The fibula is the outer, thinner bone of the lower leg; it does not reach the knee, but its lower end does form part of the ankle joint.
- **Tarsals** – along with the tibia and fibula, seven bones known collectively as the tarsals form the ankle joint including the heel. The calcaneus, or heel bone, is the largest tarsal bone. It helps to support the weight of the body and provides attachment for the calf muscles via the Achilles tendon. The tarsals are short and irregular bones.
- **Metatarsals** – there are five metatarsals in each foot; they are located between the tarsals and the phalanges (toes). Each metatarsal has a similar structure, with a distal and proximal head joined by a thin shaft (body). The metatarsals are responsible for bearing a great deal of weight, and they balance pressure through the balls of the feet. The metatarsals are a common site of fracture in sport.

Key term

Tendon – strong fibrous tissue that attaches muscle to bone.



▶ **Figure 1.6:** The bones of the foot

PAUSE POINT Can you name the main bones of the skeleton and state where they are located?

Hint Consider a sport of your choice and identify the bones that are used in the main actions involved in that sport.

Extend How could understanding how these bones work affect your performance in sport? For each action you identified, explain the functions of the listed bones.

Process of bone growth

Bone is a living organ that is continuously being reshaped through a process called remodelling. **Ossification** is the process in which bones are formed. Throughout this process parts of the bone are reabsorbed so that unnecessary **calcium** is removed (via cells called **osteoclasts**) while new layers of bone tissue are created.

The cells that bring the calcium to your bones are known as **osteoblasts** and are responsible for creating bone matter. Osteoblast activity increases when you exercise, so your bones will become stronger the more exercise you do. This means your bone calcium stores increase to cope with the demand for calcium, so exercising also reduces the risk of osteoporosis. Activities that can build stronger bones include tennis, netball, basketball, aerobics, walking and running.

The ends of each long bone contain growing areas – or plates – which allow the bone to grow longer. This continues throughout childhood until they reach full maturity. These areas are called the **epiphyseal plates** and allow the long bones to extend. Once a long bone is fully formed, the head – or end of each bone – fuses with the main shaft (diaphysis) to create the **epiphyseal line**.

Key term

Calcium – a mineral essential for bone growth and found in a wide range of foods including milk, cheese, yoghurt, nuts, broccoli and beans.

Function of the skeletal system

Your skeleton has a number of important functions both in sport and in everyday life. When performing sport or exercise there are eight main functions.

- **Support** – collectively, your bones give your body shape and provide the supporting framework for the soft tissues of your body.
- **Protection** – the bones of your skeleton surround and protect vital tissues and organs in your body. Your skull protects your brain, your heart and lungs are protected by your thorax, your vertebral column protects your delicate spinal cord, and your pelvis protects your abdominal and reproductive organs.
- **Attachment for skeletal muscle** – parts of your skeleton provide a surface for your skeletal muscles to attach to, allowing you to move. Tendons attach muscles to bone, providing leverage. Muscles pulling on bones act as levers, and movement occurs at the joints so that you can walk, run, jump, kick, throw etc. Type of joint (see page 12) determines the type of movement possible.
- **Source of blood cell production** – your bones are not completely solid, as this would make your skeleton heavy and difficult to move. Blood vessels feed the centre of your bones, and stored within the bones is **bone marrow**. The marrow of your long bones is continually producing red and white blood cells. This is an essential function as large numbers of blood cells, particularly red cells, die every minute.
- **Store of minerals** – bone is a reservoir for minerals such as calcium and phosphorus, which are essential for bone growth and the maintenance of bone health. These minerals are stored and released into the bloodstream as required, balancing the minerals in your body.

- **Leverage** – the bones provide a lever system against which muscles can pull to create movement.
- **Weight bearing** – your bones are very strong and will support the weight of your tissue including muscles. During sport large forces are applied to your body, and your skeleton provides the structural strength to prevent injury.
- **Reducing friction across joints** – the skeleton has many joints of different types. Synovial joints secrete fluid that prevents bones from rubbing together, reducing friction between the bones.

Main function of different bone types

The bones in your body have many different functions, depending on their shape and location. Consider the bones of the arms and legs and how they are used in sport. In conjunction with your muscles, these long bones can produce large movements such as kicking or throwing as the long bones act like levers. The flat bones of the body are also important in sport as they can provide protection from impact, ensuring your vital organs remain functioning. Look at Table 1.3 for examples of the different bones and their main functions.

Table 1.3: Function of different bones types

Type of bone	Function	Examples
Long	Movement, support, red blood cell production	Femur, humerus, tibia, radius, ulna
Short	Fine or small movements; shock absorption, stability, weight bearing	Carpals, tarsals
Flat	Attachment for muscles; protection	Sternum, scapula, pelvis, cranium
Sesamoid	Protection; reduction of friction across a joint	Patella, pisiform (wrist)
Irregular	Protection (spinal cord); movement	Vertebrae

PAUSE POINT What are the main functions of the skeleton? Why are these important in sport and exercise?

Hint Write down the main functions of the axial skeleton and the appendicular skeleton.

Extend Consider a sporting action. What are the roles of the axial and appendicular skeleton in this action?

Joints

You have seen that your skeleton is made up of bones that support and protect your body. For movement to occur, the bones must be linked. A joint is formed where two or more bones meet. This is known as an **articulation**. The adult human body contains around 350 joints, which can be classified in different ways depending on their structure.

The bones of the shoulder are shown in Figure 1.4(c) on page 7 and the bones of the hip, knee and ankle are shown in Figure 1.4(b). The structure and movement of the vertebrae are described on pages 7–8 under the heading 'The spine or vertebral column'.

Key term

Articulation – where two or more bones meet.

Classification of joints

There are three types of joint, classified according to the degree of movement they allow:

- fixed
- slightly movable
- synovial.

Fixed joints

Fixed joints, or **fibrous** or **immovable joints**, do not move. Fixed joints form when the bones interlock and overlap during early childhood. These joints are held together by bands of tough, fibrous tissue and are strong with no movement between the bones. An example is between the bone plates in your cranium, which are fixed together to provide protection for your brain.

Slightly movable joints

Slightly movable or **cartilaginous joints** allow slight movement. The ends of the bone are covered in a smooth, shiny covering, known as articular or hyaline cartilage, which reduces friction between the bones. The bones are separated by pads of white fibrocartilage (a tough cartilage that is capable of absorbing considerable loads). Slight movement at these joining surfaces is made possible because the pads of cartilage compress, for example between most vertebrae.

Synovial joints

Synovial joints or **freely movable joints** offer the highest level of mobility at a joint and are vital to all sporting movements. Most of the joints in your limbs are synovial.

A synovial joint (see Figure 1.7) consists of two or more bones, the ends of which are covered with articular cartilage, which allows the bones to move over each other with minimum friction. Synovial joints always have a synovial cavity or space between the bones. This cavity is completely surrounded by a fibrous capsule, lined with a synovial membrane, whose purpose is to release or secrete fluid known as synovial fluid into the joint cavity. This lubricates and nourishes the joint. The joint capsule is held together by tough bands of connective tissue known as ligaments. These ligaments provide the strength to avoid dislocation, while being flexible enough to allow a wide range of movement.

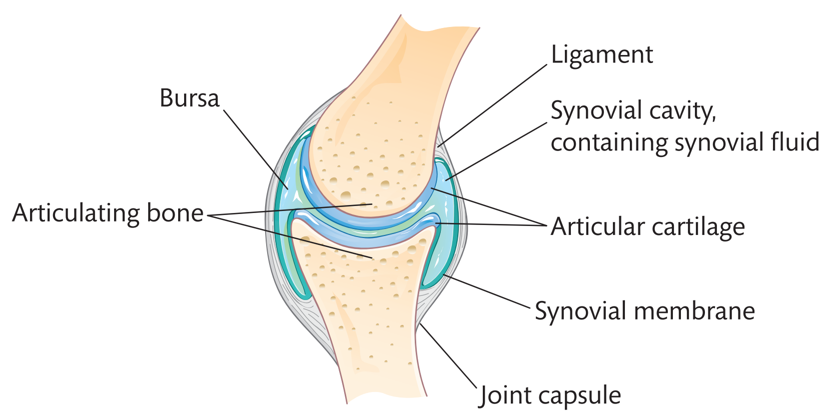


Figure 1.7: A synovial joint

All synovial joints contain the following features.

- A **joint capsule** or fibrous capsule - an outer sleeve to help to hold the bones in place and protect the joint. This capsule will also contain the main structure of the synovial joint.

- A **bursa** – a small fluid-filled sac which provides a cushion between the tendons and the bones, preventing friction. Bursae are filled with synovial fluid.
- **Articular cartilage** on the ends of the bones – provides a smooth and slippery covering to stop the bones rubbing or grinding together.
- A **synovial membrane** – the capsule lining that releases synovial fluid.
- **Synovial fluid** – a viscous (thick) liquid that lubricates the joint and reduces the friction between the bones, preventing them from rubbing together. Synovial fluid also provides nutrients to the articular cartilage.
- **Ligaments** – hold the bones together and keep them in place.

Types of synovial joint

There are six types of synovial joint, categorised according to their structure and the movements they allow. These joints will permit specific movements and, combined, will allow you to perform complex techniques such as a somersault or a tennis serve.

- **Hinge** – These allow movement in one direction only (similar to the hinge of a door). Elbow and knee joints are typical examples and only allow movements forwards and backwards. Exercise examples include running with the knee bending or a bicep curl.
- **Ball and socket** – The round end of one bone fits into a cup-shaped socket in the other bone, allowing movement in all directions. Examples include hip and shoulder joints, used in running and in throwing an object such as a javelin.
- **Condyloid** – Also known as ellipsoidal joints. These are similar to ball and socket joints, in which a bump (condyle) on one bone sits in the hollow formed by another. Movement is backwards and forwards and from side to side. Ligaments often prevent rotation. An example of a condyloid joint in action is during a basketball game when a player is dribbling or bouncing the ball, with the wrist being used to create this action.
- **Gliding** – These joints allow movement over a flat surface in all directions, but this movement is restricted by ligaments or a bony prominence, for example in the carpals and tarsals of wrists and ankles. This can be seen in a netball jump with the foot pointing downwards.

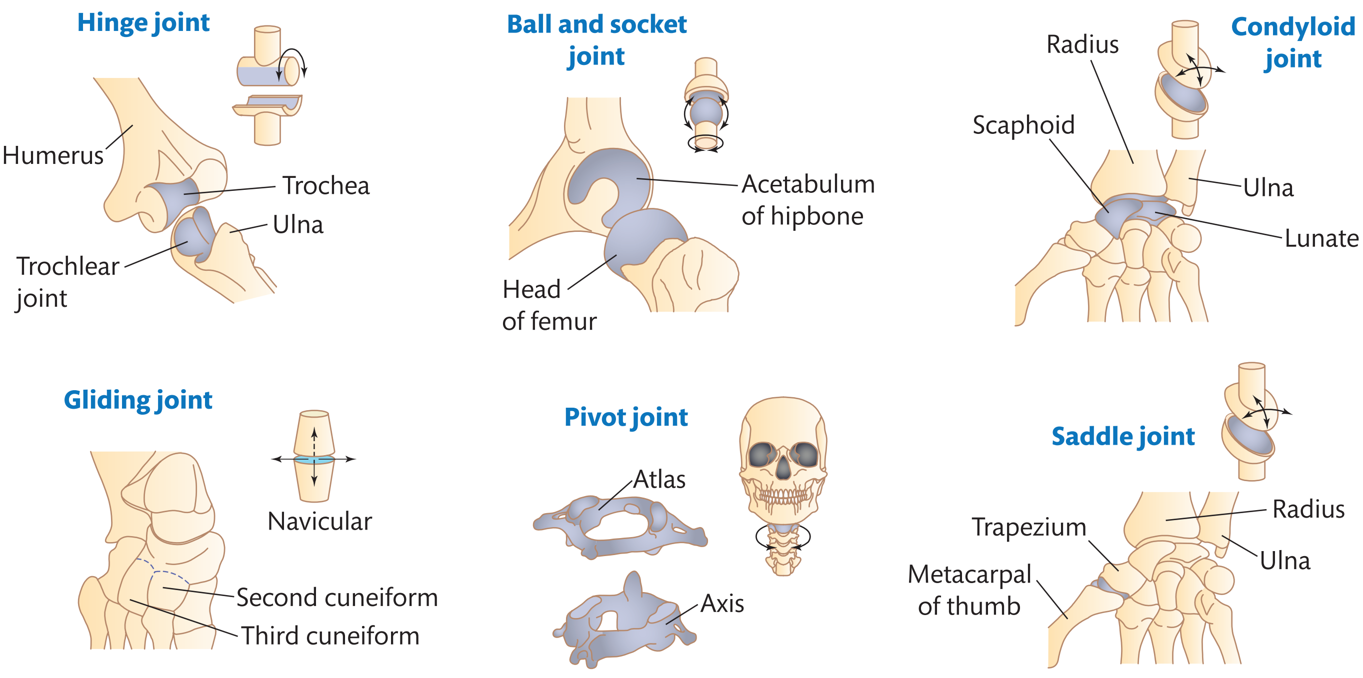


Figure 1.8: Types of synovial joint

Key terms

Concave – where the bone curves or is hollowed inwards.

Convex – where the bone curves outwards.

- **Pivot** – A circular bone fits over a peg of another bone, allowing controlled rotational movement, such as the joint of the atlas and axis in the neck. This joint allows you to turn your head from side to side. When you turn your head in sport you will be using a pivot joint.
- **Saddle** – These are similar to condyloid joints but the surfaces are **concave** and **convex**. The joint is shaped like a saddle with the other bone resting on it like a rider on a horse. Movement occurs backwards and forwards and from side to side, such as at the base of the thumb. You would use a saddle joint when gripping a racket in tennis or squash.

PAUSE POINT What are the different types of joint? Can you identify the location of each of these types of joint?

Hint Describe the location of each of the synovial joints in the body.

Extend Draw a synovial joint, labelling the main structural features.

Key terms

Flexibility – the range of movement around a joint or group of joints.

Soft tissue – the tissue that connects, supports and surrounds structures such as joints or organs. It includes tendons, ligaments, skin, fat and muscles.

The range of movements at synovial joints

The type of movement that each synovial joint allows is determined by its structure and shape. Sporting techniques usually use a combination of different joints to allow a wide range of movement or techniques. For example, a cricketer bowling a ball will use joints in the fingers (phalanges), wrist, elbow and shoulder. They will also use the joints of the foot, ankle, knee and hip when running.

It is important when studying sports performers in action that you are able to break down these techniques and identify the specific movements at each joint. A coach will often analyse the movements produced by an athlete in order to improve technique, and it is common to see movements filmed and analysed in detail using computer software.

The range of motion is the amount of movement at a joint and is often referred to as joint **flexibility**. Flexibility will also depend on a number of factors including age, the tension of the supporting connective tissues (tendons) and muscles that surround the joint, and the amount of **soft tissue** surrounding the joint.

The following movements are common across a wide range of sports and are important when performing sport and exercise techniques.

Cricketers use a large number of joints and movements when bowling

- **Flexion** – reducing the angle between the bones of a limb at a joint: muscles contract, moving the joint into a bent position. Examples include bending your arm in a bicep curl action or bending the knee when preparing to kick a football.
- **Extension** – straightening a limb to increase the angle at the joint, such as straightening your arm to return to your starting position in a bicep curl action or the kicking action when taking a penalty in football with the knee straightening.
- **Dorsiflexion** – an upward movement, as in moving the foot to pull the toes towards the knee in walking.
- **Plantar flexion** – a movement that points the toes downwards by straightening the ankle. This occurs when jumping to shoot in netball.
- **Lateral flexion** – the movement of bending sideways, for example at the waist.
- **Horizontal flexion** and **horizontal extension** – bending the elbow (flexion) while the arm is in front of your body; straightening the arm at the elbow is **extension**.

- **Hyper-extension** – involves movement beyond the normal anatomical position in a direction opposite to flexion. This occurs at the spine when a cricketer arches his or her back when approaching the crease to bowl.
- **Abduction** – movement away from the body's vertical midline, such as at the hip in a side-step in gymnastics.
- **Adduction** – movement towards the body's vertical midline, such as pulling on the oars while rowing.
- **Horizontal abduction and adduction** – this is the movement of bringing your arm across your body (flexion) and then back again (extension).
- **Circumduction** – this is a circular movement that results in a conical action.
- **Rotation** – circular movement of a limb. Rotation occurs at the shoulder joint during a tennis serve.

Reflect

Think about a common sporting movement such as a javelin throw. Consider the movement at each joint and identify the type of action that is occurring.

