Anatomy notes

Inspiration

Expiration

SPORTS NUTRITION PYRAMID
A GUIDE TO DAILY FOOD CHOICES FOR ACTIVE PEOPLE
An analysis of human movement: joints, muscles and mechanics.

What you need to know:

- Analyse shoulder and elbow action in push-ups, over-arm throwing and forehand racket strokes
- Analyse hip, knee and ankle action in running, kicking, jumping and squats.

Analysing these actions means knowledge of the following:

- The type of joint, articulating bones, joint actions, main agonists and antagonists, types of muscle contraction: concentric, eccentric and isometric related to these sporting actions.
- Relate the movements occurring at joints to planes and axes
- Identify the three classes of lever and give examples of their use in the body.
- Explain the relationship of levers to effective performance, with reference to mechanical advantages and disadvantages and range and speed of movement.

The Skeleton.
The skeleton is made up of 206 bones. It comprises the axial skeleton which is made up of the skull, vertebral column, the sternum and the ribs as well as the appendicular skeleton which composes the shoulder girdle, the hip girdle, the bones of the arms, hands, legs and feet.

The skeleton can perform the following functions:

- Support – the skeleton provides a rigid framework to the body.
- Levers – the bones act as a lever system allowing movement.
- Attachment – the skeleton provides suitable sites for the attachment of muscles.
- Protection – the skeleton can protect internal organs, for example, the cranium protects the brain and the rib cage protects the heart and lungs.
- Red blood cell production – within the bone marrow of the skeleton both red and white blood cells can be produced.
- Shape – the skeleton gives the body shape.
Top tip: you will not be asked to label a skeleton in your exam but you do need to know the names of the bones that articulate at the ankle, knee, hip, shoulder and elbow.
Joints

The skeleton is a framework joined together by joints. Joints are necessary for muscles to lever bones, thus creating movement. A joint is formed where any two or more bones meet. Joints are classified by how much movement they allow. There are three types:

1. *Fibrous joint.*
   This allows no movement, it is a completely fixed joint. There is no joint cavity and the bones are held together by fibrous, connective tissue. Examples of this type of joint can be found in the cranium, facial bones and pelvic girdle.

2. *Cartilaginous joint.*
   This allows only a slight amount of movement, it is referred to as a cartilaginous joint, as the bones are separated by cartilage. Examples of this type of joint are the ribs joining the sternum and the vertebrae joining the spine.

3. *Synovial joint.*
   This allows movement in one or more directions and is the most common of the three joints. These joints have a fluid filled cavity surrounded by an articular capsule. Hyaline/articular cartilage can be found where the bones come into contact with each other. There are six types of synovial joints:

   a) Ball and socket joint.
   This allows movement in every direction. It is formed by the round head of one bone fitting into the cup shaped capsule of the connecting bone. Examples are the hip and the shoulder joint.

   **Hip**
   ![Diagram of a hip joint](image-url)
b) Hinge joint.

This allows movement in only one direction, due to the shape of the bones making up the joint. Examples of this type of joint can be found at the ankle, knee and hip.

Top Tips:
Note the fibula stops before it reaches the knee so is not an articulating bone at this joint. The inclusion of this bone in exam answers is a common error!
c) Pivot joint

This allows only rotational movement where the head of one bone fits into a notch on another. Examples of this type of joint include the atlas and axis vertebrae in the neck (cervical 1 and 2) and the joint between the radius and ulna.

d) Condyloid joint.

This is similar to a hinge joint but instead of allowing movement in one direction it also allows sideways motion. It does this due to the dome shaped surface of one bone fitting into the hollow shaped depression of the other. An example of this type of joint is found in the wrist.

e) Gliding joint

This joint only allows slight movement in every direction between two flat surfaces. Examples can be found between the small bones of the wrist (metacarpals) and the feet (metatarsals) as well as the articular processes of the vertebrae.

f) Saddle joint

The bones making up this joint are either concave or convex. These surfaces are placed together allowing movement at right angles. This joint can be found at the thumb.

Tasks to tackle:

As the syllabus only requires knowledge of the hip, shoulder, elbow, knee and ankle, using the labelled skeleton on page 3 try to work out the articulating bones for these joints in the table below:

<table>
<thead>
<tr>
<th>Joint</th>
<th>Joint type</th>
<th>Articulating bones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle</td>
<td>Hinge</td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>Hinge</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>Ball and socket</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Ball and socket</td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>hinge</td>
<td></td>
</tr>
</tbody>
</table>

Although there are several types of synovial joints the syllabus only requires knowledge of the hip, shoulder, elbow, knee and ankle.
Planes and Axes

To help explain movement it is possible to view the body as having a series of imaginary lines running through it. These are referred to as planes of movement and divide the body up in three ways:

- The sagittal (median) plane: this is a vertical plane, which divides the body into right and left halves.
- The frontal (coronal) plane: this is also a vertical plane that divides the body into front and back halves.
- Transverse plane (horizontal): this divides the body into upper and lower halves

When performing an activity a body or body parts will move in one of these planes or in all three of them depending on the action being performed. In a full twisting somersault, for example, the gymnast will move in all three planes.

There are three axes of movement about which rotation occurs:

- Transverse axis that runs from side to side across the body
- Sagittal axis which runs from front to back
- Vertical axis that runs from top to bottom

Most movements occurring at joints are related to both axes and planes. Flexion and extension, for example, occurs in a sagittal plane about a transverse axis, rotation occurs in a transverse plane about a vertical axis and abduction and adduction occurs in a frontal plane about a sagittal axis
Movement Terminology

Movements in a sagittal (median) plane

*Flexion:* this occurs when there is a decrease in the angle that occurs around a joint, for example, bending the arm at the elbow causes the angle between the radius and humerus to decrease.

*Extension:* an increase in the angle that occurs around a joint, for example, straightening the knee causes an increase in the angle between the femur and tibia.

*Plantar flexion:* is a term used solely for the ankle joint. It involves pointing the foot downwards away from the tibia (standing on your tiptoes).

*Dorsiflexion:* bending the foot upwards towards the tibia.
Movements in a frontal (coronal) plane

**Abduction:** this is when movement occurs away from the midline of the body, for example, raising the arms out to the side away from the body.

**Adduction:** this is when movement occurs towards the midline of the body, for example, lowering the arms back to the sides of the body.

Top tip: if something is abducted it is taken away. Look at the word adduction – think of adding the arm or leg back to the body

Movements in a transverse (horizontal) plane

**Horizontal adduction (also called horizontal flexion):** arm moves forward across the body at 90° of shoulder adduction, for example, raise your arm out to the side till it is parallel to the floor (abduction of the shoulder) then move the arm back towards the body keeping it parallel all the way.

**Horizontal abduction (also called horizontal extension):** arm moves backward across the body at 90° of shoulder abduction, for example, raise your arm forward and hold it at 90° (flexion of the shoulder), then move it towards the outside of your body
Rotation: movement of a bone around its axis. This rotation can be inward (medial) or outward (lateral)

Movement in two planes: sagittal and transverse

Circumduction: this is when the lower end of the bone moves around in a circle. It is a combination of flexion, extension, abduction and adduction. Circumduction occurs at the shoulder and hip joints.
Tasks to tackle: work out the types of movement that can take place at each joint and complete the table

<table>
<thead>
<tr>
<th></th>
<th>Elbow</th>
<th>Shoulder</th>
<th>Hip</th>
<th>Knee</th>
<th>Ankle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal abduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circumduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsi flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Label the movement in the hip, knee and ankle of the runner footballer and volleyball player and label the movement occurring in the shoulder and elbow in the press-up
Actions of Muscles

A joint cannot move by itself, it needs muscles to move bones into position. Muscles are attached to bone by tendons and the ends of the muscle are referred to as the origin and the insertion. The origin is the end of the muscle attached to a stable bone and the insertion is attached to the bone that moves.

When muscles contract they shorten and bulge and the insertion moves closer to the origin. If we use the biceps brachii as an example, the origin is on the scapula and the insertion is on the radius. The bicep is responsible for flexion of the elbow and when the muscle contracts the radius moves upwards towards the shoulder, thus moving the insertion closer to the origin.

When the biceps brachii contracts it is responsible for the movement that is occurring and is said to be acting as an agonist or prime mover. There can be more than one agonist acting at a joint although this does depend on the type of movement that is being performed. An antagonist muscle is one that works in opposition to the agonist, so when the biceps brachii is contracting the triceps brachii is lengthening and acting as the antagonist.
**Key term:** agonist is the muscle that is responsible for the movement that occurring

**Key term:** antagonist is the muscle that works in opposition to the agonist (to help produce a co-ordinated movement

When one muscle is acting as an agonist and the other is acting as the antagonist, the muscles are said to be working together as a pair to produce the required movement. This arrangement is commonly referred to as antagonistic muscle action. If we look at flexion of the knee, the hamstrings are the agonist and the quadriceps are the antagonist.

As well as antagonistic muscle pairs other muscles contract causing joint movement to be stable. These are fixator muscles. *Fixators* are muscles that stabilise the origin so that agonists can work more efficiently. For example in the upward phase of an arm curl the biceps brachii is the agonist, the triceps brachii is the antagonist and the deltoid is the fixator. You will be able to feel tension in the deltoid as it helps to stabilise the shoulder joint.

**Top tips:**

Be careful: sometimes the agonist does not automatically become the antagonist when the movement changes, for example, flexion to extension. In the downward phase of the biceps curl most students think that the bicep is now the antagonist, but it is still the agonist as it is now lengthening as it contracts in order to control the lowering of the forearm while it supports the weight.

**Examined Joints**

**The Elbow Joint**

The elbow is a hinge joint, with the distal (far) end of the humerus articulating with the proximal (near) end of the radius and ulna. Movement can only take place in one plane, allowing only flexion and extension.
**The Shoulder Joint**

This is a ball and socket joint where the head of the humerus fits into a cavity on the scapula called the glenoid fossa. This type of joint allows the most movement, because of the shallowness of the joint cavity. However its structure also makes it one of the most unstable joints so it is heavily reliant on ligaments and muscles to increase its stability.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Agonist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Biceps brachii</td>
</tr>
<tr>
<td>Extension</td>
<td>Triceps brachii</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Movement</th>
<th>Agonist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Anterior deltid</td>
</tr>
<tr>
<td>Extension</td>
<td>Posterior deltid</td>
</tr>
<tr>
<td>Abduction</td>
<td>Middle deltid</td>
</tr>
<tr>
<td>Adduction</td>
<td>Latissimus dorsi</td>
</tr>
<tr>
<td>Lateral rotation</td>
<td>Teres minor</td>
</tr>
<tr>
<td>Medial rotation</td>
<td>Subscapularis</td>
</tr>
<tr>
<td>Horizontal abduction</td>
<td>Latissimus dorsi</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>Pectoralis major</td>
</tr>
</tbody>
</table>
**Top tip:** make it easy for yourself. You need to know one muscle for each of the movements so learn each of the different sections of the deltoid as it covers 3!

