THE CARDIOVASCULAR SYSTEM...

Impact on Health and Fitness

Physical activity can have the following effects on health and fitness:

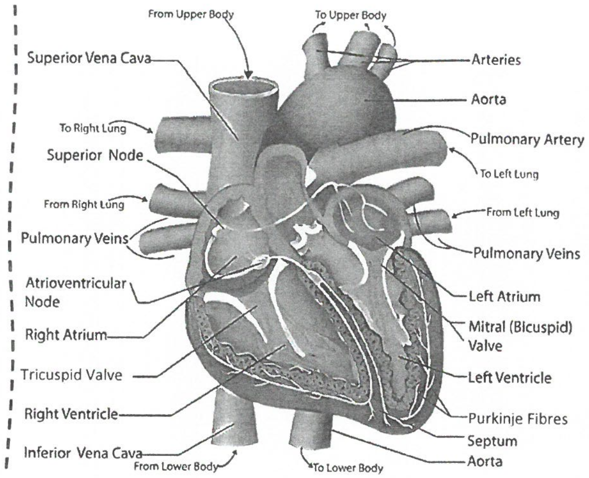
Health	Fitness
↓ Blood pressure	↑ Gaseous exchange
↓ Risk of coronary heart disease	↑ Lung volume
↓ Risk of stroke	↑ Oxygen available
↓ Plaque accumulation	↑ Stroke volume
↓ LDL cholesterol	↑ Cardiac output
↑ HDL cholesterol	↑ Heart efficiency
↑ Blood vessel width	↑ Capacity for exercise
	↑ Intensity of exercise

Coronary heart disease is the blockage of the coronary arteries (arteries that supply the heart muscle) caused by fatty build-up.

High blood pressure is a raised force of blood against the wall of the blood vessel which can be diagnosed by a systolic blood pressure greater than 140 mmHg and a diastolic pressure greater than 90 mmHg.

High levels of low-density lipoprotein **(cholesterol)** can lead to the formation of cholesterol plaques and restrict the size of the arteries.

Strokes occur when the amount of blood supplied to the brain is restricted by a blockage in the arteries supplying the brain.



Cardiac Conduction System

The conduction system involves the electrical impulses that cause the cardiac cycle of the heart. **The cardiac muscle is myogenic**, meaning it generates its own impulses. The electrical impulse occurs in the following order:

1. **Sinoatrial node:** the pacemaker of the heart – produces an electrical stimulus, resulting in the atria contracting.
2. **Atrioventricular node:** enables the ventricles to completely fill with blood by delaying the stimulus until after the AV valves shut.
3. **The bundle of His:** group of conduction cells, which branch into the Purkinje fibres.
4. **Purkinje fibres:** in the ventricular wall, conduct the electrical impulse from the bundle of His and cause ventricular contraction.

Atrial depolarisation:
Stimulus from the SA node travels across the atria, causing atrial contraction.

Ventricular depolarisation:
The effect that the AV node has on the ventricles by causing them to contract by providing an electrical stimulus.

Atrial and ventricular repolarisation:
Occurs during a brief time period following depolarisation and describes the electrical impulse returning to a baseline value.

The Relationship between Heart Values...

Cardiac output (Q): The volume of blood ejected by the heart per minute (ml/min) = **Heart rate (HR):** The number of times the heart beats per minute (bpm) × **Stroke volume (SV):** The volume of blood ejected from the heart per beat (ml)

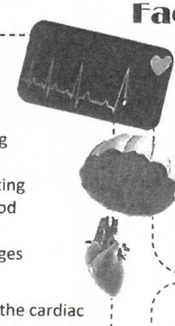
Heart values can differ according to whether someone trains or not and according to different intensities of exercise:

- **Trained individuals** will have a **lower resting HR** than untrained individuals and a **greater Stroke Volume.** Cardiac outputs will be similar but the trained athlete's heart will work less (fewer beats) as it can force more blood out with each contraction.
- **Sub-maximal exercise** will see a plateau in cardiac output when a steady state is reached as the cardiovascular system is able to supply the working muscles with adequate oxygen.
- **Maximal exercise** will result in a greater cardiac output than sub-maximal exercise and this will peak and then rapidly decline as maximal exercise cannot be sustained.

