How do I prepare to perform on the international stage? (AO3)

Exercise physiology, performance analysis and training
To answer the big question you will need to be able to complete the following tasks:

1. Analyse the short term responses to exercise which have an impact on performance. (AO3)  
   Pages 2 & 16

2. Assess the long term adaptations that have supported the athletes in finishing this endurance event. (AO3)  
   Page 23

3. Discuss the use of diet and supplementation to improve performance. (AO3)  
   Page 32

4. Evaluate the techniques used to help improve performance. (AO3)  
   Pages 42
1. Exercise physiology, performance analysis and training

Short Term Responses to Exercise on Cardiovascular system

Question

Analyse the short term responses to exercise which have an impact on performance. (AO3)

A. Content

- Systemic and pulmonary circulatory systems.
- Cardiovascular; cardiac dynamics, cardiac responses, Fran-Starling mechanism and venous return.
- Values associated with Stroke volume, heart rate and Cardiac Output at rest and during exercise (intensity dependent).
- The structure of blood vessels, vascular shunt.
- Blood pressure; values rest and exercise.
- Vasomotor control.
- Control and regulation of cardiac control centre; sympathetic and parasympathetic nervous systems.

B. Knowledge and Understanding

Introduction

Primary purposes of the cardiovascular and respiratory systems are to deliver adequate amounts of oxygen and remove waste from working muscles. During exercise, the reason for cardiovascular/respiratory regulation is to maintain adequate blood flow in order to carry oxygen and nutrients to working muscles and remove waste produces, lactic acid and carbon dioxide as well as regulated body temperature.
The Systemic and pulmonary circulatory systems

The heart is a four-chambered dual action pump. The right side of the heart receives deoxygenated blood from the muscles and other tissues and pumps it to the lungs for oxygenation (pulmonary circulation). The left side of the heart receives oxygenated blood from the lungs and pumps it to the muscles and other tissues of the body (systemic circulation). Each heartbeat results in the simultaneous pumping of both sides of the heart, making the heart a very efficient pump (cardiac cycle).

The pulmonary and the systemic systems:

Pulmonary Circulation

- Pulmonary circulation is between the heart and the lungs. It transports deoxygenated blood from the heart (via the pulmonary artery) and onto to the lungs to be re-oxygenated through gaseous exchange. At the lungs $\text{CO}_2$ is removed from the blood and $\text{O}_2$ enters. The blood then returns to the left side of the heart via the pulmonary vein. The chambers of the heart that support the pulmonary circulation loop are the right atrium and right ventricle.

Systemic circulation

- Systemic circulation carries oxygenated blood from the left side of the heart (via the aorta) to the muscles and the other tissues of the body. After the oxygen rich blood has been used in the muscles to produce energy (ATP), $\text{CO}_2$ rich, deoxygenated blood is transported to the right side of the heart. The left atrium and left ventricle of the heart are the pumping chambers for the systemic circulation loop.
Cardiac cycle is the transport of blood to the lungs and the working muscles. It has two phases the relaxation phase (diastole) and the contraction phase (systole). The whole cycle takes about 0.8 seconds.

**Diastole** - this is where the heart relaxes and fills with blood. This is the longest part of the cycle (0.5 second)

**Systole** - this is the process where the heart contracts and blood is ejected from the heart. This is the shortest part of the cycle (0.3 seconds)

During exercise the diastole increases in time due to the increase in volume of blood needing to be pumped out of the body (venous return) whereas there is little change to the systolic time.

Venous return is the rate at which the blood returns to the heart. When exercising, there is a greater need for more blood and therefore, as exercise intensity increases, venous return increases.
Starling’s Law refers to the increased stroke volume as a result of an increased amount of blood filling the heart. This occurs as a result of the cardiac muscles stretching before contracting. Similarly as venous return decreases so too does stroke volume.

Venous return can be regulated by:

- Veins controlling blood flow by valves regulating direction and smooth muscle squeezing the blood back to the heart.
- Musculo-skeletal pump where the muscles contract against the skeletal system forcing the blood through the venous system.
- Pressure gradient – moving from high pressure to low pressure with the arteries and veins.