**The Hip Joint**

The hip is a ball and socket joint where the head of the femur fits into the acetabulum of the pelvis. The joint cavity for the hip is much deeper than the shoulder thus making the hip more stable but less mobile than the shoulder joint. The addition of strong ligaments surrounding the hip joint decrease its mobility even more but at the same time this makes dislocation very difficult.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Agonist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Ilio psoas</td>
</tr>
<tr>
<td>Extension</td>
<td>Gluteus maximus</td>
</tr>
<tr>
<td>Abduction</td>
<td>Gluteus medius</td>
</tr>
<tr>
<td>Adduction</td>
<td>Adductors</td>
</tr>
<tr>
<td>Lateral rotation</td>
<td>Gluteus maximus</td>
</tr>
<tr>
<td>Medial rotation</td>
<td>Gluteus medius</td>
</tr>
</tbody>
</table>

**The Knee Joint.**

The knee is classed as a hinge joint but this not strictly true as some rotation is allowed to enable full rotation and locking of the knee. The femur articulates with the tibia (not the fibula). Strong ligaments are present in order to prevent any sideways movement.
The Ankle Joint

The ankle is a hinge joint where the articulating bones are the tibia, fibula and talus.
Types of muscular contraction

A muscle can contract in three different ways, depending on the muscle action that is required.

**Concentric contraction**

This is when a muscle shortens under tension, e.g., during the upward phase of an arm curl, the biceps brachii performs a concentric contraction as it shortens to produce flexion of the elbow.

**Key term:** concentric contraction when a muscle shortens under tension

**Eccentric contraction**

This is when the muscle lengths under tension (and does not relax). When a muscle contracts eccentrically it is acting as a brake in helping to control the movement of a body part during negative work. An example could be in landing from a standing jump. Here the quadriceps are performing negative work as they are supporting the weight of the body during landing. The knee joint is in the flexed position but the quadriceps are unable to relax as the weight of the body ensures that they lengthen under tension.

**Key term:** eccentric contraction when a muscle lengthens under tension

**Isometric contraction**

This is when a muscle can contract without actually lengthening or shortening and the result is that no movement occurs. An isometric contraction occurs when a muscle is acting as a fixator or acting against a resistance.

**Key term:** isometric contraction when a muscle is under tension but there is no visible movement

If we use the bicep curl as an example

a) During the upward phase the bicep brachii is contracting to produce flexion of the elbow joint. In this situation it is performing a concentric contraction.

b) During the downward phase if you put your hand on a partner's bicep brachii you will still feel tension. This means the muscle is not relaxing but performing an eccentric contraction where it lengthens under tension.

c) If the weight is held still at a 90 degree angle, the bicep brachii is under tension even though we do not see any movement. This is an isometric contraction.
**Top tip:** eccentric is the type of contraction most misunderstood. Remember it is a contraction so the muscle cannot be relaxing, it is lengthening under tension.

**Tasks to tackle:**

Complete the table below when performing a press-up.

1. Perform the downward phase of a press-up
   a) What is happening at the elbow joint?
   b) Which muscle is contracting?
   c) What type of contraction is it performing?

2. Now perform the upward phase of a press-up
   a) What is happening at the elbow joint?
   b) Which muscle is contracting?
   c) What type of contraction is it performing?

3. Try to hold the press-up in the downward phase
   a) Which muscle feels as if it is contracting
   b) What type of contraction is it performing?

<table>
<thead>
<tr>
<th>Movement</th>
<th>Muscle</th>
<th>Type of contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Levers

A lever consists of three main components, namely: a pivot (fulcrum); weight to be moved (resistance) and source of energy (effort or force). In the body the skeleton forms a system of levers that allows us to move. The bones act as the levers, the joints are the fulcrums and the effort is provided by the muscle.

A lever has two main functions:
1. To increase the speed at which a body can move.
2. To increase the amount of resistance that can be overcome by a force.

Classification of levers.

Levers can be classified into three types:

1. First Order Levers – in a first order lever the fulcrum is between the effort and the resistance. This type of lever can increase the effects of the effort and the speed of a body. An example of this type can be seen in the movement of the head and neck during flexion and extension and in the action of extending the limbs, for example, the arm or the lower leg.

   ![First Order Lever Diagram]

2. Second Order levers – here the resistance lies between the fulcrum and the effort. This type of lever is generally thought to increase only the effect of the effort force (i.e. it can be used to overcome heavy loads). Plantarflexion of the ankle involves the use of a second order lever.

   ![Second Order Lever Diagram]
3. Third Order Levers – are responsible for the majority of movements in the human body. They can increase the body’s ability to move quickly but in terms of applying force they are very inefficient. Here the effort lies between the fulcrum and the resistance and can be seen in the forearm during flexion.

![Fulcrum Diagram](image)

Top tip: if you are asked to classify and label a lever, make sure you do not abbreviate, for example use the label ‘effort’ not the letter ‘E’

Tasks to Tackle:

Label the fulcrum, effort and resistance for flexion of the elbow on this diagram:

---

**Force arm** – the name given to the shortest perpendicular distance between the fulcrum and the application of force (effort).

**Resistance arm** – the shortest perpendicular distance between the fulcrum and the resistance. The force and resistance arm can be seen in the 3rd order lever below:

![Diagram](image)
When the resistance arm is greater than the force arm, the lever system is at a **mechanical disadvantage**. This means that the lever system cannot move as heavy a load but can do it faster. **Mechanical advantage** is when the force arm is longer than the resistance arm. This means that the lever system can move a large load over a short distance and requires little force.

**Key term:** mechanical advantage is when the force arm is longer than the resistance arm  
**Key term:** mechanical disadvantage when the resistance arm is greater than the force arm

**Length of Lever.**

Most levers in the body are third class levers and here the resistance arm is always greater than the effort arm (mechanical disadvantage). The longer the resistance arm of the lever the greater the speed will be at the end of it. This means that if the arm is fully extended when bowling or passing the ball will travel with more force and therefore more speed. The use of a cricket bat, racket and golf club all extend the arm and allow more force

**Top Tip:**
AQA only ask you to analyse five joints. They are all 3\(^{rd}\) order levers except for the ankle which is a 2\(^{nd}\) order lever and extension of the elbow and knee joints which are 1\(^{st}\) order levers.

1. Name and sketch the lever system that operates at the ankle joint. [3]

2. What do you understand by the terms mechanical advantage and mechanical disadvantage [4]
Joint Movement Analysis-putting everything together!!

For the AQA specification you have to perform a movement analysis of the following skills:

**Shoulder and elbow action in the forehand**

<table>
<thead>
<tr>
<th>Movement</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever System</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Shoulder and elbow action in a throw**

<table>
<thead>
<tr>
<th>Movement</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever System</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Elbow action in a press-up

![Elbow action in a press-up](image)

<table>
<thead>
<tr>
<th>Movement-Phase</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upward phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downward phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Hip, knee and ankle action in a kick

![Hip, knee and ankle action in a kick](image)

<table>
<thead>
<tr>
<th>Movement a-c</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Hip, knee and ankle action in a jump

<table>
<thead>
<tr>
<th>Movement Upward phase</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Knee and ankle action in a squat

<table>
<thead>
<tr>
<th>Movement Downward phase</th>
<th>Agonist</th>
<th>Plane</th>
<th>Axis</th>
<th>Type of contraction</th>
<th>Lever system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Complete the movement analysis table below of the hip, knee and ankle action in the drive and recovery phase of running.

![Image](image_url)

Drive – always the leg in contact with the ground.

<table>
<thead>
<tr>
<th>Hip action</th>
<th>Recovery</th>
<th>Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Agonist</td>
<td>Plane</td>
</tr>
<tr>
<td>Knee action</td>
<td>Recovery</td>
<td>Drive</td>
</tr>
<tr>
<td>Movement</td>
<td>Agonist</td>
<td>Plane</td>
</tr>
<tr>
<td>Ankle action</td>
<td>Recovery</td>
<td>Drive</td>
</tr>
<tr>
<td>Movement</td>
<td>Agonist</td>
<td>Plane</td>
</tr>
</tbody>
</table>

26
Cardiac Function

What You Need To Know:

- Describe the stages of the cardiac cycle and understand how it is linked to the conduction system
- Give definitions of cardiac output, stroke volume and heart rate and explain the relationship between them
- Understand Starling’s law of the heart
- Explain heart rate range in response to exercise and describe the hormonal and nervous effects on heart rate
- Explain the role of blood carbon dioxide in changing heart rate
- Explain cardio-vascular drift.
- Describe the concept of cardiac hypertrophy and how it leads to bradycardia/athlete’s heart

Chambers of the heart

The heart is divided into two parts by a muscular wall called the septum and each part contains an atrium and a ventricle. The atria are smaller than the ventricles as all they do is push the blood down into the ventricles. This does not require much force so they have thinner muscular walls. The ventricles have much thicker muscular walls as they need to contract with greater force in order to push blood out of the heart. The left side of the heart is larger as it needs to pump blood all round the body whereas the right side pumps deoxygenated blood to the lungs which are in close proximity to the heart.
**Blood Vessels of the heart**

Several blood vessels are attached to the heart. The vena cava brings deoxygenated blood back to the right atrium and the pulmonary vein delivers oxygenated blood to the left atrium. The pulmonary artery leaves the right ventricle with deoxygenated blood to go to the lungs and the aorta leaves the left ventricle with oxygenated blood leading to the body. This can be highlighted in the simplified diagram below.

![Diagram of heart blood flow](image)

In order for the heart to work effectively, it requires a good blood supply and this is provided by the coronary artery which carries oxygenated blood. Deoxygenated blood is removed by the veins of the heart into the right atrium through the coronary sinus.

**Valves of the Heart**

There are four main valves in the heart that regulate blood flow by ensuring it moves in only one direction. They open to allow blood to pass through and then close to prevent back flow. The tricuspid valve is located between the right atrium and right ventricle and the bicuspid valve between the left atrium and left ventricle. The semi-lunar valves can be found between the right and left ventricles and the pulmonary artery and aorta.
The Conduction System

When the heart beats the blood needs to flow through it in a controlled manner, in through the atria and out through the ventricles. Heart muscle is described as being **myogenic** as the beat starts in the heart muscle itself with an electrical signal in the sinoatrial node (pacemaker). This electrical signal then spreads through the heart in what is often described as a wave of excitation (similar to a Mexican wave).