Cardiovascular Drift and A-VO₂ Difference

- **Cardiovascular drift** – the increase in heart rate which occurs despite no change in the intensity of exercise.
- **Arteriovenous oxygen difference (A-VO₂ diff)** – the difference in oxygen concentration between the arteries and veins.
- High-intensity exercise will result in a greater A-VO₂ diff as more oxygen is taken out of the arteries to fuel muscular contractions. However, a plateau will be reached when more oxygen cannot be removed from the arteries.
- Trained athletes will have higher starting A-VO₂ diffs and will experience a bigger change during exercise.
- Regular training can increase the A-VO₂ diff due to: *greater capillary density, greater alveoli density* and *greater myoglobin in the muscles.*

Factors Regulating Heart Rate



Neural

The vasomotor centre responds to changes detected by:

- **Baroreceptors:** sensors detecting changes in blood pressure
  Chemoreceptors: sensors detecting chemical changes within the blood
- **Proprioceptors and mechanoreceptors**: detect changes in body position

These receptors send an impulse to the cardiac control centre in the medulla oblongata which sends an impulse to the SA node either via:

- **Parasympathetic nervous system** (Vagus nerve) to slow heart rate
- **Sympathetic nervous system** (acceleratory nerve) to increase heart rate

Hormonal

- **Adrenaline** and **noradrenaline** released from adrenal glands.
- Adrenaline is released into the bloodstream, and stimulates the adrenergic receptors and SA node found in the heart, increasing heart rate.
- Release of adrenaline before exercise is known as the **anticipatory rise.**

Intrinsic

- **Higher temperature** caused through exercising causes increased heart rate as heart works harder to get blood to the skin so heat can be lost as radiation.
- It also concerns the venous return mechanism.

Venous return:
The rate at which blood returns to the heart.

As intensity increases:
Blood redistribution needs to be quicker otherwise cardiac output decreases. Exercise increases it through the **muscle pump** and **respiratory pump** which force blood back to the heart. This process is also aided by **pocket valves** in the veins, **smooth muscle** in the walls of the blood vessels and **gravity**. Venous return is quickest in the arteries and during **systole** as systolic blood pressure is larger than diastolic.

During recovery the lower venous return results in a lower stroke volume. This is due to reduced stretching of the ventricles with a low venous return **(Frank-Starling law)**.

Transportation of Oxygen

Oxygen is transported within the body in association with:

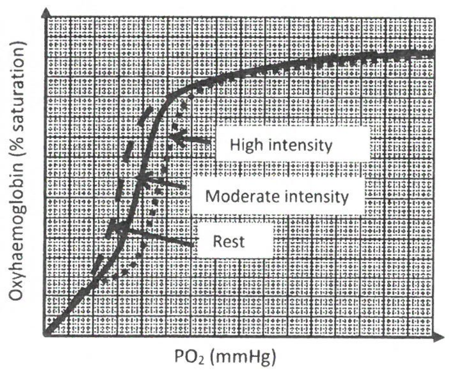
- **Haemoglobin** – the oxygen-carrying component of red blood cells
- **Myoglobin** – the oxygen-carrying component of the muscle tissue

The graph shows an oxyhaemoglobin dissociation curve which displays the **Bohr shift** during exercise of different intensities.

The Bohr shift is demonstrated by the line shifting to the right as the conditions within the blood become more acidic (reduced pH due to increased levels of CO_2) during higher-intensity exercise.

Factors influencing Bohr shift include:

1. Increase in CO_2
2. Decrease in pH – due to increase in CO_2
3. Increase in temperature



Redistribution of Cardiac Output

During exercise our blood needs to redistribute to working muscles. This is done via the methods outlined below:

Vascular shunt

Mechanism which directs blood to the exercising muscles through vasodilation and vasoconstriction.
Redistribution of blood during exercise:

- ↑ blood flow to the skeletal muscles in order to supply them with oxygen and nutrients and to remove carbon dioxide
- ↑ blood flow to the heart to provide additional oxygen, as it has to work harder during exercise
- ↑ blood flow to the skin in order to regulate body temperature
- ↓ blood flow to some abdominal organs to allow for greater blood flow to active body parts