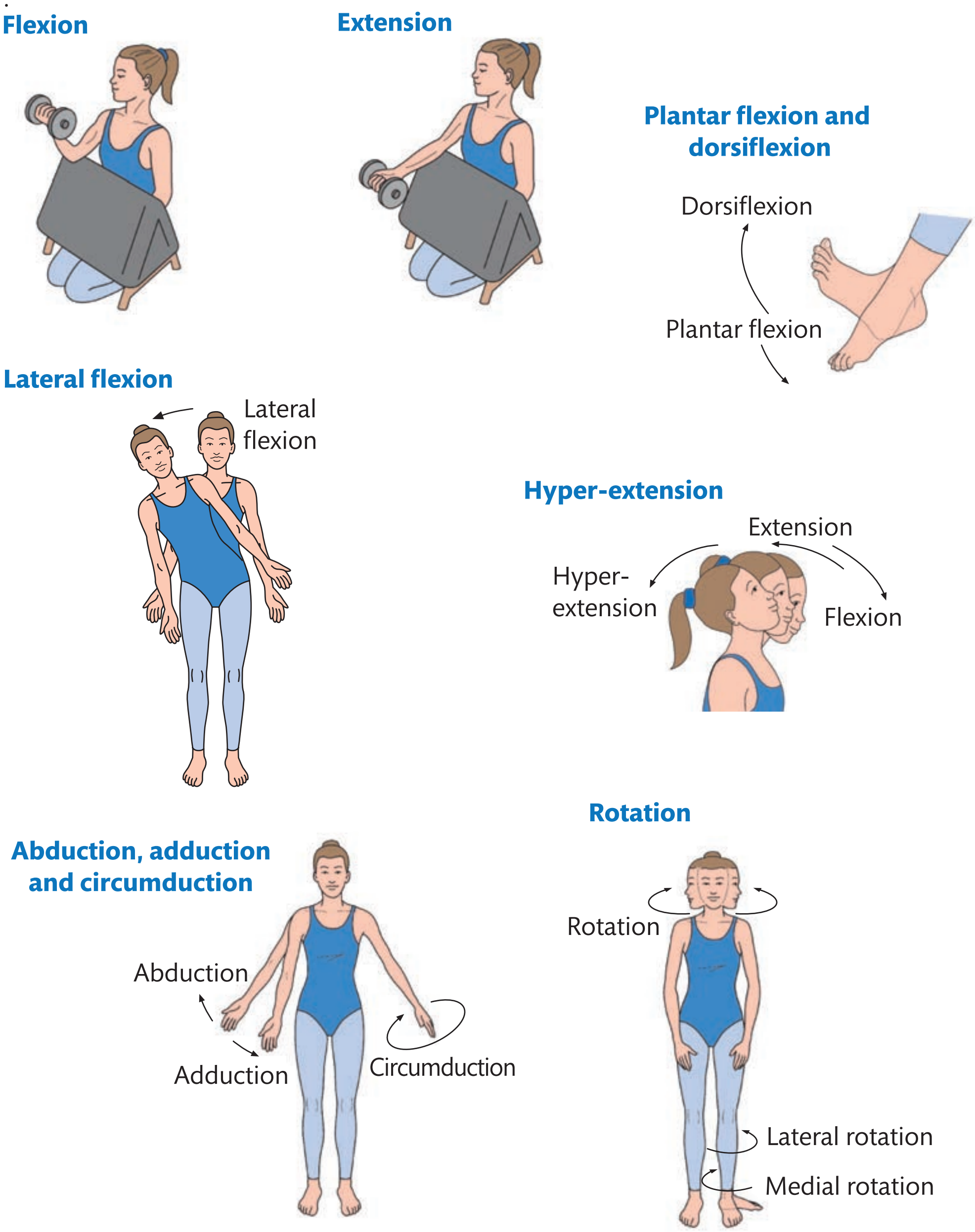


Figure 1.9: Anatomical and biomechanical terms relating to muscle action

Case study

Many sporting movements look complex but in reality they can be viewed and analysed as separate, smaller movements. It is commonplace for modern coaches to use video equipment to film specific techniques so that the series of movements can be analysed and discussed with the athlete.

Consider the action of throwing a ball. You will use a number of different joints including the ball and socket joint of the shoulder, the hinge joint of the elbow and the gliding joints of the wrist (carpals). In combination with the skeletal muscles, you will be able to use the long bones as levers to produce a large powerful movement in order to throw the ball.

Now consider a tennis serve and the joint actions used. How are these similar to the action of throwing a ball? Many different sporting techniques will use similar joint actions and muscles that are refined to meet the needs of the specific sporting technique.

Check your knowledge

1 Can you think of any other sporting techniques that are similar?

2 What sports share the same movements?

3 How would a PE teacher or coach benefit from being able to identify different and identical sporting movements?

Responses of the skeletal system to a single sport or exercise session

You are probably aware that during exercise your heart rate and breathing rate increase, but did you know that your skeletal system will also respond to exercise? This is sometimes overlooked as the changes are small and out of sight. When you exercise or take part in sport your body's systems will adapt almost instantaneously so that your body is prepared for the additional stresses that will be put on it. This is one of the reasons why you should always complete a well-planned and performed warm-up before starting any physical activity.

Your skeletal system will respond to exercise in the short term by producing more synovial fluid in the synovial joints. This is so that the joints are lubricated and can protect the bones during the increased demands that exercise puts on the skeleton and joints. The fluid will also become less **viscous** and the range of movement at the joint will increase. The release of synovial fluid from the synovial membrane will also provide increased nutrients to the articular cartilage.

Another **acute response** to exercise is the increased uptake of minerals within the bones. Just as muscles become stronger the more you use them, a bone becomes stronger and denser when you regularly place exercise demands upon it. The body will absorb minerals such as calcium which will increase your bone mineral density. This is especially important for weight bearing exercises such as bench pressing. When more stress and force is applied to the bones they must be strong enough to cope with these increased demands.

Key terms

Viscous – describes how thick a fluid is. If synovial fluid is too thick then it will be hard to move the joint.

Acute responses – when the body makes an immediate change or response; **chronic responses** are the opposite and take place over a longer period of time.

Adaptations of the skeletal system to exercise

Your body responds to the stress of exercise or physical activity in a variety of ways. Some of these are immediate and are often referred to as acute responses to exercise. Others are long-term, and are often referred to as **chronic responses** or adaptations that contribute to improved fitness for sports participation and reduced health risk.

Like other systems of the body, the skeletal system will adapt to exercise. Exercise will increase your bone mineral density and over time this will result in stronger bones which will be more resistant to the forces found in sport such as kicking, jumping or running.

Long-term physical activity will also increase the strength of the ligaments which attach your bones together at synovial joints. When you exercise as part of a training programme, your ligaments will stretch a little further than normal and as a result will become more pliable over time, resulting in increased flexibility.

PAUSE POINT When you exercise, what are the immediate responses your body makes?

Hint Think about your warm-up before exercise. What happens to your body and why?

Extend Research and draw up a list of the changes that occur in the skeletal system and explain why they happen during exercise.

Additional factors affecting the skeletal system

The benefits of taking part in regular exercise or physical activity are huge. People who take part in regular exercise are more likely to live longer and are less likely to develop serious diseases. Exercise should be part of a healthy lifestyle and it is common to hear about the benefits of physical activity in preventing heart disease and controlling weight. Regular exercise can also help common skeletal diseases such as arthritis and osteoporosis.

Arthritis

Arthritis is a condition where there is an inflammation within a synovial joint, causing pain and stiffness in the joint. The most common type of arthritis is osteoarthritis. This is caused by general wear and tear over a long period of time. This reduces the normal amount of cartilage tissue, which may result in the ends of the bones rubbing together. This natural breakdown of cartilage tissue can be made worse by injury to the joint.

However, regular exercise can prevent arthritis. During physical activity your joints will produce more synovial fluid which will not only improve the joint lubrication, reducing friction between the bones, but will also provide important minerals to the cartilage. Exercises such as stretching will also improve the joint range of motion, lengthen the ligaments holding the bones in place and improve flexibility.

Osteoporosis

Osteoporosis is the weakening of bones caused by a loss in calcium or a lack of **vitamin D**. As you get older your bones slowly lose their mineral density and naturally become brittle, fragile and more likely to break under stress. However, physical activity and exercise can help prevent osteoporosis by promoting increased uptake of minerals within the bones, resulting in an increase in bone mineral density. Resistance training is a good method of preventing osteoporosis, as overloading the skeleton will increase bone density.

Age

The skeletal system is a living tissue that is constantly growing and repairing itself so that it can provide support and protection. Generally, exercise and sports will benefit you. The exception to this is resistance training (weight training) in children, as this can cause more harm than good. The reason for this is that a child's bones are still growing and putting too much force on them can damage the epiphyseal plates which are found at each end of the long bones. Damage to these plates during childhood and puberty can result in stunted bone growth.

Key term

Vitamin D – is used to regulate the amount of calcium in the body and is produced from sunlight on our skin; it is created under the skin. Small amounts of vitamin D can also be found in oily fish and eggs.

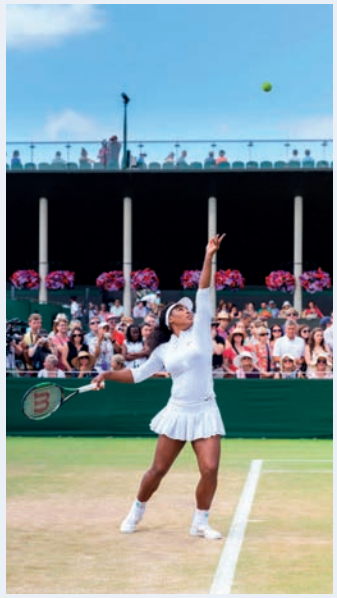
Assessment practice 1.1

1 Explain how the bones of the skeleton are used in movement for sport. **(2 marks)**

2 Jack has the first stages of osteoporosis. He has been advised to take part in exercise to help prevent this condition from worsening. Identify one type of exercise that Jack could take part in to prevent the osteoporosis from getting worse. **(1 mark)**

3 Explain why weight bearing exercises will prevent osteoporosis from getting worse. **(3 marks)**

4 Analyse how movement at the synovial joints in the upper skeleton allows a tennis player to serve the ball as shown in the picture. **(6 marks)**



Plan

- What is the question asking me to do? Do I need to give sporting examples?
- What are the key words that I will need to include relating to the skeletal system?

Do

- I will write down the key terms that need to be included in each answer.
- I will ensure that I have given sufficient examples relating to the number of marks available.

Review

- I will check my answer. Is it clear? Do I give suitable examples?

B The effects of exercise and sports performance on the muscular system

There are over 640 named muscles in the human body and these make up approximately 40 per cent of your body mass. The muscles that move your bones during activity are called **skeletal muscles**. In this section you will learn about the principal skeletal muscles, their associated actions, and muscle fibre types. This section also looks at the different types of muscles and their specific functions, as well as the responses and adaptations of the muscular system to sport or exercise.

Characteristics and functions of different types of muscle

There are three main types of muscle tissue in the human body.

- **Skeletal muscle** – also known as striated or striped muscle because of its striped appearance when viewed under a microscope, this type of muscle is voluntary, which means it is under conscious control. Skeletal muscles are critical to sport and exercise as they are connected to the skeletal system via tendons and are primarily responsible for movement. Skeletal muscles contract and, as a result, pull on your bones to create movement. They can become fatigued during exercise. Skeletal muscles are explored in more depth from page 19.
- **Cardiac muscle** – this type of muscle tissue is only found in the wall of your heart. It works continuously. It is involuntary, which means it is not under conscious control. It is composed of a specialised type of striated tissue that has its own blood supply. Its contractions help to force blood through your blood vessels to all parts of your body. Each contraction and relaxation of your heart muscle as a whole represents one heartbeat. The cardiac muscle does not fatigue, which means that it does not get tired during exercise.

- **Smooth muscle** – an involuntary muscle that works without conscious thought, functioning under the control of your nervous system. It is located in the walls of your digestive system and blood vessels and helps to regulate digestion and blood pressure.

Discussion

In small groups, compare the different types of muscle tissue and their function. Discuss the importance of each of function in relation to the characteristics of the muscle.

Major skeletal muscles of the muscular system

Skeletal muscles are voluntary muscles which means that they are under your control. For example, you must send a conscious signal from your brain to your muscles to perform any sporting action. Skeletal muscles are attached to your skeleton by tendons which pull on specific bones when a muscle contracts. Skeletal muscles not only provide you with movement, strength and power but are also responsible for maintaining posture and generating heat which maintains your normal body temperature.

It can be difficult to remember the names, location and function of all the major skeletal muscles in the body. Figure 1.10 and Table 1.4 will help you to locate the main ones which are important to sport and exercise. You should be able to identify the main muscles used when performing common movements such as a kick in rugby, a tennis serve or a simple exercise such as a press-up.

Table 1.4: Major skeletal muscles and their function

Muscle	Function	Location	Origin	Insertion	Exercise/activity
Triceps	Extends lower arm	Outside upper arm	Humerus and scapula	Olecranon process	Dips, press-ups, overhead pressing
Deltoids	Abducts, flexes and extends upper arm	Forms cap of shoulder	Clavicle, scapula and acromion	Humerus	Forward, lateral and back-arm raises, overhead lifting
Pectorals	Flexes and adducts upper arm	Large chest muscle	Sternum, clavicle and rib cartilage	Humerus	All pressing movements
Biceps	Flexes lower arm at elbow	Front of upper arm	Scapula	Radius	Bicep curl, pull-ups
Wrist flexors	Flexes hand at wrist	Front of forearm	Humerus	Metacarpal	Bouncing a basketball when dribbling
Wrist extensors	Extends or straightens hand at wrist	Back of forearm	Humerus	Metacarpal	Straightening of wrist
Supinators	Supinate forearm	Top and rear of forearm	Humerus	Ulna	Back spin in racket sports, spin bowl in cricket
Pronators	Pronate forearm	Top and front of forearm	Humerus	Ulna	Top spin in racket sports, spin bowl in cricket

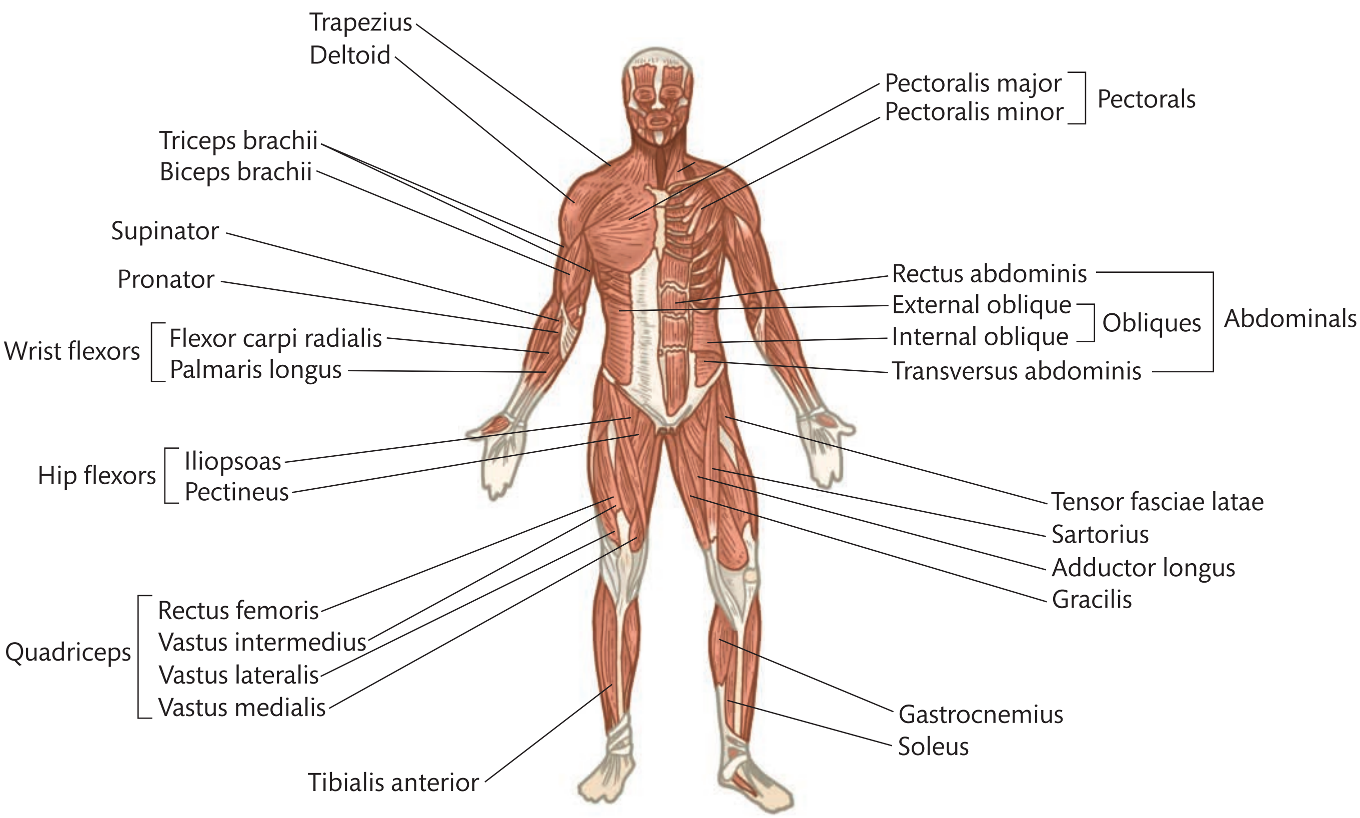
Table 1.4: Major skeletal muscles and their function – *continued*

Muscle	Function	Location	Origin	Insertion	Exercise/activity
Abdominals	Flex and rotate lumbar region of vertebral column	'Six-pack' muscle running down abdomen	Pubic crest and symphysis	Xiphoid process	Sit-ups
Hip flexors	Flex hip joint (lifting thigh at hip)	Lumbar region of spine to top of thigh (femur)	Lumbar vertebrae	Femur	Knee raises, lunges, squat activation
Quadriceps • rectus femoris • vastus lateralis • vastus medialis • vastus intermedius	Extends lower leg and flexes thigh	Front of thigh	Ilium and femur	Tibia and fibula	Squats, knee bends
Hamstrings • semimembranosus • semitendinosus • biceps femoris	Flexes lower leg and extends thigh	Back of thigh	Ischium and femur	Tibia and fibula	Leg curls, straight leg deadlift
Gastrocnemius	Plantar flexion, flexes knee	Large calf muscle	Femur	Calcaneus	Running, jumping and standing on tip-toe
Soleus	Plantar flexion	Back of lower leg	Fibula and tibia	Calcaneus	Running and jumping
Tibialis anterior	Dorsiflexion of foot	Front of tibia on lower leg	Lateral condyle	By tendon to surface of medial cuneiform	All running and jumping exercises
Erector spinae	Extension of spine	Long muscle running either side of spine	Cervical, thoracic and lumbar vertebrae	Cervical, thoracic and lumbar vertebrae	Prime mover of back extension
Teres major	Rotates and abducts humerus	Between scapula and humerus	Posterior surface of scapula	Intertubercular sulcus of humerus	All rowing and pulling movements, face pulls, bent over rows
Trapezius	Elevates and depresses scapula	Large triangular muscle at top of back	Continuous insertion along acromion	Occipital bone and all thoracic vertebrae	Shrugging and overhead lifting
Latissimus dorsi	Extends and adducts lower arm	Large muscle covering back of lower ribs	Vertebrae and iliac crest	Humerus	Pull-ups, rowing movements
Obliques	Lateral flexion of trunk	Waist	Pubic crest and iliac crest	Fleshy strips to lower eight ribs	Oblique curls
Gluteals	Extends thigh	Large muscle on buttocks	Ilium, sacrum and coccyx	Femur	Knee-bending movements, cycling, squatting

PAUSE POINT What are the different muscle types?