Cardiac values and exercise intensity

Cardiac dynamics is the physiological, neurological and hormonal changes to exercise intensity, depending upon the intensity and duration of exercise the type of physiological adaptations will differ.

The relationship between heart rate, stroke volume and cardiac output

- **Cardiac output (Q)** is the volume of blood pumped by the heart per minute (mL/blood/min). Cardiac output is a function of heart rate and stroke volume
- **Heart rate (HR)** is the number of heart beats per minute (BPM)
- **Stroke volume (SV)** is the volume of blood, in millilitres (mL), pumped out of the heart per beat. Increasing either heart rate or stroke volume increases cardiac output.

Cardiac output mL/min = heart rate (beats/min) X stroke volume (mL)

- Q = HR \times SV
An average person has a resting heart rate of 70 beats/minute and a resting stroke volume of 70 mL/beat. The cardiac output for this person at rest is:

\[ \text{Cardiac Output} = 72 \times 70 = 5040 \text{ mL/minute}. \]

\[ Q = 5 \text{ Litre/minute} \]

During intense exercise, the cardiac output can increase up to 7 fold (35 litres/minute)

Heart rate and stroke volume increase proportionally with exercise intensity.

**Aerobic exercise**

<table>
<thead>
<tr>
<th>Individual</th>
<th>Heart rate (beats/min)</th>
<th>Stroke volume (mL)</th>
<th>Cardiac output (mL/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sedentary</td>
<td>130</td>
<td>70</td>
<td>9,000</td>
</tr>
<tr>
<td>athlete</td>
<td>110</td>
<td>150</td>
<td>16,500</td>
</tr>
</tbody>
</table>

This is achieved because the athlete has a thicker myocardium (heart muscle) on the left side of the heart. The heart is therefore able to contract with greater force, increasing the ejection fraction (volume ejected each contraction) of blood out of the left ventricle.

**Anaerobic exercise**

<table>
<thead>
<tr>
<th>Individual</th>
<th>Heart rate (beats/min)</th>
<th>Stroke volume (mL)</th>
<th>Cardiac output (mL/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sedentary</td>
<td>150</td>
<td>70</td>
<td>10,000</td>
</tr>
<tr>
<td>athlete</td>
<td>180</td>
<td>180</td>
<td>35,000</td>
</tr>
</tbody>
</table>

Stroke volume may increase only up to 40-60% of maximal capacity after which it plateaus. Therefore, stroke volume remains unchanged right up until the point of exhaustion. The reason why we are able to continue increasing the intensity of exercise is because of the continued increase in heart rate.
In a sedentary individual it is difficult to increase their heart rate to maximum as they are not used to working at that intensity. If you were able the myocardium is not developed enough to take any more blood into it. Therefore the increase in cardiac output is minimal.

**Cardiovascular System**

The cardiovascular system consists of the heart, blood vessels and blood. The blood vessels of the body responsible for carrying blood include arteries, arterioles, capillaries, venules and veins. The cardiovascular system is responsible for:

- Transporting oxygen to muscles and other tissues
- Removing carbon dioxide
- Supplying nutrients such as glucose, fats, vitamins and minerals
- Transporting hormones e.g. insulin
- Removing waste products from the body e.g. urea

**Structure of Blood Vessels**

Arteries carry blood away from the heart via the aorta. Blood carried by arteries is usually highly oxygenated, after leaving the lungs on its way to the body's muscles and other tissues (exception pulmonary artery). Arteries face high levels of blood pressure as they carry blood being pushed from the heart under great force.
Veins carry deoxygenated blood back to the heart and onto the lungs (except pulmonary vein). They usually have low blood pressures. This lack of pressure allows the walls of veins to be much thinner, less elastic, and less muscular than the walls of arteries.

Capillaries are the smallest and thinnest of the blood vessels in the body. They transport the oxygen rich red blood cells through them allowing oxygen to diffuse into the muscles and carbon dioxide out.