Arterioles

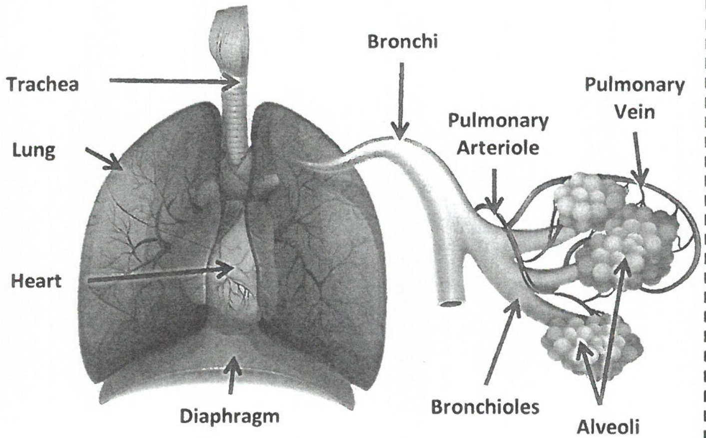
- Widen (vasodilation) to allow more blood through
- Narrow (vasoconstriction) to reduce blood flow

Pre-capillary sphincters

Allow / do not allow the flow of blood into the capillaries, where gas exchange occurs.

THE RESPIRATORY SYSTEM…

The respiratory system consists of a number of structures (outlined in the diagram below) which allow gasses to be transferred between the body and the external environment. This is an important process during exercise when large volumes of oxygen are required by the muscles and large volumes of carbon dioxide need to be removed from the body.

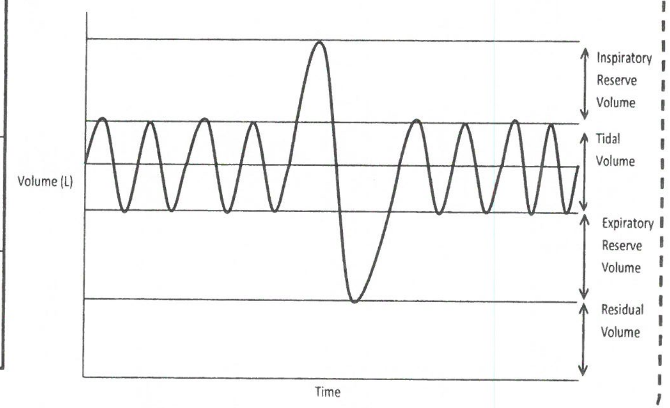


Lung Volumes

There are a number of different lung volumes which can be measured in order to determine how a person's respiratory system is functioning. These volumes will change depending on the level of physical activity, the training status and the health of the person.

	Tidal volume	Minute ventilation	Residual volume	Expiratory reserve volume	Inspiratory reserve volume
Definition	The amount of air normally breathed in/ out with each breath	The volume of air inspired /expired each minute	The volume of air that remains in the lungs after maximal expiration	The amount of air that can be expired on top of the tidal volume	The amount of air that can be inspired on top of the tidal volume
Typical resting value	500 ml	6.0 L/min	1,200 ml	1,200 ml	3,100 ml
Change during exercise	Increases	Increases	Remains almost the same but may decrease slightly	Decreases	Decreases

Minute ventilation: The volume of air inspired or expired per minute = **Breathing frequency:** The number of breaths per minute (breaths per minute) × **Tidal volume:** The amount of air inhaled/exhaled with each breath (ml)

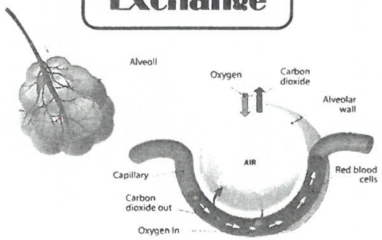


At the alveoli:
Oxygen moves from a highly concentrated area (alveoli) where it has a high partial pressure to an area of low concentration (the blood) where the partial pressure is lower. CO_2 diffuses in the other direction.

Gas exchange is efficient because:

- large number of alveoli
- large number of capillaries
- thin membrane between alveoli and capillary

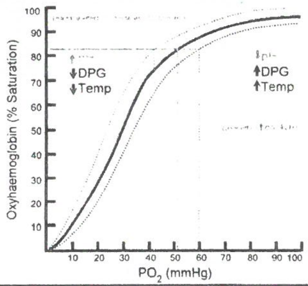
Gas Exchange



At the muscles:
At rest there is a small arteriovenous difference. When exercising, there is a higher arteriovenous difference, which increases the pressure gradient for gas diffusion.