Hint List the characteristics and functions of each muscle type.

Extend Explain the importance of the different types of muscle to sport and exercise.



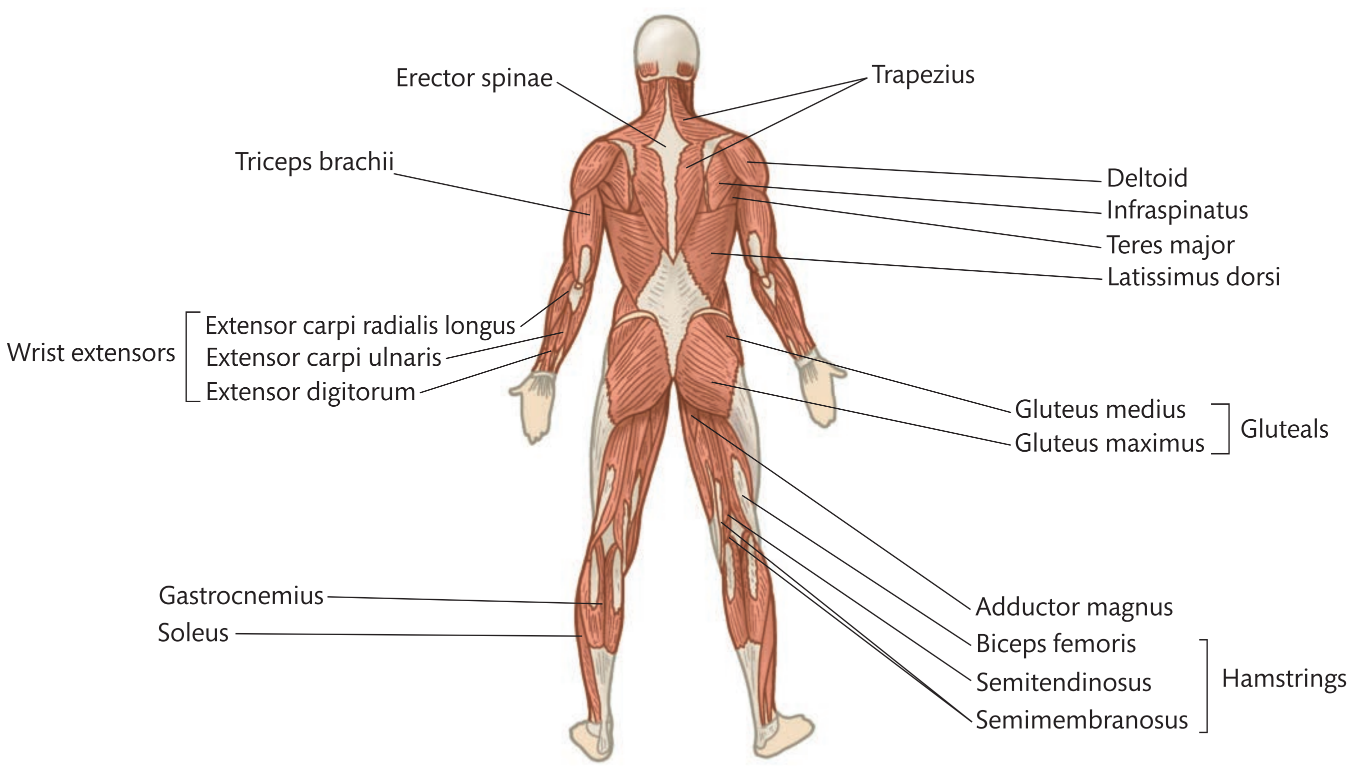


Figure 1.10: Major skeletal muscles and their location

Antagonistic muscle pairs

When a muscle contracts, it exerts a pulling force on the bones to which it is attached, causing them to move together around the joint. Muscles must cross the joints that they move. If a muscle did not cross a joint, no movement could occur.

Under normal circumstances, muscles are in a state of partial contraction, ready to react to a stimulus from your nervous system. When a stimulus from the nerve supply occurs, muscle fibres work on an 'all or nothing' basis – either contracting completely or not at all. At the point of contraction your muscles shorten and pull on the bones to which they are attached. When a muscle contracts, one end normally remains stationary while the other end is drawn towards it. The end that remains stationary is known as the **origin**, and the end that moves is called the **insertion**.

Key terms

Origin – the fixed end of the muscle that remains stationary.

Insertion – the end of the muscle that moves. The insertion normally crosses over a joint to allow movement when the muscle shortens.

Muscles do not work in isolation. They are assembled in groups and work together to bring about movement. They act only by contracting and pulling. They do not push, although they are able to contract without shortening, and so hold a joint firm and fixed in a certain position. When the contraction ends, the muscles become soft but do not lengthen until stretched by the contraction of the opposing muscles. Many muscles work in antagonistic pairs; for example, Figure 1.11 shows how the bicep and tricep work together to perform a bicep curl.

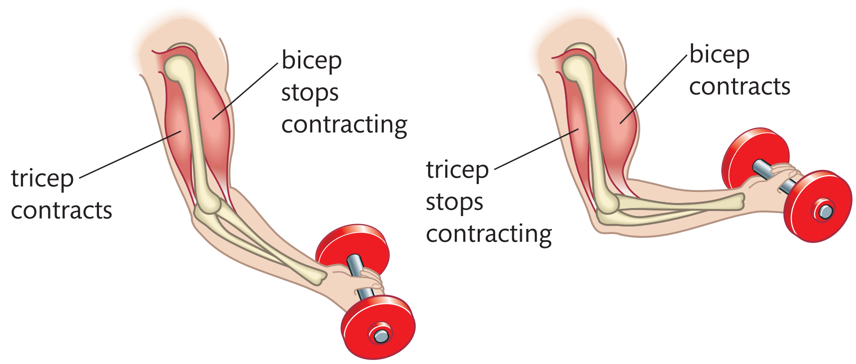


Figure 1.11: Bicep and tricep muscles work together during a bicep curl

Reflect

Consider the main muscle contracting and the opposite muscle relaxing during a movement. What happens when the opposite movement occurs?

The muscle that shortens to move a joint is called the **agonist** or prime mover. This is the muscle principally responsible for the movement taking place – the contracting muscle.

The muscle that relaxes in opposition to the agonist is called the **antagonist**. This is the muscle responsible for the opposite movement, and the one that relaxes as the agonist works. If it did not relax, movement could not take place. Antagonists exert a 'braking' control over the movement.

Synergists are muscles that work together to enable the agonists to operate more effectively. They work with the agonists to control and direct movement by modifying or altering the direction of pull on the agonists to the most advantageous position.

Fixator muscles stop any unwanted movement throughout the whole body by fixing or stabilising the joint or joints involved. Fixator muscles stabilise the origin so that the agonist can achieve maximum and effective contraction.

PAUSE POINT Can you name the main skeletal muscles and where they are located?

Hint Consider a sport and describe the role of the specific muscles in this sport.

Extend Think of a sporting movement and list the pairs of muscles being used for each phase of the movement.

Theory into practice

When your body is in action during sport and exercise, your muscles shorten, remain the same length or lengthen.

1. Using a dumbbell or other suitable resistance weight, bend your forearm upwards so that your elbow bends in a bicep curl action. Consider your bicep muscle. What is happening?
2. Now return your arm to the starting position by slowly lowering the forearm. What is happening to the bicep muscle now? Consider the action of the tricep muscle on the other side of the elbow joint.
3. Consider how these muscles work as a pair. How do these muscles control the movement?

Types of skeletal muscle contraction

There are three different types of muscle contraction which will be used depending on the sporting technique or exercise action.

Isometric

During an isometric contraction the length of a muscle does not change and the joint angle does not alter. However, the muscle is actively engaged in holding a static position. An example is the abdominal plank position. This type of muscle work is easy to undertake but rapidly leads to fatigue. It can cause sharp increases in blood pressure as blood flow is reduced.

Concentric

When you make any movement such as a bicep curl, your muscle will shorten as the muscle fibres contract. In the bicep curl, the brachialis and bicep shorten, bringing your forearm towards your upper arm. Concentric contractions are sometimes known as the **positive phase** of muscle contraction.

Eccentric

An eccentric muscular contraction is when a muscle returns to its normal length after shortening against resistance. Again using the bicep curl as an example, this is the controlled lowering of your arm to its starting position. At this point your muscles are working against gravity and act like a braking mechanism. This contraction can be easier to perform, but it does produce muscle soreness.

Eccentric contractions occur in many sporting and daily activities. Walking downstairs and running downhill involve eccentric contraction of your quadriceps muscles which are used to control the movement. Eccentric contraction can be a significant factor in the stimulus that promotes gains in muscle strength and size. Eccentric contractions are sometimes known as the **negative phase** of muscle contraction.

Discussion

Muscles can only pull on a bone, they can never push. In small groups, discuss a rugby scrum where a pushing force is required. Explain how a pushing force is created when muscles can only pull. What muscles are being used to create this movement?

PAUSE POINT Can you explain the importance of different muscle contractions in sport?

Hint Think of a press-up. Which muscles are working as antagonistic pairs in the shoulder?

Extend What types of contraction are taking place for each phase of a press-up at the shoulder joint?

Fibre types

All skeletal muscles are made up from muscle fibres. These fibres fall into two main categories depending on their speed of contraction: Type I ('slow-twitch') and Type II ('fast-twitch'). The mix of fibres varies from individual to individual, and within the individual from muscle group to muscle group. To a large extent this fibre mix is inherited. However, training can influence the efficiency of the different fibre types.

Key terms

Mitochondria – the organelles (parts of cells) in the body where aerobic respiration takes place.

Aerobic respiration – the process of producing energy using oxygen, where energy is released from glucose.

Anaerobic activity – activity where your body uses energy *without* oxygen; that is, activity that results in muscle cells using anaerobic respiration.

Anaerobic respiration – the process of breaking down glucose without oxygen to produce energy.

Type I

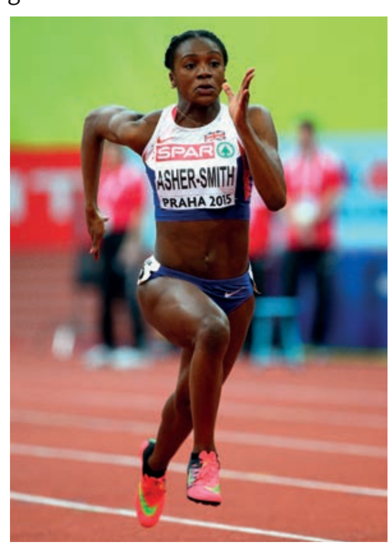
Type I (slow-twitch) fibres contract slowly and with less force. They are slow to fatigue and suited to longer-duration **aerobic** activities. Aerobic activity describes exercise where energy is produced using oxygen. The opposite of this is **anaerobic** activitiy, where movements are produced using energy that has been created without oxygen. Slow-twitch fibres have a rich blood supply and contain many **mitochondria** to sustain aerobic metabolism. Type I fibres have a high capacity for **aerobic respiration**. They are recruited for lower-intensity, longer-duration activities such as long-distance running and swimming.

Type IIa

Type IIa fibres (also called fast-twitch or fast-oxidative fibres) are fast-contracting, able to produce a great force, and are also resistant to fatigue. These fibres are less reliant on oxygen for energy supplied by the blood and therefore fatigue faster than slow-twitch fibres. Type IIa fibres are suited to speed, power and strength activities such as weight training with repeated repetitions (10–12 reps) and fast running events such as the 400 metres.

Type IIx

Type IIx fibres (also called fast-twitch or fast-glycolytic fibres) contract rapidly and have the capacity to produce large amounts of force, but they fatigue more readily, making them better suited to **anaerobic activity**. They depend almost entirely on **anaerobic respiration** and are recruited for higher-intensity, shorter-duration activities. They are important in sports that include many stop-go or change-of-pace activities such as rugby or football.



Sprinters use type IIx fast-twitch fibres

All or none law

For a muscle to contract it must receive a nerve impulse, and this stimulus must be sufficient to activate at least one motor unit which contains the motor neuron (nerve cell) and the attached muscle fibres. Once activated, **all** the muscles fibres within the motor unit will contract and produce a muscle twitch. This is known as the 'all or none' law, as muscle fibres either respond completely (all) or not at all (none).

PAUSE POINT Can you explain how different muscle fibre types affect sport?

Hint List three sports and the types of muscle fibre required for each.

Extend Explain why your chosen sports require these types of fibre and how an athlete can improve their performance by understanding this.

Responses of the muscular system to a single sport or exercise session

When you exercise or take part in sport your muscles will respond in a variety of ways. Some of these responses are immediate and are known as acute responses. Responses that take place over a longer period of time are known as chronic responses.

Discussion

In small groups, list the changes in your body immediately after starting a high-intensity exercise. What is happening to your body? Why? Now think about different sports that require different intensities. How do sportspeople train to meet the demands of these physical activities?

Increased blood supply

The short-term effects of exercise on your muscles include an increase in metabolic activity (the rate at which the muscles produce and release energy so that movement can take place). As a result of this increase in metabolic activity, there is a greater demand for oxygen and glucose in the muscles, which is met by an increase in blood supply. Blood vessels expand or get wider to allow more blood to enter your muscles. This is called **vasodilation**. Blood flow increases significantly to ensure that the working muscles are supplied with the oxygen they need as well as to remove waste products such as carbon dioxide.

Increased muscle temperature

When you exercise you get warmer. This is because your muscles need energy from fuels such as fats and carbohydrates, which are broken down using chemical reactions that produce heat as a waste product. The more you exercise or the harder you train, the more energy your muscles need. This results in more heat being produced. The amount of heat your muscles produce is in direct relation to the amount of work they perform – the harder you work out, the more heat your muscles will produce. This principle is used in a warm-up which prepares your muscles for exercise by slowly increasing their temperature.

Increase muscle pliability

The warming of your muscles during activity makes them more pliable and flexible. Pliable muscles are less likely to suffer from injuries such as muscle strains. An increase in pliability will improve joint flexibility, as warm and pliable muscles are able to stretch further.

Lactate (high intensity exercise)

You may have experienced an uncomfortable burning sensation in your muscles during high-intensity exercise. This is most likely caused by the build-up of **lactic acid** which is a waste product produced during anaerobic exercise. This build-up of acid in the muscle tissue will result in rapid fatigue and will impede muscular contractions if it is not removed quickly.

Micro tears (resistance exercise)

During resistance training such as weight training, your muscles are put under stress to the point that tiny tears occur in the muscle fibres. These micro tears cause swelling in the muscle tissue which causes pressure on the nerve endings and pain. Training improvements will only be made if the body has rest and time to repair these micro tears, making the muscle a little bit stronger than it was before. Proteins are used to repair muscle tissue.

Key term

Eccentric muscle contraction – where a muscle lengthens as it contracts. Such contractions occur when controlling a force or movement.

Delayed onset of muscle soreness

Delayed onset of muscle soreness (or DOMS) is the pain felt in muscles 24–48 hours (typically) after taking part in strenuous exercise. The soreness usually occurs at least a day after exercise and can last up to 3 days. DOMS is caused by the microtears that occur when you exercise, particularly if you are unaccustomed to the intensity of exercise. DOMS is often associated with exercises where **eccentric muscle contraction** has occurred.

PAUSE POINT What are the immediate responses your muscles make when exercising?

Hint Why do these changes happen during exercise?

Extend What aspects of the warm-up are used to prevent muscle injury? Why is a warm-up before exercise important to your muscles?