From the SA node the electrical signal spreads through the walls of the atria causing them to contract and forcing blood into the ventricles. The signal then passes through the atrioventricular node (AV) found in the atrioventricular septum. The AV node delays the transmission of the cardiac impulse for approximately 0.1 seconds to enable the atria to fully contact before ventricular contraction begins. The electrical signal then passes down through some specialised fibres which form the bundle of His. This is located in the septum separating the two ventricles. The bundle of His branches out into two bundle branches and then moves into smaller bundles called purkinje fibres which spread throughout the ventricles causing them to contract.
**The Cardiac Cycle**

This describes the emptying and filling of the heart and involves a number of stages. The diastole phase is when the chambers are relaxing and filling with blood and the systole phase is when the heart contracts and forces blood either round the heart or out of the heart to the lungs and the body. Each complete cardiac cycle takes approximately 0.8 seconds. The diastole phase lasts 0.5 seconds and the systole phase lasts for 0.3 seconds. It can be summarised in the tables below:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Action of atria</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial systole</td>
<td>Walls contract</td>
<td>Blood forced through the bicuspid and tricuspid valves into the ventricles</td>
</tr>
<tr>
<td>Atrial Diastole</td>
<td>Walls relax</td>
<td>Blood enters right atrium via the vena cava and the left atrium via the pulmonary vein but cannot pass into the ventricles as tricuspid and bicuspid valves are closed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage</th>
<th>Action of Ventricles</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular systole</td>
<td>Walls contract</td>
<td>Pressure of blood opens the semi-lunar valves and blood is ejected into the pulmonary artery to the lungs and aorta to the body. Tricuspid and bicuspid valves shut.</td>
</tr>
<tr>
<td>Ventricular diastole</td>
<td>Walls relax</td>
<td>Blood enters from atria ‘passive ventricular filling’ - not due to atrial contraction. The semi-lunar valves are closed.</td>
</tr>
</tbody>
</table>

**Key term:**

Systole: the contraction phase of the heart
Diastole: the relaxation phase of the heart

**The link between the cardiac cycle and the conduction system**

Quite simply the cardiac cycle describes the flow of blood through the heart during one heart beat. As the heart can generate its own electrical impulse it controls this flow of blood via the conduction system.
Cardiac Dynamics

**Stroke volume**
The amount of blood pumped out by the heart ventricles in each contraction. On average the resting stroke volume is approximately 70ml.

Stroke volume can be determined by the following:
- Venous return-this is volume of blood returning back to the heart via the veins. If venous return increases then stroke volume will also increase (ie. If more blood enters the heart then more blood goes out!!)
- The elasticity of cardiac fibres-this is concerned with the degree of stretch of cardiac tissue during the diastole phase of the cardiac cycle. The more the cardiac fibres can stretch the greater the force of contraction will be. A greater force of contraction can increase stroke volume. This is also called Starlings Law.
- The contractility of cardiac tissue (myocardium)-the greater the contractility of cardiac tissue, the greater the force of contraction. This results in an increase in stroke volume. It is also highlighted by an increase in the ejection fraction. This refers to the percentage of blood pumped out by the left ventricle per beat. An average value is 60% but it can increase by up to 85% following a period of training.

\[
\text{Ejection fraction} = \frac{\text{stroke volume}}{\text{end diastolic volume}}
\]

**Heart rate**
The number of times the heart beats per minute. On average the resting heart rate is approximately 72 beats per minute. The fitter an individual is the lower the heart rate. For example, Miguel Indurain, an elite cyclist, had a resting heart rate of only 28 beats per minute.

**Cardiac output**
The amount of blood pumped out by the heart ventricles per minute. It is equal to stroke volume multiplied by heart rate.

Cardiac Output (Q) = Stroke Volume (S.V.) x Heart Rate (H.R.)

\[
\begin{align*}
Q & = 70 \times 72 \\
Q & = 5040 \text{ ml (} 5.04 \text{litres)}
\end{align*}
\]

It can be seen from this calculation that if heart rate or stroke volume increase, then cardiac output will also increase.
Measuring heart rate response to varying intensities of workload.

1. Note your heart rate while you are resting for a 10 second count.

2. Record your heart rate immediately before the exercise commences for a 10 second count.

3. Commence your choice of exercise for a period of 3 minutes.

4. Take heart rate values for a 10 second pulse count:
   (a) At the end of the 3 minutes of exercise
   (b) Every minute during the recovery phase until your heart rate has returned to its resting value prior to exercise.

5. Once your heart rate has returned to its resting value, repeat the same investigation but increase the workload to medium intensity.

6. Repeat this investigation one more time but at high intensity.

7. Collate your results in the following table.

<table>
<thead>
<tr>
<th>Intensity of workload</th>
<th>Resting heart rate</th>
<th>Heart rate prior to exercise</th>
<th>Heart rate at end of exercise</th>
<th>Heart rate during recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Heart rate range in response to exercise

Heart rate increases with exercise but how much it increases is dependent on the intensity of the exercise. Heart rate will increase in direct proportion to exercise intensity. The higher the intensity the higher the heart rate. Heart rate does eventually reach a maximum. Maximum heart rate can be calculated by subtracting your age from 220. A 17 year old will have a maximum heart rate of 203 beats per minute.

\[ 220 - 17 = 203 \]

The graphs below illustrate what happens to heart rate during maximal exercise such as sprinting and sub-maximal exercise such as jogging.

Maximal exercise

Submaximal exercise
a = *Anticipatory rise* due to hormonal action of adrenalin which causes the SA node to increase heart rate

b = *Sharp rise* in heart rate due mainly to anaerobic work

c = Heart rate continues to rise due to maximal workloads stressing the anaerobic systems.

d = *Steady state* as the athlete is able to meet the oxygen demand with the oxygen supply

e = *Rapid decline* in heart rate as soon as the exercise stops

f = *Slower recovery* as body systems return to resting levels. Heart rate needs to remain elevated to rid the body of waste products, for example, lactic acid.

Regular aerobic training will result in hypertrophy of the cardiac muscle i.e. the heart physically gets bigger. This will have an important effect on stroke volume, heart rate and therefore cardiac output. A bigger heart will enable more blood to be pumped out per beat (i.e. stroke volume). In more complex language the end diastolic volume of the ventricle increases. If the ventricle can contract with more force and thus push out more blood the heart as a result does not have to beat as often so the resting heart rate will decrease. This is known as bradycardia. This increase in stroke volume and decrease in resting heart rate will mean that cardiac output at rest will remain unchanged. This is not, however, the case during exercise as an increase in heart rate, coupled with an increase in stroke volume will result in an increase in cardiac output. Cardiac output will increase as the intensity of exercise increases until maximum exercise capacity is reached and then it plateaus.

**Key term:** bradycardia is a decrease in resting heart rate to below 60 beats per minute.

The following table shows the differences in cardiac output (to the nearest litre) in a trained and untrained individual both at rest and during exercise. The individual in
this example is aged 18 so their maximum heart rate will be 202 beats per minute. (Maximum heart rate is calculated as 220- your age).

<table>
<thead>
<tr>
<th></th>
<th>SV x HR</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest Untrained</td>
<td>70 x 72</td>
<td>5 litres</td>
</tr>
<tr>
<td>Exercise Untrained</td>
<td>120 x 202</td>
<td>24 litres</td>
</tr>
<tr>
<td>Rest Trained</td>
<td>85 x 60</td>
<td>5 litres</td>
</tr>
<tr>
<td>Exercise Trained</td>
<td>170 x 202</td>
<td>34 litres</td>
</tr>
</tbody>
</table>

As can be seen from the table this increase in cardiac output will have huge benefits for the trained person as they will be able to transport more blood to the working muscles and therefore more oxygen. In addition when the body starts to exercise the distribution of blood flow changes. This means that a much higher proportion of blood passes to the working muscles and less passes to organs such as the intestine. The amount of blood passing to the kidneys and brain remains unaltered.

**Stroke Volume in response to exercise**

Stroke volume increases as exercise intensity increases. However this is only the case up to 40-60% of maximum effort. Once a performer reaches this point then stroke volume plateaus. One explanation for this is that the increased heart rate near maximum effort results in a shorter diastolic phase. Quite simply, the ventricles do not have as much time to fill up with blood so cannot pump as much out!
Control of Heart rate

Heart rate needs to increase during exercise to ensure the working muscles receive more oxygen. As discussed earlier the heart generates its own impulses from the sinoatrial node but the rate at which these cardiac impulses are fired can be controlled by two main mechanisms:

Neural control mechanism.

This involves the autonomic nervous system which consists of the sympathetic system which stimulates the heart to beat faster and the parasympathetic system which returns the heart to its resting level. These two systems are co-ordinated by the cardiac control centre located in the medulla oblongata of the brain. The cardiac control centre is stimulated by chemoreceptors, baroreceptors and proprioceptors. During exercise, chemoreceptors detect an increase in carbon dioxide, lactic acid and a decrease in oxygen. The role of blood carbon dioxide is important in controlling heart rate. An increased concentration of carbon dioxide in the blood will have the effect of stimulating the sympathetic nervous system. Baroreceptors detect an increase in blood pressure and proprioceptors detect an increase in muscle movement. These receptors then send an impulse through the sympathetic nervous system or cardiac accelerator nerve to the sinoatrial node to increase heart rate. When the parasympathetic system or par vagus nerve stimulates the sinoatrial node, heart rate decreases. This process can be summarised in the diagram below:
Top Tip: Don’t be vague, tell the examiner what the receptors detect, for example chemoreceptors detect an increase in carbon dioxide, don’t just say chemical changes!

2. Hormonal Control Mechanism

Adrenalin and noradrenalin are stress hormones that are released by the adrenal glands. Exercise causes a stress induced adrenalin response which results in the following:

- Stimulation of the SA node (pacemaker) which results in an increase in both the speed and force of contraction.
- An increase in blood pressure due to the constricting of blood vessels.
- An increase in blood glucose levels which is used by the muscles for energy.

What is Cardiovascular Drift?

We used to think that while exercising at a steady level, the body reached a steady state where the heart rate remained the same. However, new research has shown that if you monitor heart rate more closely it does not remain the same but instead slowly climbs. This is cardiovascular drift. In more detail cardiovascular drift is characterised by a progressive decrease in stroke volume and arterial blood pressure, together with a progressive rise in heart rate. It occurs during prolonged exercise in a warm environment despite the intensity of the exercise remaining the same. Suggestions as to why this occurs are that when we sweat a portion of this lost fluid volume comes from the plasma volume. This decrease in plasma volume will reduce venous return and stroke volume. Heart rate again increases to compensate and maintain constant cardiac output. To minimise this cardiovascular drift it is important to maintain high fluid consumption before and during exercise.