Gas Exchange during Exercise

Dissociation of oxyhaemoglobin
In a high partial pressure of oxygen (e.g. at the lungs), oxygen binds more readily to haemoglobin. As this partial pressure decreases (e.g. at the exercising muscles) oxygen is more readily released. As exercise intensity increases, the partial pressure of oxygen decreases and so oxygen is easily released from haemoglobin.



As exercise intensity increases, there is a larger **pressure gradient** between CO_2 and O_2 levels at the sites of gas exchange.

Regulation of Breathing Rate

The respiratory control centre of the brain is made up of the **inspiratory control centre** and the **expiratory control centre**. These two centres work together to regulate breathing at rest and during exercise without conscious thought and, therefore, require different receptors to send them information in order to control breathing rate.

1. **Neural**
   The respiratory centres regulate breathing rate by increasing or decreasing respiratory muscle activation through **sympathetic** or **parasympathetic** stimulation respectively. Neural stimulation is dependent on the following receptors:
   - **Proprioceptors** (detect movement, tension and force)
   - **Baroreceptors** (detect degree of lung inflation)
   - **Thermoreceptors** (detect changes in temperature)
2. **Chemical**
   Chemoreceptors in the aorta and medulla oblongata detect changes in blood pH level. As CO_2 increases, breathing rate increases as a result of stimulation from the inspiratory control centre.
3. **Hormonal**
   Breathing rate can be increased by the release of the hormone adrenaline from the adrenal glands.

Impact of Smoking on Respiration

Smoking

- ↑Risk of lung cancer
- ↑Risk of asthma
- ↑Risk of bronchitis
- ↑Risk of cardiovascular disease
- ↑Risk of emphysema
- ↓Movement of oxygen through airways
- Damaged alveoli
- ↓Transportation of oxygen in blood
- ↓Cardiovascular endurance
- ↓Intensity of exercise can be tolerated
- ↓Ability to be active
- ↑Risk of asthma attack during exercise

The Neuromuscular System

Muscle Contraction during Exercise and Recovery

There are two different types of muscle fibres – slow twitch and fast twitch. There are two types of fast-twitch fibres – fast oxidative glycolytic (type IIa) and fast glycolytic (type IIb). The characteristics of each fibre are shown in the table below:

Slow oxidative (I)	Fast oxidative glycolytic (IIa)	Fast glycolytic (IIb)
• Small motor neuron size • Large myoglobin content • High oxidative capacity • Slow contraction time • Suited for aerobic exercise • High resistance to fatigue • Low force production • Low glycolytic capacity • High capillary density	• Large motor neuron size • Intermediate myoglobin content • High oxidative capacity • Fast contraction time • Suited for lengthy anaerobic exercise • Medium resistance to fatigue • High force production • High glycolytic capacity • Medium capillary density	• Large motor neuron size • Small myoglobin content • Low oxidative capacity • Fastest contraction time • Suited for short anaerobic exercise • Low resistance to fatigue • Highest force production • High glycolytic capacity • Low capillary density
Endurance events, e.g. long-distance running	Swimming	100 m sprint

Muscle fibre recruitment
Muscle fibre recruitment is dependent on the intensity of the exercise; higher-intensity exercise requires more force, with lower-intensity exercise requiring less force.

The Size Principle (Henneman et al. 1974)
Smaller motor units are recruited first as they have a smaller firing threshold than larger motor units.