Adaptations of the muscular system to exercise

Training or exercising regularly over a long period of time will allow your body's muscular system to change and adapt. For example, you will notice that your muscles change in size if you undertake a strength or resistance training programme. Such changes are known as chronic adaptations to exercise.

Hypertrophy occurs when muscles are regularly overloaded

Hypertrophy

Regular resistance training where the muscles are overloaded will increase muscle size and strength. The increase in muscle size is a result of the muscles fibres becoming larger due to increases in protein in the muscle cells; this is known as hypertrophy. The muscle fibres increase in size over time so that they can contract with greater force.

Increased tendon strength

Tendons are tough bands of fibrous connective tissue designed to withstand tension. Like muscles, tendons adapt to the overloading of regular exercise. Ligaments and tendons, the connective tissue structures around joints, will increase in flexibility and strength with regular exercise. Cartilage also becomes thicker.

Increase in number and size of mitochondria

When muscles are overloaded as part of resistance training, the muscle fibres will become bigger (hypertrophy). Within these muscle fibres are tiny structures called mitochondria which are responsible for energy production. Because of the increase in fibre size, there is room for more and larger mitochondria, which results in the muscles being able to produce more aerobic energy which will improve aerobic performance.

Increase in myoglobin stores

Myoglobin is a type of haemoglobin (the red protein found in blood used for transporting oxygen) that is found exclusively in muscles. It is responsible for binding and storing oxygen in the blood within skeletal muscles. By following a planned exercise programme, you can increase the amount of myoglobin stored in your muscles. This is important as myoglobin will transport oxygen to the mitochondria which in turn will release energy. The more myoglobin you have, the more energy will be available for the muscle.

Increase in storage of glycogen

Your body needs a constant and steady supply of **glycogen** in order to produce energy. As your body adapts to long-term exercise, your muscles are able to store more glycogen. This means that you will be able to train at higher intensities for longer, as muscle glycogen does not require oxygen to produce energy.

Increase in storage of fat

You are able to use your fat stores to produce energy through a process called **aerobic glycolysis**. Well-trained athletes are able to use these fats more efficiently, breaking them down into fatty acids and into energy using oxygen. This enables them to use fats as an energy source when **carbohydrate** becomes scarce.

Increased tolerance to lactate

Anaerobic training stimulates the muscles to become better able to tolerate lactic acid, and clear it away more efficiently. With endurance training the capillary network (see page 39) extends, allowing greater volumes of blood to supply the muscles with oxygen and nutrients. The muscles are able to use more fat as a fuel source, and become more efficient at using oxygen, increasing the body's ability to work harder for longer without fatiguing. The net result is an increase in the body's maximal oxygen consumption.

Key terms

Glycogen – the stored form of glucose.

Carbohydrate – the sugars and starches found in foods such as potatoes, wheat and rice. Carbohydrates are broken down by the body into sugars which are used for energy production.

PAUSE POINT What long-term adaptations occur in your muscles when you exercise?

Hint Consider the different muscle fibre types and list the exercises that could be used specifically to train them.

Extend Explain how strength training changes the structure of the muscles and the benefits of this to sport performance.

Additional factors affecting the muscular system

There are two primary additional factors that will affect your muscular system and in turn affect exercise and sports performance.

Age

As you get older your muscle mass will decrease. The onset of this muscle mass loss begins around the age of 50 and is referred to as **sarcopenia**. Muscles become smaller, resulting in a decrease in muscle strength and power.

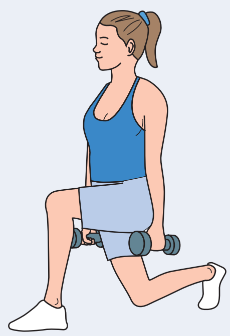
Cramp

Cramp is the sudden involuntary contraction of your muscle. The sensation of muscle spasm where you have no control of the tightening of the muscle fibres can be painful and can be prompted by exercise. The muscles of the lower leg are particularly susceptible to cramp during exercise. Cramp can last from a few seconds up to 10 minutes.

There are a number of factors that can contribute to cramp. The most common one in sport is dehydration which can result in the inadequate supply of blood to the muscles, reducing the supply of oxygen and essential minerals. To prevent cramp you should ensure that you drink plenty of fluid during exercise and sport, especially if the weather is hot. Stretching can also help to prevent cramp as this will lengthen the muscle fibres and improve muscle flexibility.

Assessment practice 1.2

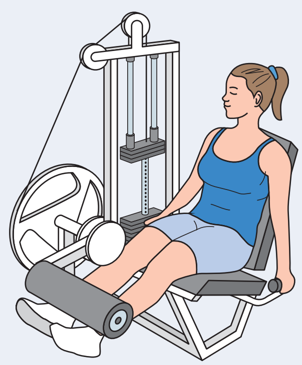
Nancy is a netball player. She uses weighted lunges as part of her training as shown.



1 Explain how the use of weighted lunges will improve Nancy's performance in netball. **(3 marks)**

2 Two days after Nancy's training session she experiences delayed onset of muscle soreness (DOMS). Describe why Nancy's training may cause DOMS. **(1 mark)**

3 Explain how muscle adaptation occurs as a result of Nancy's resistance training. **(2 marks)**



4 The second picture shows Nancy training on a resistance machine. Explain how Nancy's muscles work as antagonistic pairs for each phase of the movement. **(4 marks)**

Plan

- What are the key terms and words being used?
- Do I need to include specific examples such as different types of movement?

Do

- I will write down the key words and explain each of them.
- I will make sure I contextualise my answers by giving relevant examples.

Review

- Have I given sufficient examples linked to the marks available?
- Have I broken down any movements into key phases and explained all the key terms used?

C The effects of exercise and sports performance on the respiratory system

The respiratory system provides oxygen to all living tissue in your body, as well as removing waste products such as carbon dioxide, heat and water vapour. Oxygen is required for every cell in your body to function. Central to the respiratory system are your lungs, which enable oxygen to enter the body and carbon dioxide waste to be removed through the mechanism of breathing. Your body's ability to inhale and transport oxygen while removing waste products is critical to sports performance: the better your body is at this process, the better you will be able to train or perform in sport.

Structure and functions of the respiratory system

Air is drawn into your body via the nose and sometimes via the mouth, and passes through a series of airways to reach the lungs. This series of airways is referred to as the **respiratory tract** and can be divided into two main parts. The upper respiratory tract includes the nose, nasal cavity, mouth, pharynx and larynx. The lower respiratory tract consists of the trachea, bronchi and lungs.

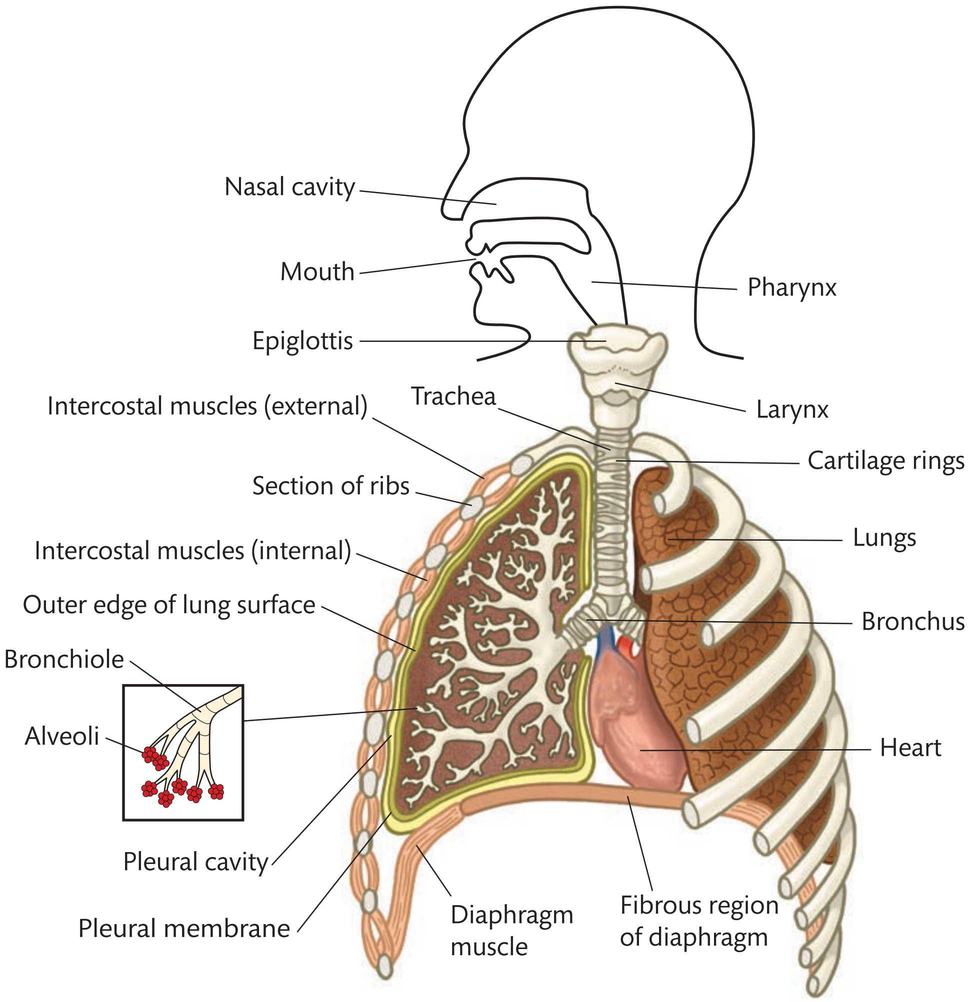


Figure 1.12: Bronchi, bronchial tree and lungs

Nasal cavity

When you breathe in, air enters the nasal cavity by passing through the nostrils. Hairs within the cavity filter out dust, pollen and other foreign particles before the air passes into the two passages of the internal nasal cavity. Here the air is warmed and moistened before it passes into the nasopharynx. A sticky mucous layer traps smaller foreign particles, which tiny hairs called cilia transport to the pharynx to be swallowed.

Pharynx

Commonly called the throat, the pharynx is a small tube that measures approximately 10–13 cm from the base of the skull to the level of the sixth cervical vertebra. The muscular pharynx wall is composed of skeletal muscle throughout its length. The funnel-shaped pharynx connects the nasal cavity and mouth to the larynx (air) and oesophagus (food). It is a passageway for food as well as air, so special adaptations are required to prevent choking when food or liquid is swallowed.

Larynx

The larynx, or voice box, has rigid walls of muscle and cartilage, contains the vocal cords and connects the pharynx to the trachea. It extends for about 5 cm from the level of the third to sixth vertebra.

Trachea

The trachea or windpipe denotes the start of the lower respiratory tract. It is about 12 cm long and 2 cm in diameter. It contains rings of cartilage to prevent it from collapsing, and it is flexible. It travels down the neck in front of the oesophagus and branches into the right and left bronchi.

Epiglottis

The epiglottis is the small flap of cartilage at the back of the tongue which closes the top of the trachea when you swallow to ensure food and drink pass into your stomach and not your lungs.

Lungs

Your lungs are the organ that allows oxygen to be drawn into the body. The paired right and left lungs occupy most of the thoracic cavity and extend down to the diaphragm. They hang suspended in the right and left pleural cavities straddling the heart. The left lung is smaller than the right.

Bronchi

The bronchi branch off the trachea and carry air to the lungs. By the time inhaled air reaches the bronchi, it is warm, clear of most impurities and saturated with water vapour.

Once inside the lungs, each bronchus subdivides into lobar bronchi: three on the right and two on the left. The lobar bronchi branch into segmental bronchi, which divide again into smaller and smaller bronchi. Overall, there are approximately 23 orders (sizes) of branching bronchial airways in the lungs. Because of this branching pattern, the bronchial network within the lungs is often called the **bronchial tree**.

Bronchioles

Bronchioles are small airways that extend from the bronchi and connect the bronchi to small clusters of thin-walled air sacs, known as alveoli. Bronchioles are about 1 mm in diameter and are the first airway branches of the respiratory system that do not contain cartilage.

Alveoli

At the end of each bronchiole is a mass of air sacs called alveoli. In each lung there are approximately 300 million gas-filled alveoli. These are responsible for the transfer of oxygen into the blood and the removal of waste such as carbon dioxide out of the blood. This process of transfer is known as **gaseous exchange**. Combined, the alveoli have a huge surface area for maximal gaseous exchange to take place – roughly the size of a tennis court. Surrounding each alveolus is a dense network of **capillaries** to facilitate the process of gaseous exchange. For more on gaseous exchange, see page 32.

PAUSE POINT Explain how air enters the body and how it is used.

Hint List the journey of air from the mouth to the alveoli.

Extend Draw a diagram of the journey of air from the nose to the alveoli. Label each part of the respiratory system on your diagram.

Diaphragm

The diaphragm is a flat muscle that is located beneath the lungs within the thoracic cavity and separates the chest from the abdomen. The diaphragm is one of several components involved in breathing, which is the mechanism of drawing air – including oxygen – into the body (inhalation) and removing gases including carbon dioxide (exhalation). Contraction of the diaphragm increases the volume of the chest cavity, drawing air into the lungs, while relaxation of the diaphragm decreases the volume of the chest cavity, pushing air out.

Thoracic cavity

This is the chamber of the chest that is protected by the thoracic wall (rib cage). It is separated from the abdominal cavity by the diaphragm.

Internal and external intercostal muscles

The intercostal muscles lie between the ribs. To help with inhalation and exhalation, they extend and contract.

- The **internal intercostal** muscles lie inside the ribcage. They draw the ribs downwards and inwards, decreasing the volume of the chest cavity and forcing air out of the lungs when breathing out.
- The **external intercostal** muscles lie outside the ribcage. They pull the ribs upwards and outwards, increasing the volume of the chest cavity and drawing air into the lungs when breathing in.

Mechanisms of breathing

Breathing or **pulmonary ventilation** is the process by which air is transported into and out of the lungs, and it can be considered to have two phases. It requires the thorax to increase in size to allow air to be taken in, followed by a decrease to allow air to be forced out.

Inspiration

Inspiration is the process of breathing air into the lungs. The intercostal muscles between the ribs contract to lift the ribs upwards and outwards, while the diaphragm is forced downwards. This expansion of the thorax in all directions causes a drop in pressure within the lungs to below atmospheric pressure (the pressure of the air outside the body), which encourages air to be drawn into the lungs.

Expiration

The opposite of inspiration is expiration, and this occurs when the intercostal muscles relax. The diaphragm relaxes, moving upwards, and the ribs move downwards and inwards. Pressure within the lungs is increased and air is expelled or pushed out of the body.

During sport or exercise, greater amounts of oxygen are required, so the intercostal muscles and diaphragm must work harder. This results in an increase in your breathing rate and an increase in the force of your breath.

Control of breathing

Neural control

Breathing is a complex process that is largely under involuntary control by the respiratory centres of your brain. Inspiration is an active process, as the diaphragm muscle is **actively** contracting which causes air to enter the lungs. Expiration is a passive process, as the diaphragm muscle **relaxes** to allow air to exit the lungs. This process is controlled by neurones (cells that conduct nerve impulses) in the brain stem. Neurones in two areas of the **medulla oblongata** are critical in respiration.

Key term

Medulla oblongata – located in the middle of your brain, this is responsible for involuntary functions such as breathing, heart beat and sneezing.

These are the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The VRG is thought to be responsible for the rhythm generation that allows rhythmic and continuous breathing.

Chemical control

Other factors that control breathing are the continually changing levels of oxygen and carbon dioxide in the blood. Sensors responding to such chemical fluctuations are called **chemoreceptors**. These are found in the medulla and in the **aortic arch** and **carotid arteries**. These chemoreceptors detect changes in blood carbon dioxide levels as well as changes in blood acidity, and send signals to the medulla that will make changes to breathing rates.

Gaseous exchange

Gaseous exchange is the process by which one type of gas is exchanged for another. In the lungs, gaseous exchange occurs by **diffusion** between air in the alveoli and blood in the capillaries surrounding their walls. It delivers oxygen from the lungs to the bloodstream and removes carbon dioxide from the bloodstream to the lungs.

The alveolar and capillary walls form a **respiratory membrane** that has gas on one side and blood flowing past on the other. Gaseous exchange occurs readily by simple diffusion across the respiratory membrane. Blood entering the capillaries from the pulmonary arteries has a lower oxygen concentration and a higher carbon dioxide concentration than the air in the alveoli. Oxygen diffuses into the blood via the surface of the alveoli, through the thin walls of the capillaries, through the red blood cell membrane and finally latches on to haemoglobin. Carbon dioxide diffuses in the opposite direction, from the blood plasma into the alveoli.

Key term

Diffusion – the process by which a substance such as oxygen passes through a cell membrane either to get into the cell or to get out of the cell. Substances move by diffusion from an area where they are more concentrated to an area where they are less concentrated.