Effects of Training on the Heart

If you perform continuous, fartlek or aerobic interval training over a period of time, physiological adaptations take place that would make the initial training sessions appear very easy. This is because your VO₂(max) has improved due to the changes your body has made. Some of these changes or adaptations effect the heart. It becomes much more efficient. The table below identifies the changes that have taken place in the heart.

Key term: VO₂(max) is the maximum amount of oxygen that can be taken in and used by the body in one minute
**Athletes heart.**

This is a common term for an enlarged heart caused by repeated strenuous exercise. Due to the increased demands of exercise the chambers of the heart will enlarge as will muscle mass. This results in an increase in the volume of blood that can be pumped out per beat. Consequently the heart has to contract less frequently.

**Hypertrophy** of the myocardium (heart gets bigger and stronger). This means that an increase in the size of the ventricles allows them to fill with more blood during the diastolic phase of the cardiac cycle and will result in *bradycardia* (a decrease in resting heart rate) and an *increase in stroke volume*.

**Maximum cardiac output** will also increase but will remain the same at rest and sub-maximal level of exercise.

**Increased capillarisation** of the heart muscle which increases the efficiency of diffusion of oxygen into the myocardium.

**Increased contractility.** Resistance/strength training causes an increase in the force of heart contractions due to a thickening of the ventricular myocardium. This will *increase stroke volume* and will also *increase the ejection fraction* as a higher percentage of blood is pumped.

---

**Practice makes perfect**

1. During exercise heart rate will increase to meet the extra oxygen demand required by the muscles. Explain how the increasing level of carbon dioxide in the blood raises heart rate. [3]

2. What effect would a 6 month period of aerobic training have on the heart of a soccer player [3]

3. Just before the start of an 800m race the athlete will experience a change in heart rate. What change occurs in the athletes heart rate and why does this happen [2]

4. Explain the terms bradycardia and ‘athletes heart’ [2]

5. Define the terms cardiac output and stroke volume and explain the relationship between them [3]

6. What are the effects of a period of training on *resting* stroke volume and cardiac output [2]
The Vascular System

What you need to know:

- Explain pulmonary and systematic circulation related to the various blood vessels (arteries/arterioles/capillaries/venules and veins)
- Describe the venous return mechanisms
- Understand how blood is redistributed during exercise (vascular shunt)
- Describe how oxygen and carbon dioxide are transported in the blood (to include an understanding of the role of haemoglobin and myoglobin
- Explain what is meant by blood pressure and velocity and relate these terms to specific blood vessels

The vascular system is made up of blood vessels that carry blood through the body. These blood vessels deliver oxygen and nutrients to the body tissues and take away waste products such as carbon dioxide. Together with the heart and lungs the blood vessels ensure that muscles have an adequate supply of oxygen during exercise in order to cope with the increased demand for energy.

Transportation of blood around the body

There are two types of circulation:

a) pulmonary – deoxygenated blood from the heart to the lungs and oxygenated blood back to the heart.

b) Systemic – oxygenated blood to the body from the heart and then the return of deoxygenated blood from the body to the heart.

Blood Vessels

The vascular system consists of five different blood vessels that carry the blood from the heart, distribute it round the body and then return it back to the heart. Arteries carry blood away from the heart. The heart beat pushes blood through the arteries by surges of pressure and the elastic arterial walls expand with each surge which can be felt as a pulse in the arteries near the surface of the skin. The arteries then branch off and divide into smaller vessels called arterioles which in turn divide into microscopic vessels called capillaries. These are a single cell layer of endothelium cells and are only wide enough to allow one red blood cell to pass through at a given time. This slows down blood flow and allows the exchange of nutrients with the tissues to take place by diffusion. There is a dense capillary network surrounding the tissues and this creates a large surface area for diffusion to take place. Then blood flows from the capillaries to the venules which increase in size and eventually form veins, which return under low pressure back to the heart.

To summarise the order in which the blood flows through the vascular system is as follows:

Heart → Arteries → Arterioles → Capillaries
   → Venules → Veins → Heart
Structure of a blood vessel

Arteries, arteriole, venules and veins all have a similar structure. Their walls consist of three layers:

1. Tunica externa (adventitia) – this is the outer layer which contains collagen fibres. This wall needs to be elastic in order to stretch and withstand large fluctuations in blood volume.

2. Tunica media – this is the middle layer which is made up of elastic fibres and smooth muscle. The elastic fibres are there to stretch when blood is forced into the arteries during ventricular systole. When they recoil they smooth out the flow of blood and push it along the arteries. The smooth muscle can contract in the walls of the smaller arteries and arterioles which ensures that the amount of blood flowing to various organs can vary according to different demands.

3. Tunica interna – this is made up of thin epithelial cells that are smooth and reduce friction between the blood and the vessel walls.

All blood vessels have features that adapt them to their particular functions. These are summarised in the table below:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Artery</th>
<th>Capillary</th>
<th>Vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunica externa (outer layer)</td>
<td>Present</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Tunica media (middle layer)</td>
<td>Thick with many elastic fibres</td>
<td>Absent</td>
<td>Thinner and less elastic than in an artery</td>
</tr>
<tr>
<td>Tunica interna (inner layer)</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Size of lumen</td>
<td>Small</td>
<td>Microscopic</td>
<td>Large</td>
</tr>
<tr>
<td>Valves</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
</tr>
</tbody>
</table>
The Venous Return Mechanism

Venous return is the return of blood back to the right side of the heart via the vena cava. Up to 70% of the total volume of blood is contained in the veins at rest. This means that a large amount of blood can be returned to the heart when needed. During exercise the amount of blood returning to the heart (venous return) increases. This means that if more blood is being pumped back to the heart then more blood has to be pumped out. Therefore stroke volume is dependent on venous return. So when venous return increases so does stroke volume and consequently cardiac output.

However the pressure of the heart beat is too low in the veins to push the blood back to the heart. In addition the large lumen offers little resistance to blood flow. This means that active mechanisms are needed to help venous return:

1. The skeletal muscle pump – when muscles contract and relax they change shape. This change in shape means that the muscles press on the nearby veins and cause a pumping effect and squeeze the blood towards the heart.
2. The respiratory pump - when muscles contract and relax during the inspiration and expiration process pressure changes occur in the thoracic and abdominal cavities. These pressure changes compress the nearby veins and assist blood return back to the heart.

3. Pocket valves – it is important that blood in the veins only flows in one direction. The presence of valve ensures that this happens. This is because once the blood has passed through the valves, they close to prevent the blood flowing back.

4. Smooth muscle within the veins. There is a very thin layer of smooth muscle in the walls of the veins. This helps squeeze blood back towards the heart.

It is important to maintain venous return during exercise to ensure the skeletal muscles are receiving enough oxygen to meet the demands of the activity. At rest valves and the smooth muscle found in veins are sufficient enough to maintain venous return. However, this is not the case during exercise! The demand for oxygen is greater and the heart is beating faster so the vascular system has to help out too! Now the skeletal muscle pump and the respiratory pump are needed to ensure venous return is maintained. During exercise this is possible because our skeletal muscles are constantly contracting and our breathing is elevated. Immediately after exercise we still need to maintain these mechanisms. Performing an active cool-down to will keep the skeletal muscle pump and respiratory pump working, therefore preventing blood pooling.

**Vascular shunt**

The distribution of blood flow is different at rest compared to exercise. During exercise the skeletal muscles require more oxygen so more blood needs to be redirected to them in order to meet this increase in oxygen demand. The redirecting
of blood flow to the areas where it is most needed and is known as shunting or the **vascular shunt mechanism**. This redistribution of blood can be seen in the table below:

<table>
<thead>
<tr>
<th>Cardiac output = 24 litres per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% 3-5% 4-5% 2-4% 0.5-1% 3-4% 1-2% 80-85%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cardiac output = 5 litres per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% 20-25% 4-5% 20% 3-5% 15% 4-5% 15-20%</td>
</tr>
</tbody>
</table>

This re-direction of blood flow to the working muscles means that sports performers should ensure they do not eat less than an hour before competition. A full gut would result in more blood being directed to the stomach instead of the working muscles and this would have an effect on performance as less oxygen is being made available. Blood flow to the brain must remain constant to ensure brain function is maintained.

**Key term:** vascular shunt mechanism. This is the redistribution of cardiac output

**The control of blood flow**

Both blood pressure and blood flow are controlled by the **vasomotor centre**, located in the medulla oblongata of the brain. During exercise chemical changes, such as increases in carbon dioxide and lactic acid, are detected by chemoreceptors. Higher blood pressure is detected by baroreceptors. These receptors will stimulate the vasomotor centre which will redistribute blood flow through vasodilation and vasoconstriction. Vasodilation will increase blood flow and vasoconstriction will decrease blood flow. In exercise more oxygen is needed at the working muscles so vasodilation will occur, increasing blood flow and bringing in the much needed oxygen, whereas vasoconstriction will occur in the arterioles supplying non-essential organs such as the intestines and liver. Redirection of blood flow also occurs through stimulation of the sympathetic nerves located in the tunica media of the blood vessel. When stimulation by the sympathetic
nerves decreases, vasodilation occurs and when sympathetic stimulation increases, vasoconstriction occurs.

Pre-capillary sphincters also aid blood redistribution. These are tiny rings of muscle located at the opening of capillaries. When they contract blood flow is restricted through the capillary and when they relax blood flow is increased. During exercise the capillary networks supplying skeletal muscle will have relaxed pre-capillary sphincters to increase blood flow and therefore saturate the tissues with oxygen.

**Key terms:**
- Vasodilation: the widening of the blood vessels
- Vasoconstriction: the narrowing blood vessels

Redistribution of blood is important to:

- Increase the supply of oxygen to the working muscles
- Remove waste products from the muscles such as a carbon dioxide and lactic acid
- Ensure more blood needs goes to the skin during exercise to regulate body temperature and get rid of heat through radiation, evaporation and sweating
- Direct more blood to the heart as it is a muscle and requires extra oxygen during exercise

**How oxygen and carbon dioxide are carried within the vascular system.**

Oxygen plays a major role in energy production and a reduction in the amount of oxygen in the body will have a detrimental impact on performance. During exercise, when oxygen diffuses into the capillaries supplying the skeletal muscles, 3% dissolves into plasma and 97% combines with haemoglobin to form oxy-haemoglobin. At the tissues oxygen will dissociate from haemoglobin due to the lower pressure of oxygen that exists there. In the muscle, oxygen is stored by myoglobin. This has a higher affinity for oxygen and will store the oxygen in the mitochondria until it is used by the muscles. The mitochondria are the centres in the muscle where aerobic respiration takes place.