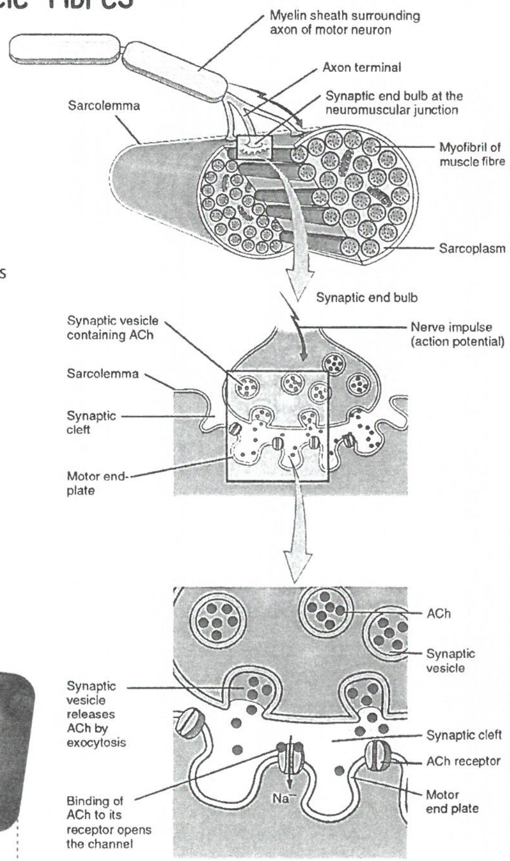
The Recruitment of Muscle Fibres

Structure and role of motor units

Key structures:

- **Myelin sheath** acts as an electrical insulator around the axons.
- **Axons** are extensions of a nerve cell that carry an impulse.
- **Myofibrils** are contractile structures of the muscle consisting of actin and myosin.
- **Sarcolemma** is the cell membrane.
- **Synaptic vesicle** is where acetylcholine is stored.
- **Synaptic cleft** is the gap between neurons.
- **Motor end plate** is where the action potential from an action travels to stimulate a muscle.

A **motor unit** consists of → A motor neuron; The muscle fibres that it stimulates



Nervous stimulation of a motor unit

A motor unit needs to be stimulated to enable muscular contraction:

1. A neuron becomes depolarised, firing an action potential (an electrical impulse that acts as a signal).
2. The action potential reaches the neuromuscular junction.
3. This causes the neurotransmitter acetylcholine to move to the motor end plate.
4. The motor end plate becomes depolarised, resulting in muscular contraction.

- Motor units vary in the number of muscle fibres that they stimulate.
- The fibres are made up of only one type.
- The brain recruits smaller motor units before larger motor units.
- Smaller motor units consist of slow-twitch fibres.
- Larger motor units consist of fast-twitch fibres.

The Nervous Systems

The autonomic nervous system is responsible for subconsciously controlling muscular contractions.

There are two systems which make up the autonomic nervous system:

- The **parasympathetic** nervous system is responsible for actions that occur when resting.
- The **sympathetic** nervous system is responsible for actions when active.

Both nervous systems innervate the muscle tissues by sending a nervous impulse to them.

Proprioceptive Neuromuscular Facilitation

Proprioceptive Neuromuscular Facilitation:

- a form of stretching which aims to overcome the stretch reflex
- an isometric contraction is performed when the muscle is stretched to its limit

Role of muscle spindles:

- sensory receptors
- found in the centre of the muscle
- provide information regarding the length of the muscle to the brain
- this information is used to initiate the stretch reflex when the muscle is stretched to its limit

Role of Golgi tendon organ:

- sensory receptor
- found at the connection of the muscle with the bone
- detects changes in tension of the muscle
- initiates the Golgi-tendon reflex which reduces muscle tension when it is high

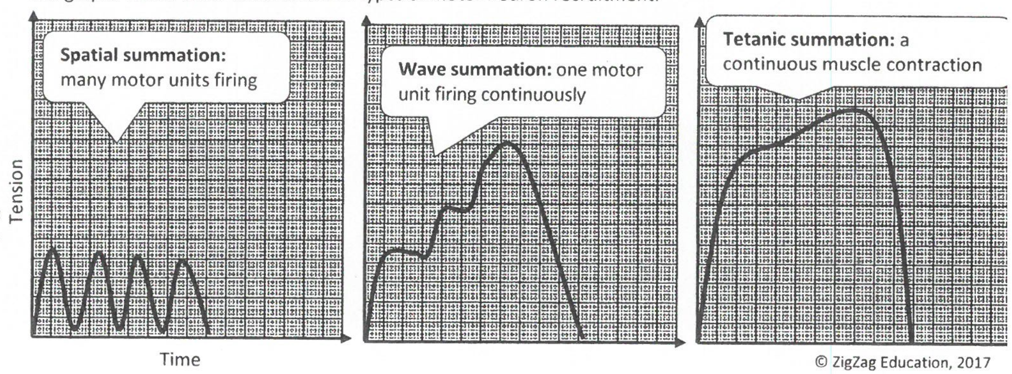
'All or none' law

Each muscle fibre controlled by a motor unit is either fully contracted or not contracted at all.