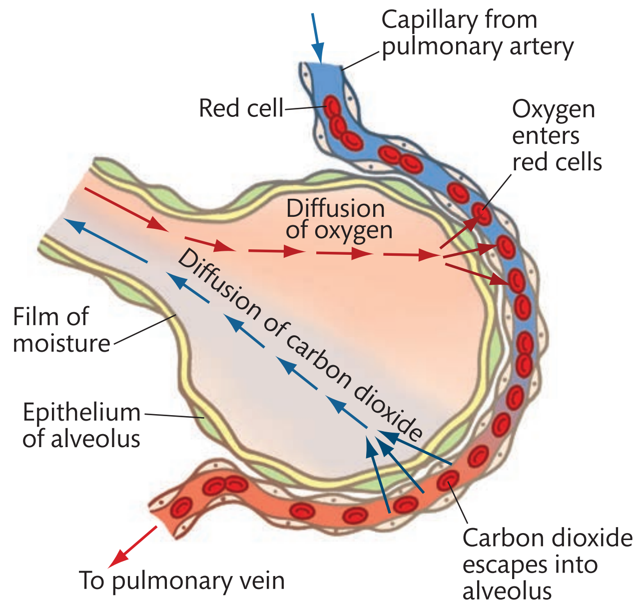


Figure 1.13: Gaseous exchange in action in an alveolus

Lung volumes

What happens to your breathing when you are exercising or training? Your lungs are designed to take in more air during exercise so that more oxygen can reach the alveoli and more carbon dioxide can be removed. Your breathing will become deeper and more frequent to cope with the demands that exercise puts on your body.

Your **respiratory rate** is the amount of air you breathe in one minute. For a typical 18-year-old, this represents about 12 breaths per minute at rest, during which time about 6 litres of air passes through the lungs. It can increase significantly during exercise, by as much as 30–40 breaths per minute.

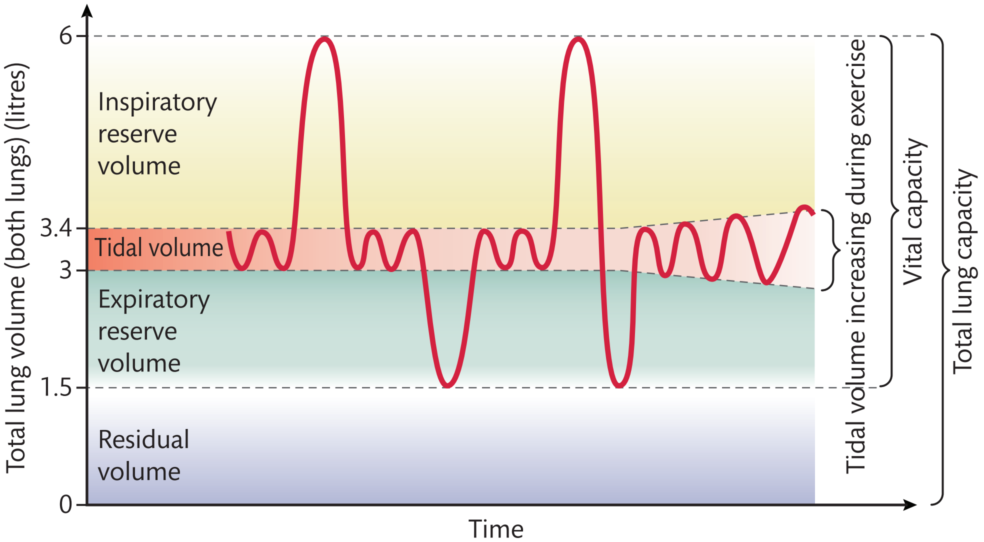


Figure 1.14: Lung volume and capacities of a healthy adult

Tidal volume

Tidal volume is the term used to describe the volume of air breathed in and out with each breath. Under normal conditions this represents about 500 cm^3 of air breathed, both inhaled and exhaled. Of this, approximately two-thirds (350 cm^3) reaches the alveoli in the lungs where gaseous exchange takes place. The remaining 150 cm^3 fills the pharynx, larynx, trachea, bronchi and bronchioles and is known as dead or stationary air.

During exercise, tidal volume increases to allow more air to pass through the lungs. The volume of air passing through the lungs each minute is known as the **minute volume** – it is determined by the breathing rate and the amount of air taken in with each breath.

- The lungs normally contain about 350 cm^3 of fresh air, 150 cm^3 of dead air and 2500 cm^3 of air that has already undergone gaseous exchange with the blood.
- The lungs are never fully emptied of air, otherwise they would collapse. The air that remains in the lungs after maximal expiration, when you breathe out as hard as you can, is referred to as **residual volume**. The volume is around 1200 cm^3 for an average male.
- **Vital capacity** is the amount of air that can be forced out of the lungs after maximal inspiration. The volume is around 4800 cm^3.
- By breathing in deeply, it is possible to take in more air than usual so that more oxygen can reach the alveoli. This is especially important during exercise. You can breathe in up to an additional 3000 cm^3 of fresh air in addition to the normal tidal volume – this is known as the **inspiratory reserve volume.**
- The **expiratory reserve volume** is the amount of additional air that can be breathed out after normal expiration. This can be up to 1500 cm^3. At the end of a normal breath, the lungs contain the residual volume plus the expiratory reserve volume. If you then exhale as much as possible, only the residual volume remains.
- **Total lung volume** is your total lung capacity after you have inhaled as deeply and as much as you can, after maximal inspiration. It is normally around 6000 cm^3 for an average-sized male.

PAUSE POINT Can you remember the different lung volumes?

Hint Write a list of the different lung volumes and briefly describe each one.

Extend Think about how your breathing changes during exercise. Explain what is happening to each specific lung volume.

Responses of the respiratory system to a single sport or exercise session

Your body is surprisingly insensitive to falling levels of oxygen, yet it is sensitive to increased levels of carbon dioxide. The levels of oxygen in arterial blood vary little, even during exercise, but carbon dioxide levels vary in direct proportion to the level of physical activity. The more intense the exercise, the greater the carbon dioxide concentration in the blood. To combat this, your breathing rate increases to ensure the carbon dioxide can be expelled through expiration.

Increased breathing rate

Exercise results in an increase in the rate and depth of breathing. During exercise your muscles demand more oxygen, and the corresponding increase in carbon dioxide production stimulates faster and deeper breathing. The capillary network surrounding the alveoli expands, increasing blood flow to the lungs and pulmonary diffusion.

A minor rise in breathing rate prior to exercise is known as an anticipatory rise. When exercise begins there is an immediate and significant increase in breathing rate, believed to be a result of receptors working in both the muscles and joints.

After several minutes of aerobic exercise, breathing continues to rise, though at a slower rate, and it levels off if the exercise intensity remains constant. If the exercise is maximal, the breathing rate will continue to rise until exhaustion. After exercise the breathing rate returns to normal, rapidly to begin with and then slowly.

Increased tidal volume

During exercise, tidal volume increases to allow more air to pass through the lungs. Tidal volume is elevated by both aerobic and anaerobic exercise. During exercise, oxygen is depleted from your body, triggering a deeper tidal volume to compensate.

During strenuous exercise, oxygen diffusion may increase by as much as three times above the resting level. Likewise, minute ventilation depends on breathing rate and total volume. During exercise adults can generally achieve minute ventilation approximately 15 times greater than the resting values.

Adaptations of the respiratory system to exercise

Like the cardiovascular system, the respiratory system undergoes specific adaptations in response to an organised and regular training programme. These adaptations help to maximise the efficiency of the respiratory system; oxygen can be delivered to the working muscles to meet the demands of the exercise while waste products can be removed quickly.

Increased vital capacity

Your vital capacity increases in response to long-term physical training to provide an increased and more efficient supply of oxygen to working muscles.

Increased strength of respiratory muscles

The diaphragm and intercostal muscles increase in strength, allowing for greater expansion of the chest cavity. This will mean that it is easier to take deeper breaths as the stronger and more pliable muscles will allow the chest cavity to expand further.

Increase in oxygen and carbon dioxide diffusion rate

Your respiratory system adapts to regular training, allowing oxygen and carbon dioxide to diffuse more rapidly. An increase in diffusion rates in tissues means that you can train longer and harder, as your muscles will be supplied with more oxygen and the increased carbon dioxide will be removed more quickly.

PAUSE POINT Why is the respiratory system so important to sports performance?

Hint Describe how the respiratory system adapts to long-term exercise.

Extend Explain why each adaptation can improve sport and exercise performance.

Additional factors affecting the respiratory system

Although regular training will improve the efficiency of your respiratory system, there are a number of additional considerations that can affect this system.

Asthma

Asthma is a common condition where the airways of the respiratory system can become restricted, making it harder for air to enter the body, resulting in coughing, wheezing or shortness of breath.

During normal breathing, the bands of muscle that surround the airways are relaxed and air moves freely. However, asthma makes the bands of muscle surrounding the airways contract and tighten so that air cannot move freely in or out of the body. Asthma can have a negative effect on sports performance as people with the condition will not be able to get enough oxygen into their lungs to supply their muscles, especially with the increased amounts required during exercise.

However, regular exercise will strengthen your respiratory system and help prevent asthma. Regular aerobic training can help to improve breathing and muscular strength, and endurance training will also improve oxygen uptake.

Safety tip

If you suffer from asthma always carry your inhaler. If you begin to experience the symptoms of asthma then stop the exercise immediately.

Research

For more information about asthma, see NHS Choices – www.nhs.uk/Livewell/asthma.

Case study

Paula Radcliffe

World record marathon runner Paula Radcliffe has had exercise-induced asthma all of her life. However, through determination and the correct medication, she has been able to compete successfully at the highest level and is currently the world record holder for the women's marathon with her time of 2 hours, 15 minutes and 25 seconds.

To ensure that she is able to train and compete, Paula always warms up gently and gradually so that her asthma does not interfere. When training she will use her preventer inhaler first thing in the morning and then her reliever inhaler before she starts exercising.

Paula's message is clear: 'control your asthma, don't let it control you'.

Check your knowledge

1 How does asthma affect sporting performance?

2 What is the difference between a preventer inhaler and a reliever inhaler?

▶ Paula Radcliffe is one of many elite athletes who compete successfully despite suffering from asthma

Effects of altitude/partial pressure on the respiratory system

Many elite athletes like to train at high altitude as the air pressure is lower and the oxygen particles are farther apart. This means that the density of oxygen in the air is lower and it is harder to breathe (inspire) this oxygen into your body due to lower partial pressure. Over time the athletes' respiratory system will adapt to this lower pressure and become more efficient.

In the short term, the effects of altitude on the body are that your lungs have to work harder. Symptoms can include shortness of breath, dizziness, headaches and difficulties in concentrating. The decreased availability of oxygen at higher altitudes can quickly lead to hypoxia, which occurs when the body has insufficient access to oxygen. To cope with the decrease in available oxygen, you must breathe faster and deeper.

Like other systems of the body, the respiratory system will adapt over a long period of time so that it can cope with the decrease in available oxygen at higher altitudes. Your lungs will acclimatise by becoming larger which enables them to take in more oxygen. The body will also produce more red blood cells and capillaries, enabling the lungs to oxygenate the blood more efficiently.

Athletes who train at altitude feel the benefits of a more efficient respiratory system when they return to compete at lower altitudes. Athletes who were born at high altitude benefit even more, having grown up and developed in that environment.

Assessment practice 1.3

Freddie is a football player.

1 Explain the short-term effect of taking part in football on Freddie's tidal volume. **(3 marks)**

2 Explain the role of carbon dioxide in the chemical control of breathing during exercise. **(3 marks)**

3 Explain how increasing the strength of the respiratory muscles aids performance in long distance running. **(4 marks)**

Plan

- I will plan longer answers by noting the key words and likely examples.
- I will look at the marks available and allow time to write a full answer.

Do

- I will write a structured answer, especially for questions that offer more marks.
- I will give relevant examples linked to the key theories.

Review

- Have I reread my answers? Have I included a response to the key terms?
- Have I fully answered the question, making the relevant number of points linked to the marks available?

D The effects of exercise and sports performance on the cardiovascular system

The cardiovascular system is sometimes referred to as the **circulatory system** and consists of the heart, blood vessels and blood. The cardiovascular system is the major transport system in your body, carrying food, oxygen and all other essential products to cells, and taking away waste products of respiration and other cellular processes, such as carbon dioxide. Oxygen is transported from the lungs to the body tissues, while carbon dioxide is carried from the body tissues to the lungs for excretion.

Structure of the cardiovascular system

The heart

The heart is a unique hollow muscle and is the pump of the cardiovascular system. It is located under the sternum (which provides protection) and is about the size of a closed fist. The function of the heart is to drive blood into and through the arteries in order to deliver it to the tissues and working muscles.

The heart is surrounded by a twin-layered sac known as the pericardium. The cavity between the layers is filled with pericardial fluid, whose purpose is to prevent friction as the heart beats. The heart wall itself is made up of three layers: the epicardium (the outer layer), the myocardium (the strong middle layer that forms most of the heart wall), and the endocardium (the inner layer).

The right side of the heart is separated from the left by a solid wall known as the **septum**. This prevents the blood on the right side coming into contact with the blood on the left side.

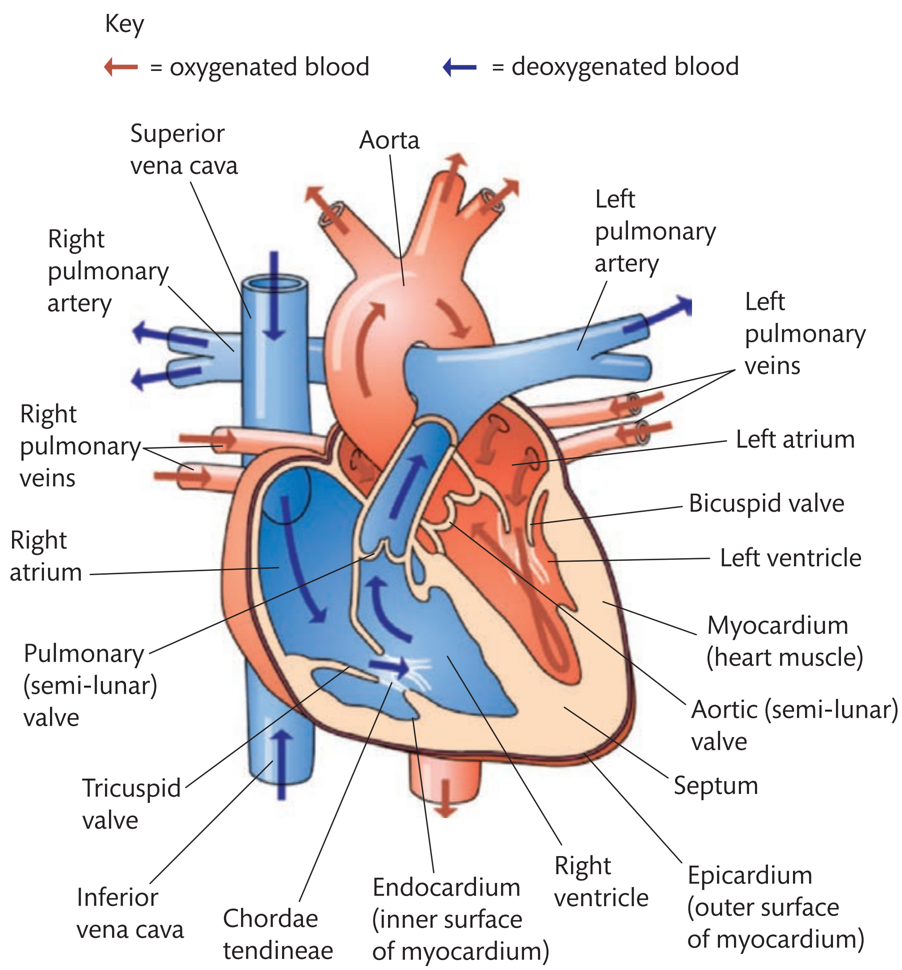


Figure 1.15: Diagram of the heart

The heart can be thought of as two pumps: the two chambers on the right (the right atrium and the right ventricle) and the two chambers on the left (the left atrium and the left ventricle; see Figure 1.15). The chambers on the right supply blood at a low pressure to the lungs via the pulmonary arteries, arterioles and capillaries, where gaseous exchange takes place. This blood is then returned to the left side of the heart via the capillaries, venules and veins.

When the chambers of the left side of the heart are full, it contracts simultaneously with the right side, acting as a high-pressure pump. It supplies oxygenated blood via the arteries, arterioles, and capillaries to the tissues of the body such as muscle cells. Oxygen passes from the blood to the cells and carbon dioxide (a waste product of aerobic respiration) is taken on board. The blood then returns to the right atrium of the heart via the capillaries, venules and veins.

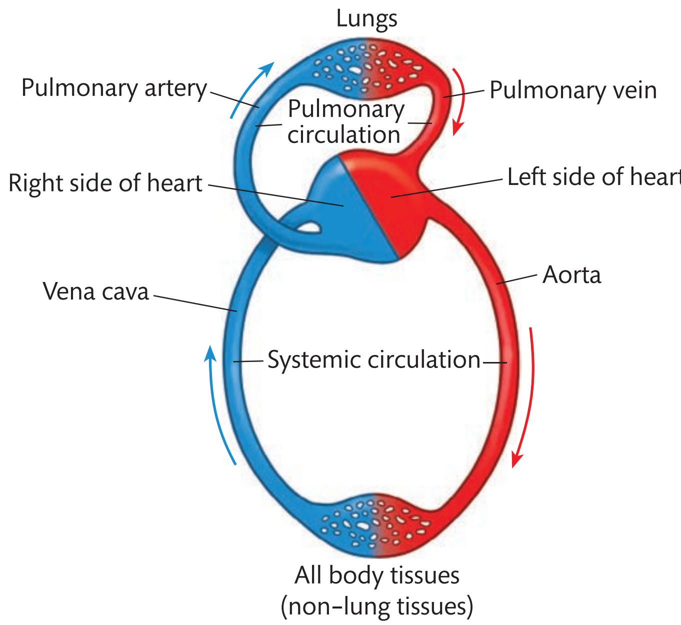


Figure 1.16: Double circulation through the heart

The main parts of the heart are as follows.