Carbon dioxide can be transported around the body in the following ways:

- 70% can be transported in the blood as hydrogen carbonate (bicarbonate) ions. The carbon dioxide produced by the muscles as a waste product diffuses into the blood stream where it combines with water to form carbonic acid. The weakness of carbonic acid results in its dissociation into hydrogen carbonate or bicarbonate ions
- 23% combines with haemoglobin to form carbaminohaemoglobin
- 7% dissolves in plasma

An increase in the levels of carbon dioxide result in an increase in blood and tissue acidity. This is detected by chemoreceptors which send impulses to the medulla which result in an increase in heart rate, breathing rate and transport so that the carbon dioxide is exhaled and the arterial blood levels of both oxygen and carbon dioxide can be maintained.
Blood pressure and blood flow.

Blood pressure is the force exerted by the blood against the blood vessel wall and is often referred to as:

\[ \text{blood flow} \times \text{resistance} \]

Ejection of the blood by the ventricles contracting creates a high pressure pulse of blood which is systolic pressure. The lower pressure as the ventricles relax is the diastolic pressure.

Blood pressure is measured at the brachial artery (in the upper arm) using a sphygmomanometer. A typical reading at rest is:

120 mmHg (millimetres of mercury)
80

Blood pressure is different in the various blood vessels and is largely dependent on the distance of the blood vessel from the heart.

<table>
<thead>
<tr>
<th>Blood pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artery</td>
</tr>
<tr>
<td>High and in pulses</td>
</tr>
</tbody>
</table>

Blood Pressure Chart
Blood velocity.

The velocity of blood flow is related to the cross sectional area of the vessels it is passing through. The smaller the cross sectional area the faster blood will flow. Although the capillaries are the smallest blood vessel the fact that there is so many of them means that their cross sectional area is much greater than the aorta. This means that the flow of blood will be much slower in the capillaries and this will allow enough time for efficient exchanges with the tissues. The relationship of blood velocity and cross sectional area of the different blood vessels is highlighted in the diagram below:

Exercise and its effects on blood pressure.

During exercise changes in blood pressure occur but these depend on the type and intensity of the exercise being performed. Systolic pressure will increase during aerobic exercise due to both an increase in cardiac output and the vasoconstriction of arterioles that occurs during the redirection of blood flow to the working muscles, while diastolic pressure will remain constant. When exercise reaches a steady state and heart rate plateaus systolic pressure can decrease because of vasodilation to the arterioles leading to the working muscles. This reduces total peripheral resistance and lowers mean blood pressure (the average value of systolic and diastolic pressures) to just above resting levels. During aerobic exercise diastolic pressure will remain constant.

During isometric work diastolic pressure will also increase due to an increased resistance on the blood vessels. This is because during isometric work the muscle remains contracted causing constant compression on the blood vessels which will result in an additional resistance to blood flow in the muscles and therefore an increase in pressure.
**Tasks to tackle**
Complete the table below to show what happens to the systolic pressure of an 18 year old PE student on a 40 minute training run

<table>
<thead>
<tr>
<th>Blood pressure changes</th>
<th>Before exercise</th>
<th>During exercise</th>
<th>Recovery</th>
</tr>
</thead>
</table>

**Control of blood pressure.**

The vasomotor centre controls blood pressure. Baroreceptors, located in the aortic and carotid arteries will detect increases and decreases in blood pressure and send an impulse to the vasomotor centre located in the medulla oblongata. The diagram below illustrates this:

![Diagram of blood pressure regulation](image-url)

- High blood pressure
  - Decrease in sympathetic stimulation
  - Vasodilation and a reduction in blood pressure
- Low blood pressure
  - Increase in sympathetic stimulation
  - Vasoconstriction and an increase in blood pressure
Practice makes perfect

1. Describe the mechanisms that are used to return blood to the heart [3]

2. Why does blood flow to the brain remain the same at rest and during exercise [2]

3. Why should an athlete not eat at least one hour before competition [3]

4. How is carbon dioxide transported in the blood [2]

5. Explain how blood is re-distributed to the working muscles [3]

6. Give an average blood pressure reading and identify what happens to blood pressure during exercise [2]
The Respiratory System

What you need to know.

- Describe the mechanics of breathing at rest and during exercise
- Identify the different lung volumes and capacities and interpret them on a spirometer trace giving values at rest and exercise
- Describe the gaseous exchange process at the alveoli and muscles.
- Explain the principles of diffusion and the importance of partial pressures
- Explain the difference in oxygen (A-VO2 diff) and carbon dioxide content between alveolar air and pulmonary blood
- Explain how exercise can have an effect on the dissociation of oxygen from haemoglobin at the tissues (Bohr shift)
- Explain how breathing is controlled (understanding the importance of carbon dioxide in this process)

Review of the structure of the lungs.
Air is drawn into the body through the **nose** where it is warmed and humidified. The air is also filtered here by a thick mucous membrane and then passes through the **pharynx** and onto the **larynx** (voice box). The epiglottis covers the opening of the larynx to prevent food entering the lungs. From here it moves onto the **trachea** (windpipe). This is approximately 10cm long and is held open by rings of cartilage. Mucous and ciliated cells line the trachea and filter the air. At the bottom the trachea divides into the right and left **bronchus**. Air moves through each bronchus and they subdivide into secondary bronchi feeding each lobe of the lung. These then get progressively thinner and branch into **bronchioles** and then respiratory bronchioles which lead into the **alveolar** air sacs.

![Diagram of respiratory system]

The alveoli are responsible for the exchange of gases between the lungs and the blood. Their structure is designed to help gaseous exchange. Their walls are very thin (only one cell thick) and are supplied by a dense capillary network. They have a huge surface area which allows for a greater uptake of oxygen. It has been said that if all the alveoli were laid on the ground they would cover the area similar in size to a tennis court!

**Tasks to tackle:**

Rearrange the following words to show the correct passage of air:

Larynx → **nose** → trachea → pharynx → alveoli → bronchioles → bronchi

**The Mechanics of Breathing**

It is important to remember that air will always move from an area of high pressure to an area of low pressure. The greater the difference in pressure the faster air will flow. This means that in order to get air into the lungs (inspiration) the pressure needs to be lower here than in the atmosphere. To get air out (expiration) air pressure needs to be higher in the lungs than the atmosphere.
**Inspiration**
Increasing the volume of the thoracic cavity will reduce the pressure of air in the lungs. This happens when muscles surrounding the lungs contract. At the bottom the diaphragm contracts so that it flattens while the external intercostals contract pulling the ribs up and out.

**Expiration**
Decreasing the volume of the thoracic cavity will increase the pressure of air in the lungs forcing the air out. At rest expiration is passive. The diaphragm and external intercostals relax and the volume of the thoracic cavity reduces.

---

**Breathing During Exercise**
During exercise more muscles are involved as air needs to be forced in and out of the lungs much more quickly. The extra inspiratory muscles are the sternocleidomastoid which lifts the sternum, and the scalenes and pectoralis minor which help to lift the ribs. The extra expiratory muscles are the internal intercostals which pull the ribs down and in and the abdominal muscles which push the diaphragm up.

**Lung volumes and capacities**

This is the movement of air into and out of the lungs. Taking air into the lungs is inspiration and moving air out is expiration. At rest we inspire and expire approximately 0.5 litres of air. The volume of air inspired or expired per breath is referred to as the tidal volume. The volume of air inspired or expired per minute is referred to as minute ventilation and can be calculated by multiplying the number of breaths taken per minute (approximately 12) by the tidal volume:

\[
\text{Number of breaths (per min) } \times \text{ tidal volume } = \text{ minute ventilation}
\]

\[
12 \times 0.5 = 6 \text{ litres}
\]
At rest we still have the ability to breathe in and breathe out more air than just the tidal volume. This extra amount of air inspired is the inspiratory reserve volume (IRV) and expired is the expiratory reserve volume (ERV). Exercise will have an effect on these lung volumes. More oxygen is required so tidal volume will need to increase but this will reduce the ability to breathe in or out an extra amount of air so IRV and ERV will decrease.

<table>
<thead>
<tr>
<th>Lung volume or capacity</th>
<th>Definition</th>
<th>Average values at rest (litres)</th>
<th>Changes during exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume</td>
<td>Volume of air breathed in or out per breath</td>
<td>0.5</td>
<td>Increase</td>
</tr>
<tr>
<td>Inspiratory reserve volume</td>
<td>Volume of air that can be forcibly inspired after a normal breath</td>
<td>3.1</td>
<td>Decrease</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>Volume of air that can be forcibly expired after a normal breath</td>
<td>1.2</td>
<td>Slight decrease</td>
</tr>
<tr>
<td>Residual volume</td>
<td>Volume of air that remains in the lungs after maximum expiration</td>
<td>1.2</td>
<td>Remains the same</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>Volume of air forcibly expired after maximum inspiration in one breath</td>
<td>4.8</td>
<td>Slight decrease</td>
</tr>
<tr>
<td>Minute ventilation</td>
<td>Volume of air breathed in or out per minute</td>
<td>6</td>
<td>Big increase</td>
</tr>
<tr>
<td>Total lung capacity</td>
<td>Vital capacity + residual volume</td>
<td>6</td>
<td>Slight decrease</td>
</tr>
</tbody>
</table>

These lung volumes can also be highlighted on a spirometer trace:
Changes in pulmonary ventilation occur during different types of exercise. As you would expect the more demanding the physical activity the more breathing increases to meet the extra oxygen demand. This can be illustrated in a graph similar to the ones we use for heart rate.

Maximal exercise

\[\begin{align*}
\text{Minute Ventilation} & \quad \text{Time} \\
\text{Rest} & \quad \text{Exercise} & \quad \text{Recovery}
\end{align*}\]

Submaximal exercise

\[\begin{align*}
\text{Minute Ventilation} & \quad \text{Time} \\
\text{Rest} & \quad \text{Exercise} & \quad \text{Recovery}
\end{align*}\]

\[\begin{align*}
a &= \text{Anticipatory rise} \\
b &= \text{Sharp rise in minute ventilation} \\
c &= \text{Slower increase} \\
d &= \text{Steady state} \\
e &= \text{Rapid decline in minute ventilation} \\
f &= \text{Slower recovery as body systems return to resting levels.}
\]
Gaseous Exchange at the Lungs (external respiration)

This is concerned with the replenishment of oxygen in the blood and the removal of carbon dioxide. Partial pressure is often used when describing the gaseous exchange process. Quite simply all gases exert a pressure. Oxygen makes up only a small part of air (approximately 21%) so it therefore exerts a partial pressure. As gases flow from an area of high pressure to an area of low pressure it is important that as air moves from the alveoli to the blood and then to the muscle the partial pressure of oxygen of each needs to be successively lower.