They can contract in different ways depending on how they are innervated.

Therefore, a muscle fibre cannot partially contract.

The way that individual motor units are recruited determines the amount of force that is produced in a muscle. The graphs below show three different types of motor neuron recruitment.

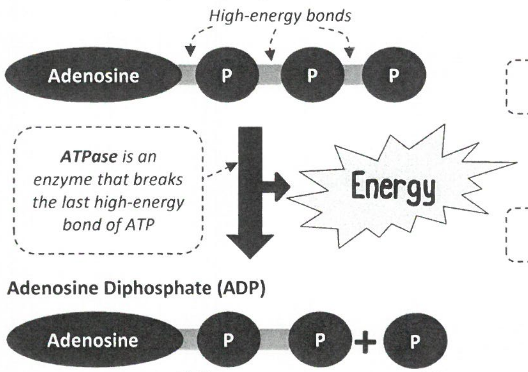


Energy for Exercise

We get our energy from food, but the nutrients we get from food are stored as a high-energy compound known as ATP. This is broken down and resynthesised to continually supply us with energy for exercise.

Adenosine Triphosphate (ATP)

ATP is the primary energy source for the human body. Energy is produced from ATP when the adenosine and three phosphate molecules are broken down.



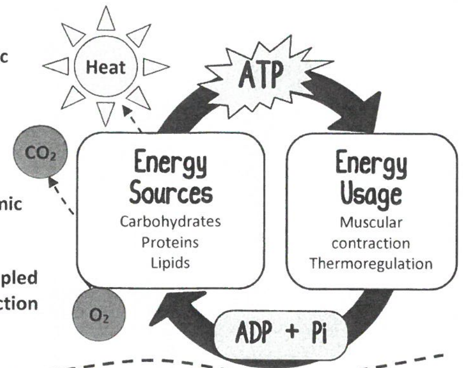
ATP Breakdown

ATP = ADP + P + Energy — Exothermic reaction

ATP Resynthesis

Energy + ADP + P = ATP — Endothermic reaction

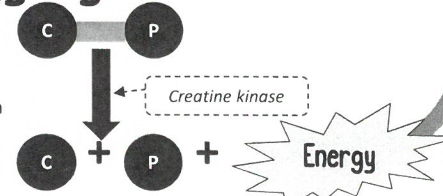
In order for ATP resynthesis to happen, energy is used from the ATP-PC System — Coupled reaction



The Energy Systems

ATP-PC

This is an **anaerobic energy system** which **provides energy for 10–15 seconds of high-intensity** exercise. The energy released when phosphocreatine (PC) is broken down into phosphate and creatine molecules is used to resynthesise ATP from ADP and P.