To withstand this pressure, the walls of the arteries are thicker, more elastic, and more muscular than those of other vessels such as veins and venules. The largest arteries of the body contain the most elastic tissue that allows them to vasodilate and causes vasoconstriction; accommodating the high pressure of blood being pumped from the heart.

Vasodilation is the opening up of the blood vessels to accommodate increased blood flow.

Vasoconstriction is the contraction of the blood vessels, reducing the size of the lumen causing a reduction in blood flow and/or increase in blood pressure.

As exercise intensity increases blood flow is redistricted via vasoconstriction and vasodilation, this is known as the vascular shunt.

Blood pressure responses to exercise

At rest only about 20% of the total volume of blood is distributed to skeletal muscle. However during prolonged exercise up to 87% of the circulating blood can be redistributed to the working muscles. See in diagram below.
Redistribution of blood flow

As mentioned in the cardiac cycle as the systolic blood pressure in the ventricles with increase linearly with the increase in exercise intensity. As more blood is pumped out of the heart the blood pressure in the arteries rises.

In a healthy person the average systolic pressure is 120mmHg and the diastolic pressure is 80mmHg, this is represented as:

120/80mmHg

Aerobic exercise (low/moderate) on blood pressure

<table>
<thead>
<tr>
<th>Individual</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>180</td>
<td>85</td>
</tr>
</tbody>
</table>

Anaerobic exercise (moderate/high) on blood pressure

<table>
<thead>
<tr>
<th>Individual</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>200</td>
<td>110</td>
</tr>
</tbody>
</table>

With most types of exercise there is a minimal change to the diastolic pressure, compared with the systolic pressure.
Anaerobic high intensity strength training

<table>
<thead>
<tr>
<th>Individual</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete</td>
<td>240</td>
<td>160</td>
</tr>
</tbody>
</table>

Careful consideration must be given when planning a training programme as cardiovascular aerobic training has the lowest increases on the systolic pressure and therefore is the safest for those with Cardiac risk factors.

**Control and regulation of heart rate**

Control of heart rate is carried out in the Cardiac Control Centre (CCC) found in the Medulla Oblongata of the brain; this is part of the Autonomic Nervous System (ANS). The (ANS) has two sub-divisions:

**Sympathetic Nervous System** (SNS), which speeds up heart rate via the cardiac accelerator nerve.

**Parasympathetic Nervous System** (PNS), which slows heart rate through the vagus nerve. Both the accelerator nerves and the vagus nerve send messages to the Sino-atrial node (SA), which is responsible for controlling heart rate.

The heart has an electrical conduction system made up of two nodes they are the sino-atrial node (SA) and the atroventricular node (AV). Unlike voluntary skeletal muscle, the heart produces its own impulses (myogenic) and hence these impulses spread throughout the heart causing the heart muscle (Myocardium) to contract.
During Exercise

When our bodies are at rest the parasympathetic nervous system is in control of heart rate. The (PNS) keeps heart rate down via the vagus nerve, which releases a hormone called Acetylcholine. Exercising for any duration will increase heart rate and will remain elevated for as long as the exercise is continued. At the beginning of exercise, your body removes the parasympathetic stimulation, which enables the heart rate to gradually increase. Subsequently as exercise increases in intensity then the sympathetic nervous system becomes more dominant and takes control of heart rate. The cardiac control centre (CCC) has three ways of regulating or controlling heart rate. This refers to the mechanism that causes the heart rate to increase and decrease.

1. Nervous System controlling Heart Rate

Two nerves link the cardiovascular centre in the medulla oblongata of brain with the SA node of the heart

1. Accelerator nerve (sympathetic NS). When stimulated, releases neurotransmitter at the SA node to INCREASE heart rate

2. Vagus nerve (parasympathetic NS). When stimulated, releases neurotransmitter at the SA node to DECREASE heart rate

Numerous sympathetic nerves also link to the walls of the two ventricles where they increase the force of contraction of these chambers

There are 3 control mechanisms of heart rate (HR):

1. Neural
2. Hormonal
3. Intrinsic
Neural and hormonal control are considered external control mechanisms of (HR), while intrinsic control is the heart’s own internal mechanism controlling both rhythm and depth of (HR).