**Key term:** Partial pressure - the pressure exerted by an individual gas when it exists within a mixture of gases

The partial pressure of oxygen in the alveoli (105mmHg) is higher than the partial pressure of oxygen in the capillary blood vessels (40mmHg). This is because oxygen has been removed by the working muscles so its concentration in the blood is lower and therefore so is its partial pressure. The difference between any two pressures is referred to as the concentration/diffusion gradient and the bigger this gradient the faster diffusion will be. Oxygen will diffuse from the alveoli into the blood until the pressure is equal in both.

**Key term:** diffusion gradient is often referred to as the concentration gradient. It explains how gases flow from an area of high concentration to an area of low concentration. The bigger this gradient (difference between concentration levels at high and low areas) the faster diffusion occurs

The movement of carbon dioxide occurs in the same way but in the reverse order. This time the partial pressure of carbon dioxide in the blood entering the alveolar capillaries is higher (45mmHg) than in the alveoli (40mmHg) so carbon dioxide diffuses into from blood into the alveoli until the pressure is equal in both.

<table>
<thead>
<tr>
<th></th>
<th>Inspired air at rest (% gases)</th>
<th>Expired air at rest (% gases)</th>
<th>Expired air during exercise (% gases)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxygen</strong></td>
<td>21</td>
<td>16.4</td>
<td>14</td>
</tr>
<tr>
<td><strong>Carbon Dioxide</strong></td>
<td>0.03</td>
<td>4.0</td>
<td>6</td>
</tr>
<tr>
<td><strong>Nitrogen</strong></td>
<td>79</td>
<td>79.6</td>
<td>79</td>
</tr>
<tr>
<td><strong>Water vapour</strong></td>
<td>varied</td>
<td>saturated</td>
<td>Saturated</td>
</tr>
</tbody>
</table>

**Top tip:**
Remember the diffusion of gases at the alveoli is helped enormously by their structure. Alveoli are only one cell thick so there is a short diffusion pathway, they have a vast surface area which facilitates diffusion and they are surrounded by a vast network of capillaries.

Gaseous exchange at the tissues (internal respiration)

The partial pressure of oxygen has to be lower at the tissues than in the blood for diffusion to occur. As such in the capillary membranes surrounding the muscle the
The partial pressure of oxygen is 40mmHg and it is 105mmHg in the blood. This lower partial pressure allows oxygen to diffuse from the blood into the muscle until equilibrium is reached. Conversely the partial pressure of carbon dioxide in the blood (40mmHg) is lower than in the tissues (45mmHg) so again diffusion occurs and carbon dioxide moves into the blood to be transported to the lungs.

**Arterio-Venous Difference**

This is the difference between the oxygen content of the arterial blood arriving at the muscles and the venous blood leaving the muscles. At rest the arterio-venous difference is low as not much oxygen is required by the muscles. But during exercise much more oxygen is needed from the blood for the muscles so the arterio-venous difference is high. This increase will affect gaseous exchange at the alveoli due to the high concentration of carbon dioxide returning to the heart in the venous blood and less oxygen. This will increase the diffusion gradient for both gases. Training also increases the arterio-venous difference as trained performers can extract a greater amount of oxygen from the blood.

The following diagram highlights the differences in the partial pressure of oxygen and carbon dioxide in the alveoli, blood and muscle cell and also shows the arterio-venous difference.

**Partial pressures of Oxygen and Carbon dioxide (mmHg)**

- **Atmosphere**
  - PO2 160mmHg
  - PCO2 0.3mmHg

- **Alveolar air**
  - PO2 105mmHg
  - PCO2 40mmHg

- **Mixed Venous Blood**
  - PO2 40mmHg
  - PCO2 45mmHg

- **Arterial blood**
  - PO2 105mmHg
  - PCO2 40mmHg

- **Tissues**
  - PO2 40
  - PCO2 45
Transportation of oxygen

During exercise when oxygen diffuses into the capillaries supplying the skeletal muscles, 3% dissolves into plasma and 97% combines with haemoglobin to form oxy-haemoglobin. When fully saturated haemoglobin will carry four oxygen molecules. This occurs when the partial pressure of oxygen in the blood is high, for example in the alveolar capillaries of the lungs. At the tissues oxygen will dissociate from haemoglobin due to the lower pressure of oxygen that exists there.

The oxy-haemoglobin dissociation curve

The relationship of oxygen and haemoglobin is often represented by the oxy-haemoglobin dissociation curve:

From this curve you can see that in the lungs there is almost full saturation of haemoglobin but at the tissues the partial pressure of oxygen is lower. This means that there is less oxygen in the tissues so haemoglobin has to give up some of its oxygen and therefore is no longer fully saturated.

During exercise this S shaped curve shifts to the right because when muscles require more oxygen the dissociation of oxygen from haemoglobin in the blood capillaries to the muscle tissue occurs more readily.
Four factors are responsible for this increase in the dissociation of oxygen from haemoglobin which results in more oxygen being available for use by the working muscles:

- temperature – when blood and muscle temperature increases during exercise oxygen will dissociate from haemoglobin more readily
- partial pressure of oxygen decreases-as the level of oxygen decreases in the muscle (thus increasing the oxygen diffusion gradient) oxygen will dissociate from haemoglobin in the blood capillaries to the muscles more readily
- partial pressure of carbon dioxide increases – As the level of carbon dioxide rises during exercise oxygen will dissociate quicker from haemoglobin
- pH – more carbon dioxide will lower the pH in the body. A drop in pH will cause oxygen to dissociate from haemoglobin more quickly (Bohr effect)

**Key term:** Bohr Effect: when an increase in blood carbon dioxide and a decrease in pH results in a reduction of the affinity of haemoglobin for oxygen.

**Control of Ventilation**

Breathing is controlled by the nervous system which automatically increases or decreases the rate, depth and rhythm of breathing. Again blood carbon dioxide levels are important in controlling breathing. An increased concentration of carbon dioxide in the blood will have the effect of stimulating the respiratory centre located in the medulla oblongata of the brain to increase respiratory rates
Chemoreceptors
(detect an increase in blood acidity as a result of an increase in the plasma concentration of carbon dioxide and lactic acid production)

Proprioceptors
(detect movement)

Thermoreceptors
(detect an increase in temperature)

Stretch receptors
(prevent over inflation of the lungs. If these start to get excessively stretched they send impulses to the expiratory centre to induce expiration - Hering-Breuer reflex).

Inspiratory Centre

Expiratory Centre

Respiratory centre
(found in the medulla oblongata)

Phrenic and Intercostal Nerves

Diaphragm, external intercostals, scalenes, sternocleidomastoid and pectoralis minor

Abdominals, internal intercostals

Increase breathing rates

increase expiration

Top tip: questions may often refer to how an increase in carbon dioxide can effect breathing remember a question on control of ventilation
Practice makes perfect

1. During exercise the demand for oxygen by the muscles increases. How is breathing rate controlled to meet these demands [4]

2. What does the term arterio-venous difference (a-vO\textsubscript{2} diff) mean. Why does it increase during exercise

3. During exercise the oxy-haemoglobin curve shifts to the right. Explain the causes of this change and identify the effect that this has on oxygen delivery to the muscles [4]

4. Define tidal volume and identify what happens to this respiratory volume during exercise [2]

5. Gas exchange and oxygen delivery influence performance in sporting activities. Explain how oxygen diffuses from the lungs into the blood and how it is transported to the tissues. [4]

6. Describe the mechanisms of breathing at rest [3]
Health, exercise and fitness

What you need to know:

- Define health and fitness and understand the relationship between them and the problems associated in their definition
- Understand the effects of lifestyle choices on health and fitness.
- Define the health-related components of fitness: stamina, muscular endurance, strength, speed, power and flexibility
- Define the skill related components of fitness: reaction time, agility, co-ordination and balance

Defining fitness

Fitness can be difficult to define as it means different things to each individual. It can also depend on the lifestyle choices an individual will make. An average person who chooses not to exercise regularly, may think they are fit if they can run for the bus or play football in the park without getting too out of breath, whereas a person who has chosen an active lifestyle and exercises regularly may look at resting heart rate or heart rate recovery after exercise as an indication of fitness. One generic definition of fitness is:

‘the ability to perform daily tasks without undue fatigue’.

It is important to remember that these daily tasks will be different for an elite performer in comparison to a non-athlete. Also the fitness requirements of physical activities can also vary, for example, the 100m requires the body to work anaerobically with great strength, speed and power whereas, the marathon requires good muscular endurance and a good aerobic capacity

Defining health

Health can be influenced by physical, emotional, mental, social, and spiritual dimensions. There are lots of definitions concerning health and each one is slightly different. The World Health Organization defines health as

"... a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity."

This can mean that an elite performer who has excellent fitness will be seen as unhealthy if they are suffering from depression. Again lifestyle choices are important for our health. An individual in a demanding career may have high stress levels and therefore will not be as healthy as someone in a less stressful environment.
Tasks to tackle:

Can you think of at least three lifestyle choices that can have a negative affect on an individuals health.

Fitness components

Health-related components of fitness: stamina, muscular endurance, strength, speed, power and flexibility

Skill related components of fitness: reaction time agility, co-ordination and balance

Top tip: AQA class speed as a health related component of fitness, but in some textbooks it is classed a skill/motor component of fitness
Health components of fitness

Cardio-respiratory endurance (stamina)

This is often referred to using different terms such as stamina, VO$_2$(max) or cardiovascular endurance. Whatever the term used cardio-respiratory endurance can be defined as the ability to take in and use oxygen. This is dependent on three factors:

1. How effectively an individual can inspire and expire
2. Once they have inspired how effective the transportation of the oxygen is from the lungs to the muscles
3. How well that oxygen is then used in the muscle cell

Cardio-respiratory endurance is important for participation in continuous sub-maximal activity, such as jogging or cycling. In team games it helps the performer to withstand fatigue and last the duration of the game.

Strength

A common definition for strength is the ability to exert a force against a resistance. In sport we use various types of strength, for example, a weight lifter needs a different type of strength to perform a maximum bench press in comparison to a sprinter who needs to explode from the starting blocks. This therefore implies that there are different types of strength. The three main types of strength are:

1. Maximum strength
2. Explosive strength
3. Static strength

Maximum Strength

This is the maximum force a muscle is capable of exerting in a single maximal voluntary contraction and is used during weight lifting. Due to higher levels of testosterone men have a larger muscle mass so can exert greater maximum strength than women. The greater the cross sectional area of muscle mass, the stronger the performer is. In addition fast glycolytic fibres are important for maximum strength as they can produce more force than slow twitch fibres.