- **Coronary arteries** – these are the blood vessels that supply oxygenated blood to the heart muscle. There are two coronary arteries, the left and right.
- **Atria** – these are the upper chambers of the heart. They receive blood returning to your heart from either the body or the lungs. The right atrium receives **deoxygenated blood** from the superior and inferior vena cava. The left atrium receives **oxygenated blood** from the left and right pulmonary veins.
- **Ventricles** – the pumping chambers of the heart. They have thicker walls than the atria. The right ventricle pumps blood to the pulmonary circulation for the lungs, and the left ventricle pumps blood to the systemic circulation for the body including the muscles.
- **Bicuspid (mitral) valve** – one of the four valves in the heart, situated between the left atrium and the left ventricle. It allows the blood to flow in one direction only, from the left atrium to the left ventricle.
- **Tricuspid valve** – situated between the right atrium and the right ventricle, it allows blood to flow from the right atrium to the right ventricle and prevents blood from flowing backwards.
- **Semi-lunar valves (aortic valve and pulmonary valve)** – the aortic valve is situated between the left ventricle and the aorta and prevents flow from the aorta back into the left ventricle. The pulmonary valve is situated between the right ventricle and the pulmonary artery.

Key terms

Oxygenated blood – blood containing oxygen.

Deoxygenated blood – blood without oxygen (containing carbon dioxide).

The major blood vessels connected to the heart are as follows.

- **Aorta** – this is the body's main artery. It originates in the left ventricle and carries oxygenated blood to all parts of the body except the lungs.
- **Superior vena cava** – a vein that receives deoxygenated blood from the upper body to empty into the right atrium of the heart.

- **Inferior vena cava** – a vein that receives deoxygenated blood from the lower body to empty into the right atrium of the heart.
- **Pulmonary vein** – carries oxygenated blood from the lungs to the left atrium of the heart.
- **Pulmonary artery** – carries deoxygenated blood from the heart back to the lungs. It is the only artery that carries deoxygenated blood.

PAUSE POINT	Explain the function of the heart in the cardiovascular system.
Hint	Close the book and draw a diagram of the heart. Try to label each part of your diagram.
Extend	Label the blood flow through the heart, showing where the blood is flowing to and from.

Structure of blood vessels

As the heart contracts, blood flows around the body in a complex network of vessels. Around 96,000 km of arteries, arterioles, capillaries, venules and veins allow the blood's circulation throughout the body. The structure of these different vessels is determined by their different functions and the pressure of blood within them.

Blood flowing through the arteries appears bright red due to its oxygenation. As it moves through the capillaries it drops off oxygen and picks up carbon dioxide. By the time it reaches the veins it is a darker shade of red than oxygenated blood.

Arteries

Arteries carry blood **away** from the heart, and with the exception of the pulmonary artery they carry oxygenated blood. They have thick muscular walls to carry blood at high speeds under high pressure. When the heart ejects blood into the large arteries, the arteries expand to accommodate this blood. They do not require valves as the pressure within them remains high at all times, except at the point where the pulmonary artery leaves the heart. Arteries have two major properties: **elasticity** and **contractility**.

The smooth muscle surrounding the arteries enables their diameter to be decreased and increased as required. This contractility of the arteries helps to maintain blood pressure in relation to changes in blood flow. The arteries are mostly located deep within the body, except where they can be felt at a pulse point. These vessels branch into smaller arterioles that ultimately deliver blood to the capillaries.

Arterioles

Arterioles have thinner walls than arteries. They control blood distribution by changing their diameter. This mechanism adjusts blood flow to the capillaries in response to differing demands for oxygen. During exercise, muscles require an increased blood flow in order to get extra oxygen, so the diameter of arterioles leading to the muscles dilates, or gets wider. To compensate for this increase in demand for blood by the muscles, other areas, like the gut, have their blood flow temporarily reduced, and the diameter of their arterioles is decreased. Arterioles are essentially responsible for controlling blood flow to the capillaries.

Capillaries

Capillaries connect arteries and veins by uniting arterioles and venules. They are the smallest of all the blood vessels, narrow and thin. The number of capillaries in muscle may be increased through frequent and appropriate exercise. They form an essential part of the cardiovascular system as they allow the diffusion of oxygen and nutrients required by the body's cells. Capillaries that surround muscles ensure they get the oxygen and nutrients they require to produce energy. The walls of capillaries are only one cell thick, allowing nutrients, oxygen and waste products to pass through. The pressure of blood within the capillaries is higher than that in veins, but lower than in the arteries.

Veins

Veins facilitate **venous return** – the return of deoxygenated blood to the heart. They have thinner walls than arteries and a relatively large diameter. By the time blood reaches the veins, it is flowing slowly and under low pressure. Contracting muscles push the thin walls of the veins inwards to help squeeze the blood back towards the heart. As these muscle contractions are intermittent, there are a number of pocket valves in the veins that help to prevent any backflow when the muscles relax. Veins are mainly close to the surface and can be seen under the skin. They branch into smaller vessels called **venules**, which extend to the capillary network.

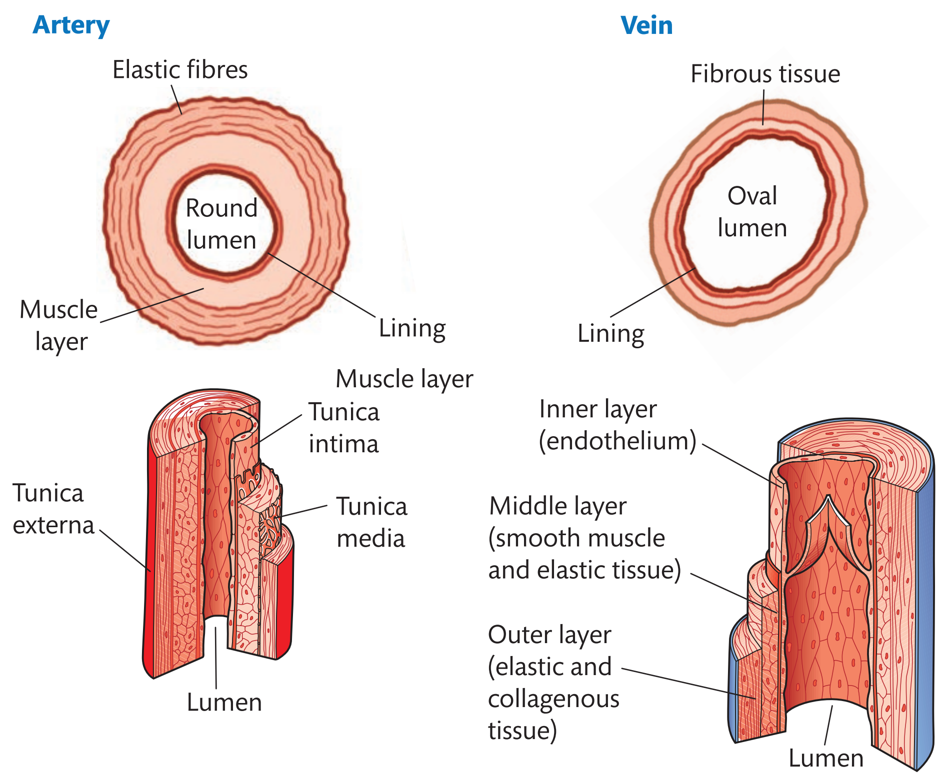


Figure 1.17: Structure of arteries and veins

Table 1.5: Comparison between veins and arteries

Veins	Arteries
Carry blood from the tissues of the body to the heart	Carry blood away from the heart to the tissues of the body
Usually found just beneath the skin	Found deeper within the body
Have less muscular walls than arteries	Are more muscular than veins, with much more elastic fibres
Have valves to prevent the backflow of blood	Do not contain valves
Contain blood under low pressure	Contain blood under high pressure

Venules

Venules are the small vessels that connect the capillaries to the veins. The venules will take the blood from the capillaries and transport this deoxygenated blood under low pressure to the veins which, in turn, will lead back to the heart.

PAUSE POINT Explain the functions of veins, venules, arteries, arterioles and capillaries.

Hint Close the book and list the differences between arteries and veins.

Extend Explain why there are structural differences between arteries and veins.

Composition of blood

The average adult has approximately 4–5 litres of blood. This blood is composed of:

- **red blood cells** (erythrocytes) – the main function of red blood cells is to carry oxygen to all living tissue. All red blood cells contain a protein called haemoglobin which gives blood its red colour and when combined with oxygen forms oxyhaemoglobin. Red blood cells are round, flattened discs with an indented shape which gives them a large surface area and allows them to flow easily within plasma. A drop of blood contains millions of red blood cells.
- **plasma** – the straw-coloured liquid in which all blood cells are suspended. It is made up of approximately 90 per cent water as well as electrolytes such as sodium, potassium and proteins. The plasma also carries carbon dioxide, dissolved as carbonic acid.
- **white blood cells** (leucocytes) – the components of blood that protect the body from infections. White blood cells identify, destroy and remove pathogens such as bacteria or viruses from the body. White blood cells originate in the bone marrow and are stored in your blood.
- **platelets** (thrombocytes) – disc-shaped cell fragments produced in the bone marrow. The primary function of platelets is clotting to prevent blood loss.

Function of the cardiovascular system

There are a number of important functions that the cardiovascular system plays during exercise and sports performance.

Delivering oxygen and nutrients

The key function of the cardiovascular system is to supply oxygen and nutrients to the tissues of the body via the bloodstream. During exercise your body will need more of these so the cardiovascular system responds to ensure that there is a suitable supply to meet the increased demands. When the cardiovascular system can no longer meet these demands, fatigue will occur in the muscles and performance will deteriorate.

Removing waste products – carbon dioxide and lactate

As well as providing oxygen and nutrients to all the tissues in the body, the circulatory system carries waste products from the tissues to the kidneys and the liver, and returns carbon dioxide from the tissues to the lungs. During exercise your muscles will produce more carbon dioxide and lactate and it is essential that these are removed, otherwise muscle fatigue will occur.

Thermoregulation

The cardiovascular system is responsible for the distribution and redistribution of heat within your body to maintain thermal balance during exercise. This ensures that you do not overheat during exercise.

Your cardiovascular system uses the following ways of controlling and distributing heat around your body.

- **Vasodilation of blood vessels near the skin** – during exercise, vasodilation of blood vessels occurs in the parts of the active muscles where gaseous exchange takes place. Vasodilation is caused by the relaxation of the involuntary muscle fibres in the walls of the blood vessels and causes an increase in the diameter of blood vessels. This decreases resistance to the flow of blood to the area supplied by the vessels. This will result in a decrease in body temperature as heat within the blood can be carried to the skin surface.
- **Vasoconstriction of blood vessels near the skin** – blood vessels can also temporarily shut down or limit blood flow to tissues. This process is known as vasoconstriction and causes a decrease in the diameter of blood vessels. This will result in an increase in body temperature, as heat loss is reduced as blood is moved away from the surface.

Fighting infection

Leucocytes (white blood cells) are constantly produced inside the bone marrow. They are stored in, and transported around the body by, the blood. They can consume and ingest pathogens (substances that cause illness) and destroy them, produce antibodies that will also destroy pathogens, and produce antitoxins which will neutralise the toxins that may be released by pathogens.

Clotting blood

Clotting is a complex process during which white blood cells form solid clots. A damaged blood vessel wall is covered by a fibrin clot to help repair the damaged vessel. Platelets form a plug at the site of the damage. Plasma components known as coagulation factors respond to form fibrin strands which strengthen the platelet plug. This is made possible by the constant supply of blood through the cardiovascular system.

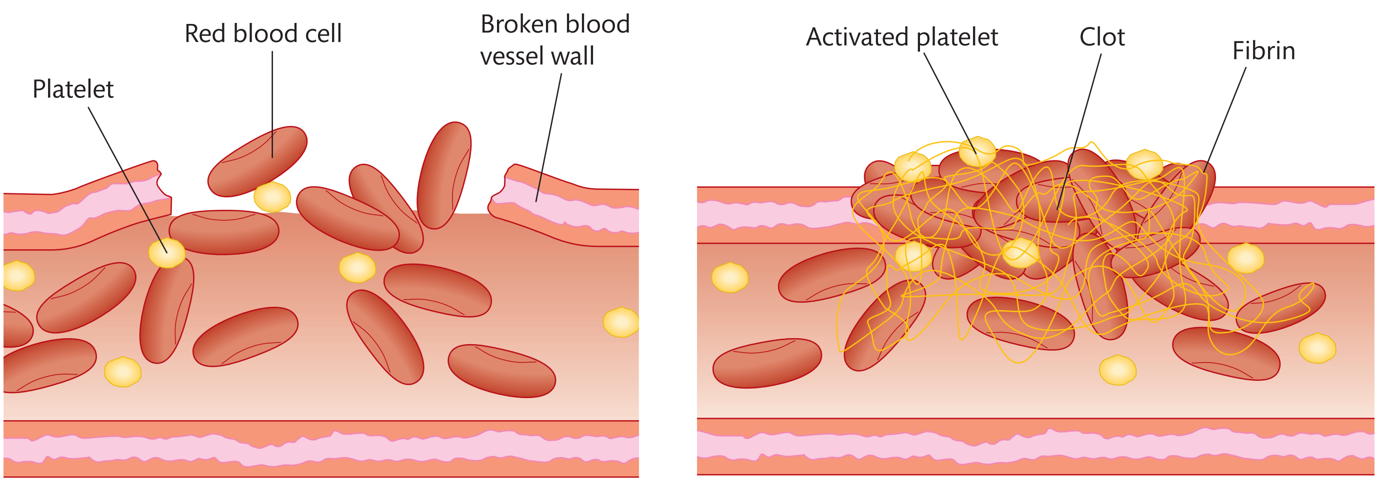


Figure 1.18: Clotting prevents excessive bleeding when a blood vessel is damaged

PAUSE POINT Identify the functions of the cardiovascular system and explain why they are important to sports performance.

Hint Describe the main functions of the cardiovascular system.

Extend Explain each of the main functions of the cardiovascular system and why they are so important to sport and exercise performance.

Nervous control of the cardiac cycle

Your heart pumps (or beats) when the atria and ventricles work together. Both the atria and the ventricles contract independently, pushing blood out of the heart's chambers. The process of the heart filling with blood followed by a contraction where the blood is pumped out is known as the **cardiac cycle**. The electrical system of your heart is the power source that makes this possible.

Your heart's electrical system is made up of three main parts: the sinoatrial node, the atrioventricular node, and the Bundle of His and Purkinje fibres (Figure 1.19).

Sinoatrial node (SAN)

The sinoatrial node (SAN) is commonly referred to as the heart's pacemaker and is located within the wall of the right atrium. The SAN sends an impulse or signal from the right atrium through the walls of the atria, causing the muscular walls to contract. This contraction forces the blood within the atria down into the ventricles.

Atrioventricular node (AVN)

The atrioventricular node (AVN) is located in the centre of the heart between the atria and the ventricles, and acts as a buffer or gate that slows down the signal from the SAN. Slowing down the signal allows the atria to contract **before** the ventricles, which means that the ventricles are relaxed (or open) and ready to receive the blood from the atria at the top of the heart.

Bundle of His and Purkinje fibres

Bundle of His are specialist heart muscle cells that are responsible for transporting the electrical impulses from the AVN. They are found in the walls of the ventricles and septum. At the end of the Bundle of His are thin filaments known as Purkinje fibres which allow the ventricle to contract at a paced interval. This contraction causes the blood within the ventricle to be pushed up and out of the heart, either to the lungs or to the working muscles.

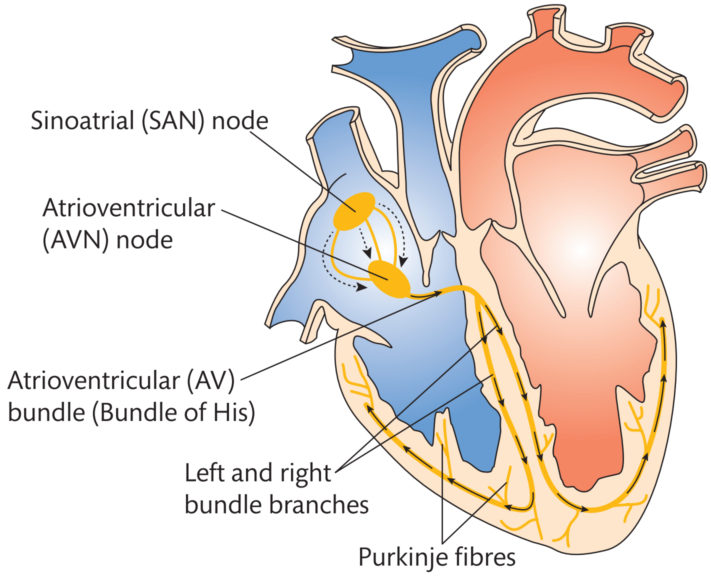


Figure 1.19: The heart's electrical system

Effects of the sympathetic and parasympathetic nervous system

The autonomic nervous system is the part of the nervous system that regulates body functions such as breathing and your heart beating, and it is involuntary.

This system can be further divided into the following nervous systems.