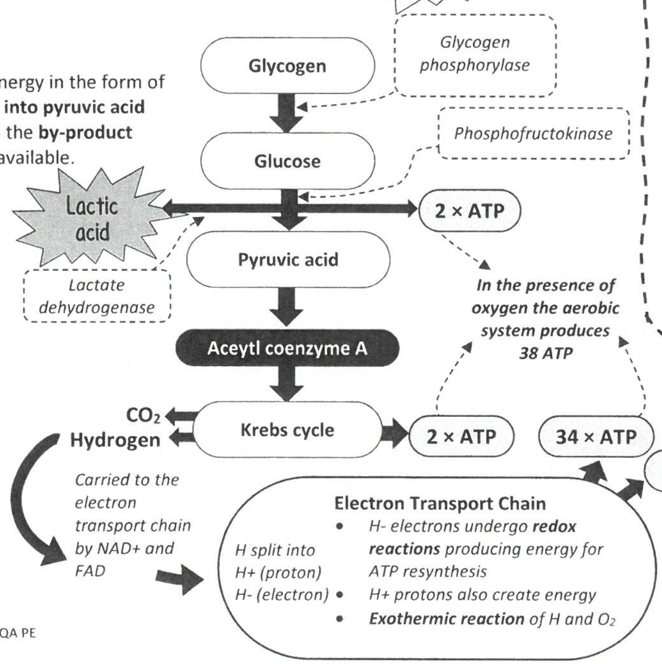


Glycolytic System

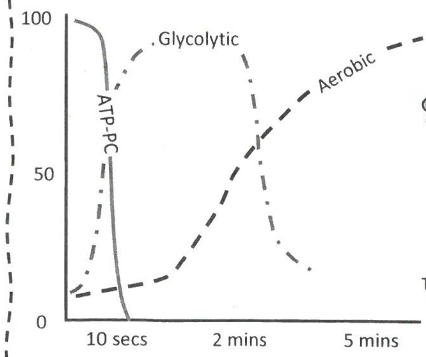
This energy system produces energy in the form of ATP by **breaking down glucose into pyruvic acid** which then gets converted into the **by-product lactic acid** when oxygen is not available.

Aerobic System

If oxygen is available, the **pyruvic acid** produced through glycolysis is **converted to aceytl coenzyme A** and **enters the Krebs cycle** where ATP and hydrogen are produced. The hydrogen then enters the electron transport chain.



Energy Continuum



Fitness levels
The higher the aerobic fitness levels, the longer the time spent using the ATP-PC and glycolytic energy systems.

Which energy system? Also affected by

Recovery periods
Aerobic: up to 24 hours
Glycolytic: 20 mins to 2 hrs
ATP-PC: 3 mins

Muscle fibre
Type I fibres are more likely to use aerobic system, type IIx are more likely to use the glycolytic system and type IIa are more likely to use the ATP-PC system.

Duration
The graph to the left is of the energy continuum, demonstrating how the predominant energy system being used differs as the length of exercise increases.

Intensity
Low intensity: aerobic
High intensity: glycolytic
Very high intensity: ATP-PC

Energy Transfer during Exercise of Different Intensities

The type of energy transfer that occurs is dependent on the duration and intensity of exercise.

Short duration / high intensity

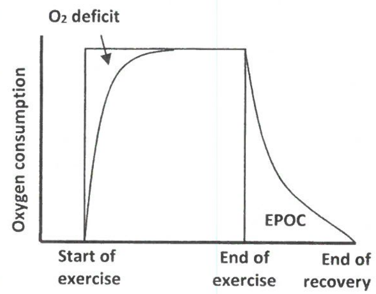
This type of exercise uses the **anaerobic energy system**, i.e. the **ATP-PC system**, and is utilised in sports which require **sprint and power** performance, e.g. 100 m sprinting.

A downside of performing this type of exercise is that it leads to **lactate accumulation**. If lactate continues to accumulate, it will exceed the **lactate threshold** and, therefore, levels will rise dramatically leading to **OBLA** (a level of lactate accumulation which causes fatigue).

Athletes who rely on their ability to quickly produce energy will have a greater lactate-producing capacity than athletes who rely on aerobic energy production. This is largely due to a greater lactate buffering capacity which allows them to utilise this system for longer before fatigue occurs.

Long duration / lower intensity

This type of exercise uses the **aerobic energy system** to produce energy. At the start of aerobic exercise, there is an **oxygen deficit** as not enough oxygen is available to produce the required energy. The size of the deficit is greater during **maximal** exercise compared to **submaximal** exercise. The oxygen deficit is repaid after exercise by **excess post-exercise oxygen consumption (EPOC)**.



VO_2 max is a measure of aerobic fitness. It can be affected by:

- Weight
- Gender
- Height
- Training status
- Fat mass

Summary of Energy Systems

	ATP-PC System	Glycotic System	Aerobic System
Type of Reaction	Anaerobic	O_2 present (aerobic) No O_2 present (anaerobic)	Aerobic
Chemical/Fuel used	Phosphocreatine (PC)	Glucose	Pyruvate
Site	Sarcoplasm	Sarcoplasm	Mitochondria
Controlling Enzyme	Creatine kinase	Phosphofructokinase (PFK) Glycogen phosphorylase (GP) Lactate dehydrogenase (LDH)	Lipase Phosphofructokinase (PFK) Glycogen phosphorylase (GP)
ATP Yield	1	2	Glycolysis – 2 Krebs cycle – 2 Electron transport chain – 34 Total – 38
By-products	ATP + Pi	NADH	CO_2 + H_2O