Explosive strength

This is the rapid contraction of muscle fibres to achieve maximum force.

Static strength

This is holding a position. Here the muscles maintain a state of contraction.

Power

This equates to the amount of work performed per unit of time. It is the ability to overcome resistance with a high speed of contraction. (Strength x speed). This can be seen in explosive events such as sprinting, throwing or hitting where a high percentage of fast glycolytic fibres are needed for a good performance.
**Muscular endurance**

This is the ability of a muscle to perform repeated contractions over a period of time, thus withstanding fatigue. It is important for a rower or swimmer where the same muscle action is repeated for the duration of the event. In addition when a team game goes into extra time, those players with better strength endurance will be in a stronger position to maintain a high level of performance. This type of strength is characterised by a high proportion of type 1 (slow oxidative) and type 2a (fast oxidative glycolytic) fibres.

**Flexibility**

Good flexibility is important in assisting in the prevention of injury. It can also help generate faster and more forceful muscle contractions. There are two main types of flexibility:

- **Static** flexibility is the range of movement around a joint, for example doing the splits
- **Dynamic** flexibility is the resistance of a joint to movement, for example kicking a football without hamstring and hip joint resistance.

There are many factors that determine the flexibility of an individual:

- The elasticity of ligaments and tendons
- The amount of stretch allowed by surrounding muscles
- The type of joint, for example, the knee is a hinge joint allowing movement in only one plane, (flexion and extension). The shoulder is a ball and socket joint and allows movement in many planes (flexion, extension, abduction, adduction, medial and lateral rotation, circumduction).
- The structure of a joint – the hip and shoulder are both ball and socket joints but the hip joint has a deeper joint cavity and tighter ligaments to keep it more stable but less mobile than the shoulder.
- The temperature of surrounding muscle and connective tissue
- Training – flexibility can reduce during periods of inactivity
- Age – the older you are the less flexible you are.
- Gender – females tend to be more flexible than males due to hormonal differences

**Speed**

This refers to how fast a person can move over a specified distance or how quickly a body part can be put into motion. Speed is important in all sports, a winger in rugby needs to be able to sprint quickly, but a fast bowler in cricket needs to be able to move his arm quickly rather than run fast. Fibre type will play a major role in terms of speed. If genetically you have a greater number of fast glycolytic fibres you will receive stimuli quicker and release energy anaerobically so that you are faster than someone with a greater number of slow twitch fibres.

**Motor/Skill Related Components of Fitness**

**Agility**
This is the ability to move and position the body quickly and effectively while under control. Here the combination of speed, co-ordination, balance and flexibility is very important, for example, netball when you twist to catch and pass on the run or basketball when you dribble around opponents.

**Balance**

This is the ability to keep the centre of gravity over the base of support. A balance can be *static*, such as a handstand in gymnastics which has to be kept still, or *dynamic* where balance is retained while in motion, for example when side-stepping to get round an opponent.

**Reaction Time**

The time taken from detection of a stimulus to the initiation of a response, for example the time taken between the starting pistol going off and movement from the blocks or reacting to a tennis serve.

**Co-ordination**

This is the ability of the motor and nervous systems to interact so that motor tasks can be performed more accurately. Coordination requires the performer to move two or more body parts under control both smoothly and efficiently. Good levels of balance and agility are needed. Examples of good coordination tend to be concerned with good timing so in golf, being able to match the swing of the club to hit the ball correctly.

**Tasks to tackle**

Look at the different sports performers in the table below and identify the components of fitness that are relevant for that performer.

<table>
<thead>
<tr>
<th></th>
<th>Cricketer</th>
<th>High jumper</th>
<th>Marathon runner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardio-respiratory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>endurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscular endurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-ordination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Practice makes perfect

1. A games player needs to be agile in order to be effective. Identify two other components of fitness that are required by a games player and give an example of how one of these can be used in a game. [3]

2. Define the term power [2]

3. Name two fitness components that are important for a high jumper [2]

4. What is understood by the terms fitness and health [2]
Nutrition

What you need to know:

- Identify the seven classes of food as: carbohydrates, fats, proteins, vitamins, minerals, fibre and water and highlight types of food that fall into these categories
- Identify the exercise related function of each of these types of food
- Describe a balanced diet and the energy balance of food and be able to relate this to your own practical activity.
- Identify the difference in diet composition between endurance athletes and power athletes
- Identify the percentage body fat/body composition and Body Mass Index (BMI) as measures of nutritional suitability.
- Give a definition of obesity and understand the limitations in trying to define it

Nutrition and diet can contribute to a successful performance. A balanced diet is essential for optimum performance in all sporting activities. What you can eat can have an affect on your health, your weight and your energy levels! Top performers place huge demands on their bodies during both training and competition. Their diet must meet those energy requirements as well as provide nutrients for tissue growth and repair. There are six groups of nutrients that should be present in all sports performers:

**Carbohydrates**

There are two types of carbohydrates.

*Simple carbohydrates:* found in fruits and are easily digested by the body. They are also often found in processed foods and anything with refined sugar added. *Complex carbohydrates:* found in nearly all plant-based foods, and usually take longer for the body to digest. They are most commonly found in bread, pasta, rice, and vegetables.

Carbohydrates play an important role in the performance of exercise lasting an hour or more. They are the main fuel for high intensity or anaerobic work. Therefore it is imperative that carbohydrate is consumed before, during and after exercise. Carbohydrates are now not just simply thought to provide fuel for muscles. It is now important to consider the ‘glycaemic index’ and release rate of different carbohydrates and the consequence this has on when they should be consumed in relation to training. Foods with a lower glycaemic index, such as fruit cause a slower, sustained release of glucose to the blood, whereas foods with a high glycaemic index such as bread and potatoes cause a rapid, short rise in blood glucose. Suitable foods to eat 3-4 hours before exercise include beans on toast, pasta or rice with a vegetable based sauce, breakfast cereal with milk, crumpets with jam or honey. Suitable snacks to eat 1-2 hours before exercise include fruit smoothies, cereal bars, fruit flavoured yoghurt and fruit. Whereas one hour before exercise, liquid consumption appears more important through sports drinks and cordials.
Key term: glycaemic index - this ranks carbohydrates according to their effect on our blood glucose levels.

Fats
Fats are the secondary energy fuel for low intensity, aerobic work such as jogging. Fats are made from glycerol and fatty acids. Each glycerol is attached to three fatty acids. Glycerol and fatty acids contain the elements carbon, hydrogen, and oxygen. Fats contain a lot of carbon. This is why they give us so much energy. Fat is an important energy fuel during low intensity exercise. It is also a carrier for fat soluble vitamins A D E and K. However, too much fat can lead to excessive weight which will affect levels of stamina and limit flexibility.

Proteins
These are a combination of many chemicals called amino acids and are important for tissue growth and repair and to make enzymes, hormones and haemoglobin. Generally proteins tend to provide energy when glycogen and fat stores are low. However, during strenuous activities or sustained periods of exercise proteins in the muscles may start to be broken down to provide energy.
**Vitamins**
Vitamins are needed for muscle and nerve functioning, tissue growth and the release of energy from foods. Excessive consumption will not have any beneficial effects as vitamins cannot be stored in the body so additional amounts will be excreted through urine.

**Minerals**
Minerals assist in bodily functions, calcium, for example is important for strong bones and teeth and iron helps form haemoglobin which will enhance the transport of oxygen and therefore improve stamina levels. Minerals tend to be dissolved by the body as ions and are called electrolytes. Two of the functions they have are to facilitate the transmission of the nerve impulses and enable effective muscle contraction, both of which are important during exercise. It is important to get the right balance. Too much sodium (contained in salt) can result in high blood pressure. As with vitamins, excessive consumption is unlikely to enhance performance.

**Fibre**
Good sources of fibre are wholemeal bread and pasta, potatoes, nuts, seeds, fruit, vegetables and pulses. Fibre is important during exercise as it can slow down the time it takes the body to break down food which results in a slower, more sustained release of energy.

**Water**
Water constitutes up to 60% of a persons body weight and is essential for good health. It carries nutrients to cells in the body and then removes waste products. It also helps to control body temperature. When an athlete starts to exercise their production of water increases (water is a bi-product of the aerobic system). We also lose a lot of water through sweat. The volume of water we lose depends on the external temperature, the intensity and duration of the exercise and the volume of water consumed before, during and after exercise. Water is important to maintain optimal performance. Make sure you take on fluids regularly. Sports drinks such as lucozade sport and gatorade can boost glucose levels before competition while water will re-hydrate during competition.
A Balanced Diet

This diet should contain 15% protein, 30% fat and 55% carbohydrate. During exercise this percentage needs to change in favour of carbohydrates. Sports nutritionists recommend the following:

Proteins 10-15%
Fats: 20-25%
Carbohydrates 60-75%

Energy balance of food

When we take part in physical activity, the body requires energy and the amount of energy we need is dependent on the duration and type of activity. Energy is measured in calories and is obtained from the body stores or the food we eat. A calorie (cal) is the amount of heat energy required to raise the temperature of 1g of water 1°C. A kilocalorie (kcal) is the amount of heat required to raise the temperature of 1000g of water 1°C.

Most nutritionists state that the basic energy requirements of the average individual are 1.3 kcal per hour for every kg of body weight. Therefore if you weigh 60kg you would require:

\[ 1.3 \times 24 \text{ (hours in a day)} \times 60 = 1872 \text{ kcal/day} \]

This energy requirement increases during exercise up to 8.5 kcal per hour for each Kg of body weight. Therefore in a one hour training session the performer would require an extra \[ 8.5 \times 1 \times 60\text{kg} = 510\text{kcal} \]

From these calculations it is possible to calculate the energy requirements of this performer by adding their basic energy requirements (1872Kcal) to the extra energy needed for that one hour training session (510Kcal)

\[ 1872 + 510 = 2382 \]

What should you eat before a competition?

In order to achieve optimal performance in sport it is essential to be well-fuelled and well-hydrated. This means the importance of a pre-competition meal should not be understated. It should be eaten about 3-4 hours before competing as the food consumed needs to be digested and absorbed in order to be useful. The meal needs to be high in carbohydrate, low in fat and moderate in fibre in order to aid digestion (foods high in fat, protein and fibre tend to take longer to digest). High levels of carbohydrate will keep the blood glucose levels high throughout the duration of the competition/performance. Suggestions for pre-competition meals can be seen in the box below:
Tasks to tackle: Complete the table below with suggestions for a diet for an 18 year old long distance runner weighing 60kg who trains 5 sessions per wk each lasting 2 hours.