- **Sympathetic nervous system** – prepares the body for intense physical activity and is often referred to as the 'fight or flight' response.
- **Parasympathetic nervous system** – relaxes the body and inhibits or slows many high energy functions. This is often referred to as the 'rest and digest' response.

During exercise and sport the **sympathetic nervous system** will cause the heart to beat faster and your lungs to work harder, allowing you to produce more energy and meet the demands of the exercise.

After exercise your heart rate will need to slow down to its normal resting levels. It is the job of the **parasympathetic nervous system** to do this; if the parasympathetic nervous system did not function then your heart rate would continue to be elevated.

Responses of the cardiovascular system to a single sport or exercise session

During exercise your contracting muscles require a continual supply of nutrients and oxygen to support energy production. These requirements are over and above those required to support normal activities at work or rest. Your heart has to beat harder and faster to meet these increased demands. If these demands are repeated frequently as a result of a systematic training programme, over time your heart will become stronger and your cardiovascular system will become more efficient at supplying oxygen and removing waste products.

Anticipatory increase in heart rate prior to exercise

You may have experienced the feeling that your heart is beating faster than usual immediately before a sports match. This is known as an **anticipatory response**. Your heart rate will increase just before exercise in order to prepare for the increased demands that are about to be put on your body. Nerves that directly supply your heart and chemicals in your blood can rapidly alter your heart rate. The greatest anticipatory heart-rate response is observed in short sprint events.

Increased heart rate

In order for your muscles to receive more oxygenated blood, your heart rate will increase during exercise. Nerve centres in your brain detect cardiovascular activity and this results in adjustments that increase the rate and pumping strength of your heart. At the same time, regional blood flow is altered in proportion to the intensity of the activity undertaken.

Increased cardiac output

Cardiac output is the amount of blood pumped out of the left side of the heart to the body in one minute. It is the product of heart rate (beats per minute) and stroke volume (the amount of blood per heart beat):

- cardiac output = heart rate × stroke volume

During participation in sport and exercise, cardiac output will be greater as a result of increases in heart rate and/or stroke volume. Stroke volume does not increase significantly beyond the light work rates of low-intensity exercise, so the increases in cardiac output required for moderate to high-intensity work rates are mostly achieved by increases in heart rate. Your maximum attainable cardiac output decreases with increasing age, largely as a result of a decrease in maximum heart rate.

Increased blood pressure

Blood pressure is the pressure of the blood against the walls of your arteries and results from two forces:

- **systolic pressure** – the pressure exerted on your artery walls when your heart contracts and forces blood out of the heart and into the body
- **diastolic pressure** – the pressure on the blood vessel walls when the heart is relaxed between beats and is filling with blood.

During exercise your systolic blood pressure increases as your heart is working harder to supply more oxygenated blood to the working muscles. Your diastolic blood pressure stays the same or decreases slightly.

When blood pressure is measured, it is written with both the systolic and the diastolic pressure noted.

The top number is the **systolic pressure** and the bottom number is the **diastolic pressure**, e.g. $\frac{120}{80}$ mm Hg

Redirection of blood flow

To ensure that blood reaches the areas of the body that need it the most during exercise (i.e. the working muscles), your body will redirect and redistribute the flow of blood. This ensures that the maximum amount of oxygenated blood can reach the muscles, but other areas of the body that need less oxygen during exercise will receive less blood. The body does this using vasodilation and vasoconstriction – refer back to the section on thermoregulation starting on page 41 for more information.

Theory into practice

In pairs, choose a sport that you both enjoy. Take 8–10 minutes to perform a thorough warm-up and then take part in your chosen activity for at least 20 minutes at moderate intensity levels. At the end of the session take approximately five minutes to cool down.

During each part of the activity, pay close attention to the changes that are taking place in your body. Get your partner to record these for you.

1. During the warm-up, what changes occurred to your heart rate and breathing?
2. During the main exercise what changes occurred? Think about how you felt: did you get hot? How did your body adapt to control your temperature? What do you think would have happened if you had exercised at higher intensities?

Adaptations of the cardiovascular system due to exercise

If you undertake a purposeful and well-planned exercise programme, your cardiovascular system will adapt over time and you will become fitter and more able to cope with the demands of exercise. The extent of these changes will depend on the type, intensity and frequency of exercise undertaken, and the overload achieved.

Cardiac hypertrophy

Cardiac hypertrophy is the enlargement of your heart over a long period of time. Training will cause the walls of your heart to get thicker. In particular the wall of the left ventricle will thicken, increasing the strength potential of its contractions.

Increase in resting and exercising stroke volume

Stroke volume is the amount of blood that can be ejected from the heart in one beat. In simple terms, the more blood that can be pushed out of the heart, the more oxygen can get to the muscles. Stroke volume at rest has been shown to be significantly higher after a prolonged endurance-training programme. The heart can therefore pump more blood per minute, increasing cardiac output during maximal levels of exercise. Blood flow increases as a consequence of an increase in the size and number of blood vessels. This allows for more efficient delivery of oxygen and nutrients.

Decrease in resting heart rate

The result of cardiac hypertrophy and an increase in stroke volume through long-term exercise is that your resting heart rate falls, reducing the workload on your heart.

Reduction in resting blood pressure

Exercise causes your blood pressure to rise for a short time. However, when you stop, your blood pressure should return to normal. The quicker it does this, the fitter you are likely to be. Research indicates that regular exercise can contribute to lowering blood pressure. For people suffering from high blood pressure (hypertension), steady aerobic exercise is often recommended to reduce this.

Decreased heart rate recovery time

Heart rate recovery is a measure of how much your heart rate falls during the first minute after exercise. The fitter your heart, the quicker it returns to normal after exercise. Fitter individuals generally recover more rapidly because their cardiovascular system can adapt more quickly to the imposed demands of exercise.

Capillarisation of skeletal muscle and alveoli

Long-term exercise, particularly aerobic exercise, can lead to an increase in the number of capillaries in the cardiac and skeletal muscle. Blood flow increases as a consequence of this increase in the size and number of blood vessels. This allows for more efficient delivery of oxygen and nutrients.

Increase in blood volume

Your blood volume represents the amount of blood circulating in your body. It varies from person to person, and increases as a result of training. Blood volume increases as a result of capillarisation. An increase in blood volume means your body can deliver more oxygen to your working muscles and your body will also be able to regulate your body temperature more effectively during exercise.

PAUSE POINT What is meant by 'cardiac output'?

Hint Describe what happens to your cardiac output during exercise.

Extend Consider the two components of cardiac output. What are the long-term adaptations affecting your cardiac output due to an exercise programme?

Additional factors affecting the cardiovascular system

Regular training has many long-term benefits for the cardiovascular system. However, when considering any training programme there are a number of additional factors that can affect the cardiovascular system which will impact on exercise and sport performance. Therefore when starting any new training programme, and especially if you have not exercised for a long period of time, you should see a doctor to get checked over.

Sudden arrhythmic death syndrome (SADS)

Sudden arrhythmic death syndrome (SADS) is a genetic heart condition that can cause sudden death in young, apparently healthy people even though the person has no disease affecting the structure of the heart. If the heart's normal, natural rhythm becomes disrupted then the heart can stop beating, which can cause death. There have been a number of high-profile cases where elite sportspeople have suffered from SADS, such as Bolton Wanderers footballer Fabrice Muamba.

Case study

Fabrice Muamba

Fabrice Muamba was a professional footballer playing for Bolton Wanderers in the English Premier League. During an FA Cup match between Tottenham Hotspur and Bolton on 17 March 2012 he suffered a cardiac arrest (heart attack) and collapsed on the pitch.

Muamba received lengthy treatment on the pitch to revive him and he was transferred to a specialist heart hospital, where it was later revealed that his heart had stopped beating for 78 minutes. Muamba made a full recovery, although due to the seriousness of the incident he has retired from football.

This incident highlights that even elite athletes who are seemingly fit and healthy can suffer from serious illness, and many clubs now have regular specialist heart testing for all of their athletes.

In pairs, find out more about Sudden Arrhythmic Death Syndrome (SADS). Visit the Cardiac Risk in the Young (CRY) website, www.c-r-y.org.uk.

Check your knowledge

1. Find examples of SADS in sport.
2. What is being done to help protect sportspeople from SADS?
3. Report back your findings to the rest of the group.

▶ In 2012 footballer Fabrice Muamba, aged 23, collapsed on the pitch during Bolton Wanderers' game against Tottenham Hotspur

High and low blood pressure

The long-term benefits of exercising are enormous. However, exercise can affect your blood pressure, especially during exercise. When you start to exercise, your blood pressure will increase as your heart works harder and pushes more blood out of the heart with greater force. If you already suffer from high blood pressure (**hypertension**), this sudden increase in demand on the heart can be dangerous as too much force may be exerted on the heart and arteries. Anybody suffering from hypertension should seek medical advice before starting an exercise programme.

Low blood pressure (**hypotension**) means that your blood is moving slowly around your body, which can restrict the amount of blood reaching vital organs and muscles. Symptoms of low blood pressure include dizziness, fainting and tiredness. If you suffer from low blood pressure then it will be harder for your cardiovascular system to respond during exercise; if your muscles are not receiving enough oxygenated blood, this will affect performance. If insufficient blood is supplied to the brain then fainting may occur. As with hypertension, anybody suffering from hypotension should seek medical advice before starting an exercise programme.

Hyperthermia/hypothermia

All athletes should be aware of hyperthermia and hypothermia, and their causes and symptoms.

- **Hyperthermia** is the prolonged increase in body temperature that occurs when the body produces or absorbs too much heat. When you exercise your body produces heat as a waste product. Your cardiovascular system will regulate your body temperature by dilating the blood vessels closer to the body's surface and making you sweat so that the heat can dissipate. However, if you are exercising in a hot environment it is difficult for the heat to be removed. Likewise, if you are wearing incorrect clothing that traps the heat then you may suffer from hyperthermia.

Exercising in hot conditions can contribute to hyperthermia

- **Hypothermia** is where your body becomes too cold, with your core temperature dropping below 35°C. (The ideal internal body temperature for humans is 37°C.) Symptoms will include shivering, confusion and, in severe cases, an increased risk of your heart stopping. Hypothermia may occur if you are training in a cold environment without adequate clothing.

Assessment practice 1.4

1. Describe the pathway of blood flow from the heart through the major blood vessels to the body and lungs. **(4 marks)**
2. State the function of the bicuspid valve. **(1 mark)**
3. Describe the nervous control of the cardiac cycle. **(4 marks)**
4. Grace is a basketball player. The table shows Grace's heart rate at rest and then one minute before taking part in basketball. Grace has been taking part in regular basketball for over 8 months. In this time Grace's resting heart rate has decreased from 77 to 70 bpm (beats per minute). Explain why Grace's resting heart rate has decreased. **(3 marks)**

Resting heart rate (bpm)	Heart rate one minute before taking part in basketball (bpm)
70	80

5. Explain the change in Grace's heart rate shown in the two columns of the table. **(4 marks)**

Plan

- I will plan my answer and have a clear idea of the point I am making. I will make sure this point comes across in everything I write.
- When reading through a question, I will write down notes on a blank page.

Do

- I will try to answer all the simpler questions first and then come back to the harder questions.
- I will allow time to answer all the questions and to check my answers.

Review

- I will reread my answers and make any corrections.

E The effects of exercise and sports performance on the energy systems

All movement requires energy. The method by which your body generates energy is determined by the intensity and duration of the activity being undertaken. Activities that require short bursts of effort, such as sprinting or jumping, require the body to produce large amounts of energy over a short period. In contrast, marathon running or cycling require continued energy production over a longer period and at a slower rate.

The body's energy systems facilitate these processes. The energy systems of the body can function aerobically (with oxygen) or anaerobically (without oxygen). Movements that require sudden bursts of effort are powered by energy systems that do not require oxygen – anaerobic systems – whereas prolonged activities are aerobic and require oxygen.

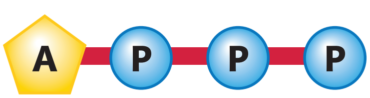
All energy systems work together, but the type of activity and its intensity will determine which system is predominant.

The role of ATP in exercise

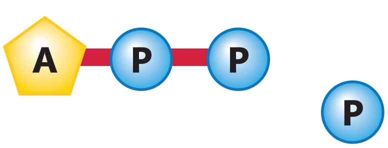
Energy is required in order to make the muscle fibres contract. This energy is obtained from the breakdown of foods in the diet, particularly carbohydrate and fat. The body maintains a continuous supply of energy through the use of **adenosine triphosphate (ATP)**, which is often referred to as the energy currency of the body.

ATP is a molecule that stores and releases chemical energy for use in body cells. When ATP is broken down, it gives energy for immediate muscle contractions. It is the only molecule that can supply the energy used in the contraction of muscle fibres (see Figure 1.20).

ATP consists of a base (adenine) and three phosphate groups. It is formed by a reaction between an **adenosine diphosphate (ADP)** molecule and a phosphate. Energy is stored in the chemical bonds in the molecules; when a bond is broken, energy is released.



(a) ATP is formed when adenosine diphosphate (ADP) binds with a phosphate



(b) When a cell needs energy, it breaks the bond between the phosphate groups to form ADP and a free phosphate molecule

Figure 1.20: ATP and energy released from the breakdown of ATP

ATP works like a rechargeable battery. Energy is released by converting ATP to ADP, which is the 'uncharged' form. By binding a phosphate back with the ADP to resynthesise ATP, the 'battery' is charged again and ready to be used for immediate and powerful muscular contractions.

However, your muscles have only very small amounts of ATP stored in them, so to replenish ATP quickly, the body has to use a number of other systems as well.

The ATP–PC (alactic) system in exercise and sports performance

The ATP–PC (alactic) system is **anaerobic**, which means that it does not require oxygen to produce energy. This is important in sports where sudden and powerful movements are required, such as shot put or sprinting, as the muscles can use ATP to produce energy and movement without having to 'wait' for oxygen to be delivered.

A muscle cell has a small amount of ATP in it that it can use immediately, but there is only enough to last for about three seconds. To replenish the ATP levels quickly, muscle cells also contain a high-energy phosphate compound called creatine phosphate (or phosphocreatine, or PCr). When the high-energy bond in PCr is broken, the energy it releases is transferred to ADP to resynthesise ATP.

The ATP–PC system only supports high-intensity exercise for short periods of time (approximately 10 seconds) as the PC store runs down quickly. If exercise continues at a high intensity these stores will only partially replenish, as there will not be enough energy available for creatine and phosphate to reform phosphocreatine. A ratio called the 'work-to-rest ratio' can be used to determine how quickly a system will replenish. For the ATP–PC system this ratio is 1 : 10–12. This means that for every second of work you need to allow 10–12 seconds for recovery.

The lactate system in exercise and sports performance

The lactate system is a short-term energy system and is used to meet energy requirements of higher intensity over a longer period, such as during a 400-metre race. It is an **anaerobic** process that does not require oxygen and therefore is not sustainable over a long duration.

The body breaks down most carbohydrates from the foods we eat and converts them to a type of sugar known as glucose. When the body does not need to use the glucose for energy, it stores some of it in the liver and muscles where it is easily accessible for energy production and is known as **glycogen.**

In the lactate energy system, ATP is made by the partial breakdown of glucose and glycogen through the process of **anaerobic glycolysis**. Around 60–90 seconds of maximal work are possible using this system.

Anaerobic glycolysis

When the ATP–PC system begins to fade at around 10 seconds, the process of anaerobic glycolysis begins. This system breaks down liver and muscle glycogen stores without needing the presence of oxygen. The breakdown of glucose and glycogen releases energy which can be used to resynthesise ATP; the breakdown of glucose produces two molecules of ATP, whereas the breakdown of glycogen can produce three molecules of ATP.

Lactic acid production

Unfortunately, anaerobic glycolysis produces lactic acid as a by-product. Lactic acid is the limiting factor of the anaerobic system. It accumulates and diffuses into the tissue fluid and blood. If this substance is not removed quickly enough by the circulatory system, it builds up to impede muscle contraction and cause fatigue. You may have experienced this as an uncomfortable burning sensation and soreness in your muscles during intense exercise.

A recovery time of approximately eight minutes will aid the removal of lactic acid from the muscles as well as the storage of glycogen in your muscles.

The aerobic system in exercise and sports performance

The **aerobic** energy system is the long-term energy system. If plenty of oxygen is available, as it is during everyday movements and light exercise, glycogen and fatty acids break down to yield the largest amounts of ATP. This produces carbon dioxide and water, which do not affect the ability of muscles to contract, unlike the lactic acid produced by the lactate system.

Aerobic energy production occurs in the mitochondria of the muscle cells. The aerobic system relies on the breakdown of carbohydrates and stored fats to produce energy, and improved aerobic fitness makes it easier for the body to convert these food sources.

The production of energy within the aerobic system is slow to engage because it takes a few minutes for the heart to deliver oxygenated blood to working muscles. Long, continuous and moderate exercise, such as long-distance running, produces energy using this system.

The aerobic energy system can be broken down into three processes.

1 **Aerobic glycolysis** – this is the first stage of **aerobic metabolism** (the breakdown of foods into energy). It converts carbohydrates (in the form of either glucose or glycogen) into pyruvic acid using oxygen. This breakdown requires 10 chemical reactions: another reason why the aerobic system is slower to deliver energy and is suited to steady sports performance. The process of aerobic glycolysis produces two molecules of ATP.