Energy Expenditure

Energy expenditure is a measure of the calories required to perform a task. It can be measured using the following methods:

- Indirect calorimetry
- Lactate sampling
- VO_2 max test
- Respiratory exchange ratio (RER)

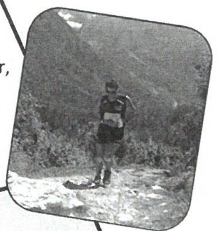
Impact of Specialist Training Methods on Energy Systems

There are a number of specialist training methods which can be used in order to train the aerobic and anaerobic energy systems. These include: **altitude training**, **high-intensity interval training (HIIT)**, **plyometrics** and **speed agility quickness (SAQ)**.

Altitude Training

What is it?

Athletes train at an altitude of at least 2,400 m above sea level where the partial pressure of oxygen is lower, in order to give them an advantage over their opponents.



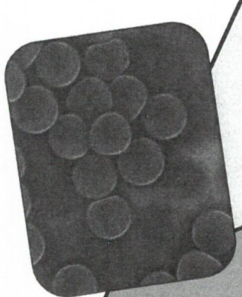
The Effects

Low partial pressure of oxygen negatively impacts on efficiency of oxygen transport to the working muscles.

The heart now has to beat faster and the athlete's ventilation rate also needs to increase.

To compensate for the lower amount of oxygen, the athlete's body produces more red blood cells which aid the transport of oxygen.

This increased red blood cell count will be an advantage when the athlete exercises at sea level as they will be able to transport a greater amount of oxygen.



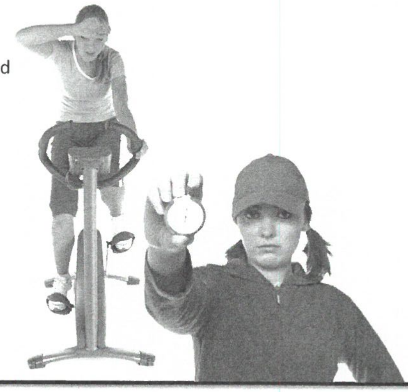
Acclimatisation and Timing

The increase in the number of red blood cells allows the athlete to acclimatise to the conditions and this acclimatisation can last for up to 14 days.

It is, therefore, important that high-altitude training camps are timed so that they have an effect during an important competition.

High-intensity Interval Training (HIIT)

- The performance of multiple short bursts of maximal intensity exercise followed by a limited rest or recovery period
- Anaerobic energy production
- Trains the ATP-PC and glycolytic energy systems
- Due to the short amount of time spent exercising and the short recovery time between each bout, a whole exercise session can be performed in 10–15 minutes
- Can also improve VO_2 max through improved aerobic fitness
- Useful for team sports that require changes in intensity, such as rugby and football.
- Due to the high intensity, this method is not safe for those with health issues



Plyometrics

- Improves power and explosive strength, useful for sports such as basketball and hurdling
- Involves anaerobic energy production
- Utilises the ATP-PC system
- It is performed by bounding between raised platforms which leads to the three types of muscular contraction described to the right (**stretch-shortening cycle**)
- However, this method puts the muscles under a lot of stress which increases the risk of injury

1. **Eccentric stage**: The muscle undergoes an eccentric phase as it lengthens. In this stage, potential elastic energy is stored as the agonist is preloading.
2. **Amortisation phase**: The time period between the eccentric and concentric phases. The shorter this phase, the better the retention of the elastic energy.
3. **Concentric phase**: The elastic energy helps to stimulate a powerful muscular contraction. The **stretch reflex** prevents overstretching by contracting the agonist muscle and relaxing the antagonist.

Speed Agility Quickness (SAQ)

- Improves speed, agility and quickness, useful for many high-intensity sports such as hockey, netball, and athletics
- Improves anaerobic energy production through the ATP-PC and glycolytic systems
- Increases proportion of fast-twitch muscle fibres
- These three components of fitness are targeted through running drills which involve rapid acceleration and changes in direction
- Faults in technique can lead to injury if they are not addressed before training