<table>
<thead>
<tr>
<th>Energy requirements without exercise (per week)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy requirements including exercise (per week)</td>
<td></td>
</tr>
<tr>
<td>% carbohydrates</td>
<td></td>
</tr>
<tr>
<td>% fats</td>
<td></td>
</tr>
<tr>
<td>% proteins</td>
<td></td>
</tr>
<tr>
<td>Suggested meals</td>
<td></td>
</tr>
</tbody>
</table>

Food:
- Chicken breast without skin (preferably poached)
- Vegetable based sauce served on the side rather than over the dish
- Two carbohydrate sources such as brown rice or wholemeal pasta
- Unglazed vegetables
- Salad, without a dressing
- Selection of fresh fruit (lots of bananas)
- Fresh fruit salad and yoghurt
- Scrambled eggs, bacon, baked beans and fresh wholemeal toast
- Porridge, special K, muesli

Drinks
- still water, orange and apple juice
A balanced diet for most games players is approximately 60% carbohydrate, 20% fat and 15% protein. Devise a diet sheet for a games player, for one day listing all the food and liquid that will be consumed.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breakfast</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lunch</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dinner</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Supper</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Snacks</strong></td>
<td></td>
</tr>
</tbody>
</table>
Diet composition of an endurance athlete v power athlete

The body’s preferred fuel for any endurance sport is muscle glycogen. If muscle glycogen breakdown exceeds its replacement then glycogen stores become depleted. This results in fatigue and the inability to maintain the duration and intensity of training. In order to replenish and maintain glycogen stores, an endurance athlete needs a diet rich in carbohydrates. Most research seems to suggest that endurance athletes need to consume at least 6 to 10 grams of carbohydrate per kilogram of their body weight. Another key nutrient that is a must is water to avoid dehydration.

Some endurance athletes manipulate their diet to maximise aerobic energy production. One method is glycogen loading (often called carbo-loading). Six days before an important competition a performer eats a diet high in protein and fats for three days and exercises at relatively high intensity to burn off any existing carbohydrate stores. This is followed by three days of a diet high in carbohydrates and some light training. The theory is that by totally depleting glycogen stores they can then be increased by up to two times the original amount.

In general endurance athletes require more carbohydrates than power athletes simply because they exercise for longer periods of time and need more energy.

Proteins are very important for power athletes. Not getting enough protein will lead to muscle breakdown. Proteins are important for tissue growth and repair.

Body fat composition

This is the physiological make-up of an individual in terms of the distribution of lean body mass and body fat. On average men have less body fat than women, 15% as oppose to 25% approximately. Obviously body composition has an important role in sport. Excess body fat can lead to health problems such as cardiovascular disease and any exercise will require greater energy expenditure as more weight has to be moved around. It is generally agreed that the less body fat the better the performance, but there are some sports with specific requirements for larger amounts of fat such as the defensive linesman in American football or if we take it to the extreme a sumo wrestler!

In most team games, for example, excess body fat would affect the performers’ ability to move freely around the court/field and would increase the onset of fatigue during the game.
Body mass index (BMI)

Body mass index or (BMI) takes into account body composition. To calculate your BMI divide your weight in kilograms by your height in metres squared. A 17 year old, for example, who weighs 75 kg and is 1.80m can calculate their BMI as follows:

$$\text{BMI} = \frac{\text{weight (kg)}}{\text{height (m)} \times \text{height (m)}}$$

$$\text{BMI} = \frac{75}{1.8 \times 1.8} = 23.15$$

BMI values vary according to which book you read but the table below is representative of most literature:

<table>
<thead>
<tr>
<th>BMI</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;19</td>
<td>Underweight</td>
</tr>
<tr>
<td>19-25</td>
<td>Normal</td>
</tr>
<tr>
<td>26-30</td>
<td>Overweight</td>
</tr>
<tr>
<td>30-40</td>
<td>Obese</td>
</tr>
<tr>
<td>&gt;40</td>
<td>Morbidly obese</td>
</tr>
</tbody>
</table>

Obesity and limitations of definition

Definitions of obesity vary from one text book to another. In general, obesity is when there is an excess proportion of total body fat usually due to energy intake being greater than energy output! Obesity carries an increased risk of heart disease, hypertension, high blood cholesterol, strokes and diabetes. It can also increase stress on joints and limit flexibility, as well as the psychological problems of dealing with being obese (a problem even more apparent with size 0 culture)! It occurs when an individual’s body weight is 20% or more above normal weight or when a male accumulates 25% and a female 35% total body fat. The body mass index or BMI is also a common measure of obesity. This takes into account body composition. An individual is considered obese when his or her BMI is over 30.

Practice makes perfect:

1. Eating a diet with sufficient calcium and iron would have physiological benefits for an athlete. State the importance of these two minerals for the athlete [3]

5. In what ways should the diet of a long distance runner be different from that of a weight lifter. Give reasons for your answer. [3]

3. A balanced diet for most games players is approximately 60% carbohydrate, 20% fat and 15% protein. Describe the role of each of these food types in maintaining a balanced diet for the games player [3]

Practice makes perfect answers:
### Chapter 1

1.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Recovery</th>
<th>Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Agonist Hip flexors (iliopso as)</td>
<td>Plane sagittal</td>
</tr>
</tbody>
</table>

#### Knee action

<table>
<thead>
<tr>
<th>Movement</th>
<th>Recovery</th>
<th>Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Agonist Hamstrings</td>
<td>Plane sagittal</td>
</tr>
</tbody>
</table>

#### Ankle action

<table>
<thead>
<tr>
<th>Movement</th>
<th>Recovery</th>
<th>Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexion</td>
<td>Agonist Tibialis anterior</td>
<td>Plane sagittal</td>
</tr>
</tbody>
</table>

2.  

![Fulcrum | Resistance | Effort (force)](image)
2 marks form 2 of:
Mechanical advantage: large effort arm or short resistance arm
   Heavy loads can be moved but only over a short distance
   Does not need a lot of force

2 marks from 2 of:
Mechanical disadvantage: short resistance arm or large effort arm
   Cannot move as heavy a load
   But can move it faster

Max 4

Chapter 2

1. 3 marks for 3 from:
   - Detected by chemoreceptors
   - Nerve impulse sent to medulla/cardiac control centre
   - Impulse sent via sympathetic system/nerve/cardiac accelerator nerve
   - To SA node/SAN

2. 3 marks from 3 of:
   - Hypertrophy of the cardiac muscle
   - Athletes heart
   - Bradycardia
   - Increase in resting stroke volume
   - Increase in the ejection fraction
   - Increase in maximum cardiac output
   - Increased capillarisation of the heart muscle

3.
   - Heart rate increases/anticipatory rise
   - Due to the effects of adrenalin

   2 marks

4.
   - Athletes heart. An increase in chamber size or equivalent
   - Bradycardia. A reduction of resting heart rate/below 60 bpm

   2 marks

5.
• Cardiac output is the amount of blood leaving the heart ventricles per minute
• Stroke volume is the amount of blood leaving the heart ventricles per beat
• Relationship- cardiac output = stroke volume x heart rate

3 marks

6.
• Cardiac output does not change
• Stroke volume will increase

2 marks

Chapter 3

1.
3 marks for 3 from:
Skeletal muscle pump- muscles change shape when they contract and relax and this squeezes the veins pushing blood through
Respiratory pump- changes in thoracic pressure cause a squeezing effect on the veins
Valves- prevent back flow
Smooth muscle in veins

2.
Brain function/activity needs to be maintained both during exercise and at rest
Brain requires glucose/oxygen
2 marks

3.
3 marks for 3 from
Active muscles require oxygen
During exercise less blood flows to the gut
If there is food in the gut blood will re-directed to the stomach
This reduces the blood to the working muscles
Will reduce performance
Performer may feel sick or equiv

4. 2 marks from 2 of:
Combines with haemoglobin
Dissolves in plasma
As bicarbonate/hydrogen carbonate

5.
3 marks from 3 of:
Increase in carbon dioxide/drop in pH
Chemoreceptors detect this
Impulse sent to the medulla/vasomotor centre
Vasoconstriction in arterioles to non-essential organs
Vasodilation in arterioles to working muscles
Pre-capillary sphincters control blood flow/open leading to muscles/closed leading to non-essential organs

6.

Blood pressure/systolic pressure increases

2 marks

Chapter 4

1.
4 marks from 4 of:
Increase in carbon dioxide/decrease in pH of the blood
Chemoreceptors detect this
Nerve impulses sent to the medulla/respiratory centre
Phrenic/intercostal nerves
Deeper and faster breathing

2.
Arterio-venous difference is the difference between the oxygen content of arterial and venous blood
More oxygen is being used by the muscles or equiv

2 marks

3.
4 marks from 4 of:
Increase in blood temperature
Increase in blood carbon dioxide
Increase in the acidity of blood
Bohr shift
Less saturation of haemoglobin with oxygen as a result
Therefore an increase in oxygen release or equiv

4.
The mount of air breathed in or out per breath
It increases during exercise

2 marks

5.
4 marks for 4 from:
Gas flows from area of high pressure to low pressure
(Partial) pressure/concentration of O2 is high in the lungs/alveoli and low in the blood
Therefore O2 diffuses down the diffusion gradient into the blood
(3%) dissolves in the plasma
(97%) combines with haemoglobin

6.
3 marks for 3 from:
Diaphragm contracts increasing dimension of thoracic cavity
External intercostals contract pulling ribs upward and out, increasing the dimension of the thoracic cavity
This has the net effect of lowering pressure and air moves the lungs
Expiration is passive

Chapter 5

1. 2 marks for any of the following: power, speed, stamina (or equiv) flexibility, co-ordination, muscular endurance, strength, balance
1 mark for a correct example of one of the above

2.
2 marks from 2 of:
Amount of work or effort done
Per unit of time
Speed x strength or equiv

3.
Only speed, strength, flexibility and agility (only count the first two)
2 marks

4.
the ability to perform daily tasks without undue fatigue
a state of complete physical, mental, and social well-being
Chapter 6

1. Iron:
   - Haemoglobin/red blood cells
   - will enhance the transport of O2
   - improved stamina

   Calcium:
   - Bones
   - important for nerve transmission and muscle contraction

Max 3 marks

2. A marathon runner requires:
   - more carbohydrate
   - for energy

   Weight lifter requires:
   - more protein
   - for muscle growth

Max 3 marks

3. Carbohydrate is the main energy fuel for both aerobic and anaerobic work
   - Fats are the secondary energy fuel for low intensity work
   - Proteins are for tissue growth and repair