2 **Krebs cycle** – sometimes known as the **citric acid cycle**, this is the second phase in the process of anaerobic metabolism. It takes place in the mitochondria. The pyruvic acid that was produced during aerobic glycolysis enters the mitochondria and is converted to citric acid. This results in two molecules of ATP being produced, with carbon dioxide and hydrogen being produced as waste products. The carbon dioxide will be exhaled by the lungs and the hydrogen will be used in the next phase of energy production, the electron transport chain.

3 **Electron transport chain** – the hydrogen that was released as part of the Krebs cycle is vital in the production of energy. The electron transport chain is the most important step in energy production and is where the majority of ATP is created. This process will create 34 molecules of ATP from glucose. The hydrogen created as part of the Krebs cycle is accepted by the hydrogen acceptor found in the mitochondria where, in the presence of oxygen, ATP can be produced.

In total the aerobic energy system will produce 38 molecules of ATP from one molecule of glucose. Depending on the duration and intensity of the exercise, as well as your level of fitness, recovery of the aerobic energy systems can range from a few hours to 2–3 days.

The energy systems in combination

During exercise the body does not switch from one system to another – energy at any time is derived from all three systems. However, the emphasis changes depending on the intensity of the activity relative to the efficiency of your aerobic fitness, i.e. your ability to deliver and utilise oxygen. Table 1.6 shows different types of sport and the relative contributions made by the different energy systems. Figure 1.21 illustrates the contribution of different energy systems during exercise.

When you start running, the following process takes place.

- The muscle cells burn off the ATP they already contain in about three seconds.
- The creatine phosphate system kicks in and supplies energy for 8–10 seconds. This would be the major energy system used by the muscles of a 100-metre sprinter or a weightlifter, where rapid acceleration, short-duration exercise occurs.
- If exercise continues, the lactic acid energy system kicks in. This occurs in short-distance exercises such as a 200- or 400-metre run or a 100-metre swim.
- If exercise continues, the aerobic energy system takes over. This occurs in endurance events such as an 800-metre run, a marathon run, rowing, cross-country skiing and distance skating.

Table 1.6: The different lengths of time for each energy system, with sport examples

Duration	Classification	Energy supplied by	Sport example
1–3 seconds	Anaerobic	ATP (in muscles)	A punch in boxing
3–10 seconds	Anaerobic	ATP + PC	100-metre sprint
10–45 seconds	Anaerobic	ATP + PC + muscle glycogen	200-metre run
45 seconds–2 minutes	Anaerobic, Lactic	Muscle glycogen	400-metre run
2 minutes–4 minutes	Aerobic + Anaerobic	Muscle glycogen + lactic acid	1500-metre run
Over 4 minutes	Aerobic	Muscle glycogen + fatty acids	Marathon running

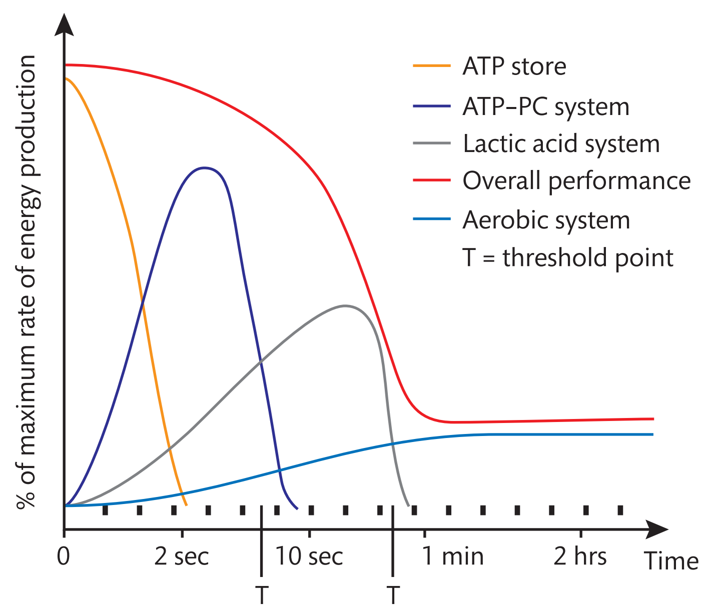


Figure 1.21: The contribution of different energy systems during exercise

PAUSE POINT Why do different sports use different energy systems?

Hint Choose a sport. What is the main energy system that is used?

Extend Now consider a team sport and a specific position. Are different energy systems used during a performance? If so, why?

Case study

Mo Farah versus Usain Bolt

As part of his charity, the Mo Farah Foundation, Mo Farah has challenged the world 100-metre champion, Usain Bolt, to race over a distance that would not suit either runner. Mo Farah is the current Olympic champion over 5000 metres and 10,000 metres, while Usain Bolt is the Olympic champion over 100 metres and 200 metres. Farah has suggested that they race between 600–800 metres.

1. Suggest an optimum distance that would be fair for both athletes.
2. Why do you think that one athlete is better suited to one distance than another distance?

Adaptations of the energy systems to exercise

Long-term exercise will allow the body's energy systems to adapt to the physical demands of exercise. This means that by following an exercise programme it is possible to train each energy system so that you can perform for longer and at increasingly harder intensities.

Increased creatine stores

Short-duration, interval training sessions using high-intensity exercises will improve your ability to produce anaerobic energy. Your body will adapt and be able to store more creatine in the muscles which will improve the ATP–PC system. This will result in you being able to exercise anaerobically for longer using fast and powerful movements.

Increased tolerance to lactic acid

Anaerobic training stimulates the muscles to become better able to tolerate lactic acid and to clear it away more efficiently. With endurance training the capillary network extends, allowing greater volumes of blood to supply the muscles with oxygen and nutrients. The muscles are able to use more fat as a fuel source and become more efficient at using oxygen, increasing the body's ability to work harder for longer without fatiguing. The net result is an increase in the body's maximal oxygen consumption.

Aerobic energy system

Long-term exercise will improve the ability of the aerobic energy system to produce energy, as improvements in the cardiovascular system will allow for increased oxygen to be delivered which is needed to produce ATP aerobically. Likewise, adaptations of the cardiovascular system will aid the removal of lactic acid through oxidisation.

Increased use of fats as an energy source

Fat is the primary energy source during low-intensity exercise. Fat combustion powers almost all exercise at approximately 25 per cent of **aerobic capacity** (which is approximately 60–70 per cent of your maximum heart rate). Fat oxidation increases if exercise extends to long periods, as glycogen levels deplete. When considering the effects of long-term exercise, the trained athlete has a greater opportunity to burn fat as a fuel than the non-trained athlete because they have a more efficient system of delivering oxygen to the working muscle, as well as a greater number of mitochondria.

Key term

Aerobic capacity – the maximum amount of oxygen that can be consumed during maximal exercise.

Increased storage of glycogen and increased numbers of mitochondria

Muscles increase their oxidative capacity with regular training. This is achieved by an increase in the number of mitochondria within the muscle cells, an increase in the supply of ATP and an increase in the quantity of enzymes involved in respiration. The ability of the muscles to store more glycogen is also increased, meaning that anaerobic glycolysis can last for longer.

Link

You can find more information on this topic in *Unit 5: Application of Fitness Testing*.

Additional factors affecting the energy systems

There are two main additional factors that must be considered when examining the energy systems and their impact on sport and exercise performance.

Diabetes and hypoglycaemic attack

Diabetes is a condition where the amount of glucose in your blood is too high. This is known as type I diabetes. It develops when glucose cannot enter the body's cells to be used as fuel. **Insulin** is the hormone produced by the pancreas that allows glucose to enter the body's cells, where it is used as fuel for energy. If you have diabetes, your body cannot make proper use of this glucose so it builds up in the blood and cannot be used.

Hypoglycaemia is an abnormally low level of glucose in your blood. When your glucose (sugar) level is too low, your body does not have enough energy to carry out its activities. Hypoglycaemia mainly occurs if someone with diabetes takes too much insulin, misses a meal or exercises too hard. Typical early warning signs are feeling hungry, trembling or shakiness, and sweating. Additional symptoms include confusion, and you may have difficulty concentrating. In severe cases, a person experiencing hypoglycaemia can lose consciousness.

Children's lack of lactate system

Although we all possess the same body systems, a child's body systems are still growing and developing, with significant changes occuring during puberty. One such area is the lactate energy system, which is not fully developed in children. During high-intensity exercise, lactic acid will build up in the muscles and, due to their developing cardiovascular system, it is more difficult for children to remove this waste product. Therefore it is generally recommended that children exercise aerobically.

Assessment practice 1.5

1 Explain why it is an advantage for marathon runners to have high numbers of mitochondria. **(2 marks)**

2 Describe the process of ATP production from carbohydrates through the aerobic energy system. **(5 marks)**

3 The graph (Figure 1.22) shows the ATP–PC stores in a performer's muscles while competing in a rugby match. Explain why playing in a rugby match will have this effect on muscle ATP–PC stores. **(3 marks)**

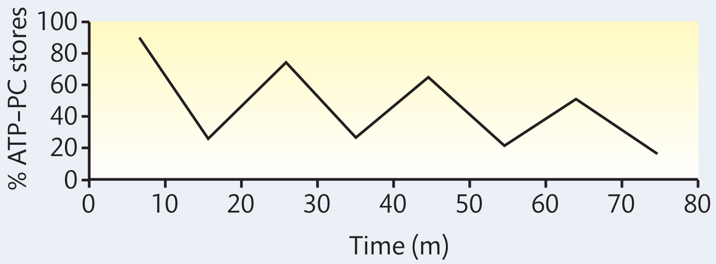


Figure 1.22: ATP is the only immediately usable source of energy in the human body

4 Compare and contrast the importance of the aerobic and anaerobic energy systems for an elite 100-metre sprinter in competition and in training. **(8 marks)**

5 Denise is training for a marathon. Analyse how adaptations to Denise's cardiorespiratory system could improve her marathon-running performance. **(8 marks)**

6 Identify four key long-term adaptations that are linked to aerobic training and explain the benefit of each adaptation. **(8 marks)**

Plan

- I will listen to, and read carefully, any instructions that I am given.
- I will look for the command words in the question and plan a response to them.

Do

- I will make sure I write a detailed response for the questions with more marks.
- I will include key words and information and use them to structure my answer.

Review

- I will check that I have answered all the questions.
- I will check that I have given examples and that they are clear.

Further reading and resources

Books

Bartlett, R. (2014) *Introduction to Sports Biomechanics*, London: Routledge.

Marieb, E. (2015) *Human Anatomy and Physiology*, Oxford: Pearson.

Palastanga, N. (2012) *Anatomy and Human Movement: Structure and Function*, London: Churchill Livingstone.

Sharkey, B.J. and Gaskill, S.E. (2006) *Fitness and Health*, Champaign, IL: Human Kinetics.

Tortora, G.J. and Derrickson, B.H (2008) *Principles of Anatomy and Physiology*, London: John Wiley and Sons.

Websites

www.humankinetics.com – Human Kinetics: educational resources relating to all areas of sport and physical activity.

www.sportsci.org – Sport Science: research into sport, including articles considering the functions of different bodily systems in sport.

www.topendsports.com – Top End Sports: information on many aspects of anatomy and physiology.

THINK FUTURE

Helen Reardon

Sports Therapist

I have been working as a sports therapist for seven years, and over this time I have worked with a wide range of people in a variety of places. In any given day I will work with different people, each of whom will have specific fitness goals. For example, I may provide one-to-one support for somebody training to run a marathon or work with an athlete who is returning from a long-term injury.

Having a detailed knowledge of anatomy and physiology is essential to my job, as I have to understand how each body system works and how the body will be affected by exercise. In particular I have to understand anatomy and physiology so that I can manage and prevent sporting injuries. It is essential that I understand the adaptations the body makes so that I can set each of my clients personal and challenging goals and develop specific training programmes. Often I will be working with clients who are returning from injury, so it is essential that the programmes I set are at the correct level so that the injury does not reoccur. I have to ensure that each of my clients can train safely and use the correct techniques so that they do not injure themselves.

As part of my job I am responsible for providing sports massage and giving advice on preventive and rehabilitative exercises to help prevent and manage injuries. My work also involves testing joints for ease and range of movement, strapping and taping, and advising on stretching and warm-up and cool-down exercises.

One of the most important skills for a successful sports therapist is the ability to motivate people. Being able to get a client to reach their goal when they are tired or returning from injury is challenging but also one of the most rewarding parts of my job. Seeing individuals and teams achieve their long-term goals and knowing that you were key to their success is hugely satisfying.

Focusing your skills

Think about the role of a personal trainer. Consider the following questions.

- What types of people will you work with and how will you support them?
- What role will you play in helping them achieve their goals?
- What different types of exercise will you recommend and how will these affect each of the body's systems?
- What types of training goals will you need to help people with? Will you work with elite athletes or people who are trying to lose weight?
- What skills do you currently have? What skills do you think may need further development?

Getting ready for assessment

This section has been written to help you to do your best when you take the assessment test. Read through it carefully and ask your tutor if there is anything you are still not sure about.

About the test

The assessment test will last 1 hour and 30 minutes and there is a maximum of 90 marks available. The test is in one section and will ask a range of short answer questions as well as some longer answer questions worth up to 8 marks.

Remember that all the questions are compulsory and you should attempt to answer each one. Consider the question fully and remember to use the key words to describe, explain and analyse. For longer questions you will be required to include a number of explanations to your response; plan your answer and write in detail.

Preparing for the test

To improve your chances on the test you will need to make sure you have revised all the key **assessment outcomes** that are likely to appear. The assessment outcomes were introduced to you at the start of this unit.

Do not start revising too late! Cramming information is stressful and does not work.

Useful tips

- **Plan a revision timetable** – identify all the topics you need to revise and try to spend several short revision sessions on each of them. Coming back to each topic several times will help you to reinforce the key facts in your memory.
- **Take regular breaks** – short bursts of 30–40 minutes are more effective than long hours of revision. Remember, most people's concentration lapses after an hour and they need a break.
- **Allow yourself rest** – do not fill all your time with revision. You could schedule one evening off a week, or book in a 'revision holiday' of a few days.
- **Take care of yourself** – stay healthy and rested, and eat properly – this will help you to perform at your best. The less stressed you are, the easier you will find it to learn.

Revise all the key areas likely to be covered – draw up a checklist to make sure you do not forget anything!

Read each question carefully before you answer it to make sure you understand what you have to do.

Sitting the test

- Listen to, and read carefully, any instructions you are given. Lots of marks are lost because people do not read questions properly and then fail to complete their answers correctly.
- Most questions contain command words (see Table 1.1). Understanding what these words mean will help you understand what the question is asking you to do.
- The number of marks can relate to the number of answers you are expected to give – if a question asks for two examples, do not only give one! Similarly, do not offer more information than the question needs: if there are two marks for two examples, do not give four examples.
- Plan your time carefully. Work out what you need to answer and then organise your time. You should spend more time on longer questions. Set yourself a timetable for working through the test and then stick to it – do not spend ages on a short 1–2 mark question and then find you only have a few minutes for a longer 7–8 mark question.
- It is useful when reading through a question to write down notes on a blank page. This way you can write down all the key words and information required and use this to structure your answer.
- If you are writing an answer to a longer question, try to plan your answer before you start writing. Have a clear idea of the point you want to make, and then make sure this point comes across in everything you write.
- If you finish early, use the time to re-read your answers and make any corrections – this could really help to make your answers even better and could make a big difference to your final mark.

Sample answers

For some questions you will be given some background information on which the questions are based. Look at the sample questions which follow and our tips on how to answer them well.

Answering short answer questions

- ☐ Read the question carefully and highlight or underline key words.
- ☐ Note the number of marks available.
- ☐ Make additional notes that you can include in your answer.
- ☐ Make the same number of statements as there are marks available. For example, a two-mark question needs two statements.

Worked example

Explain the effects of taking part in exercise on tidal volume. [3]

Answer: Tidal volume increases during exercise because during exercise a person has to take in (inhale) more air. More air is required as it contains oxygen which is needed to provide energy for the working muscles.

This answer gives a brief description of what happens to tidal volume during exercise (1 mark) plus an explanation of how (1 mark) and why this increases (1 mark).

Answering extended answer questions

Example:

Craig is a 17-year-old swimmer who has asthma. Discuss the effects of participating in swimming on the respiratory system for an individual suffering with asthma. [6]

For a question using the word 'discuss', you must do more than just explain. You might need to talk about the issues or the advantages (positive) and disadvantages (negative) of an approach or theme.

Answer: Craig may experience both positive and negative effects of swimming. The positive aspects of swimming for an asthma sufferer are that the air breathed in will be moist and warm, which reduces the chances of an exercise-induced asthma attack. Exercise will also increase Craig's vital capacity and strengthen the respiratory muscles. This will allow more air to be breathed, which will help reduce the effects of asthma.

The negative or disadvantage of exercise for Craig is that he may suffer from an exercise-induced asthma attack. This may result in wheezing while breathing or coughing. Craig may experience tightness in his chest. If asthma occurs then the bronchi may become inflamed or the airways might narrow, which will reduce the amount of air getting into the lungs.

This answer describes the causes and symptoms of asthma in general as well as in relation to exercise. Further discussion includes the advantages and disadvantages of exercise with specific reference made to swimming.

When answering an extended answer question, you may write several paragraphs. Remember to make notes before you start to answer the question and ensure that you plan all aspects of your longer answer to gain all the available marks.