1. **Neural control**

This involves receptors picking up changes in the body as a result of an increase physical activity. These then send messages to the (CCC) in the medulla oblongata. The (ANS) in the brain in turn sends a message to the SA node to either speed up or slow down the heart rate. The receptors that pick up the changes are:

- **Proprioceptors** (golgi tendon organs) – These pick up movement in joints and muscles. An increase in intensity of exercise generally means increased amounts of movement.

- **Chemoreceptors** (found in muscle tissue, aorta, carotid artery) – These pick up chemical changes such as a lowering of blood pH (blood becomes more acidic), this occurs because as exercise intensity increases there is an increase in carbon dioxide and lactic acid.

- **Baroreceptors** (found in aorta and carotid artery) – Pick up changes in blood pressure as the result of increased exercise intensity.

- **Thermoreceptors** (found in the skin, skeletal muscle and liver) – These pick up changes in body temperature. As exercise intensity increases then there is an increase in body temperature, which is detected by the thermoreceptors.

2. **Hormonal control**

Before and during exercise **adrenaline** and **noradrenaline** is released into the blood stream from the adrenal medulla in the kidneys. These hormones act directly on the **SA node** stimulating an increase in (HR) and (SV). This explains the *anticipatory rise* in HR prior to exercise often associated with being nervous and excited. Furthermore, both adrenaline and noradrenaline aid the redistribution of blood to the muscles through vasodilation and vasoconstriction of arterioles.
3. **Intrinsic control**

This is the heart internally controlling itself. There are two factors to consider:

**Temperature** – as the temperature of the cardiac muscle increases it speeds up nerve impulses causing an increase in HR.

**Starling’s Law of the Heart** - as venous return increases so does SV.
C. Overview Short term effects of exercise on the cardiovascular system

- There are two circulatory systems; pulmonary and systemic, their functions are transportation and removal of nutrients, oxygen, carbon dioxide and waste products.
- The cardiac cycle consists of two phases diastole (relaxation phase) and systole (contraction phase).
- One cardiac cycle (heart beat) takes on average 0.8 seconds.
- Venous return is the volume of blood returning back to the heart. It is supported by valves and smooth muscle in the veins, musculo-skeletal pump and pressure gradients.
- Starling's Law refers to the increased stroke volume, due to increased filling of the heart.
- Cardiac values at rest and at different intensities, the relationship between Cardiac Output, Heart rate and Stroke Volume ($Q = HR \times SV$).
- At rest $Q = 5 \text{l/min}$ compared with up to $35 \text{l/min}$ when exercising.
- The bodies transport system consists of arteries, veins, and capillaries that vasodilate or constricts to maintain increase or decrease blood pressure.
- Blood pressure at rest 120/80mmHg. It tends to be the systolic pressure that increases significantly compared with the diastolic. Aerobic exercise increases blood pressure to 180/85mmHg whereas strength training can increase both up to 240/160mmHg.
- It is important to note that aerobic exercise causes that lowest increases to blood pressure and are therefore the safest for those with cardiac problems.
- Control of heart rate is carried out in the Cardiac Control Centre (CCC) found in the Medulla Oblongata of the brain; this is part of the Autonomic Nervous System (ANS). The (ANS) has two sub-divisions, the Sympathetic Nervous System (SNS) and the Parasympathetic Nervous System (PNS).
- When our bodies are at rest the parasympathetic nervous system is in control of heart rate compared with the sympathetic nervous system when exercising.
• The cardiac control centre (CCC) has three ways of regulating or controlling heart rate; neural (various receptors), hormonal (adrenaline/noradrenaline), intrinsic (Starling’s Law).

• Redistribution of blood to muscles during exercise (blood shunting) is caused by vasomotor control.
Exercise physiology, training and performance

Short Term Responses to Exercise on Cardiorespiratory system

Question

Analyse the short term responses to exercise which have an impact on performance. (AO3)

A. Content

- Respiratory response to different exercise intensities.
- Respiratory values form rest to exercise (intensity dependent).
- Tidal volume, breathing frequency and minute ventilation.
- How carbon dioxide and oxygen are carried within the vascular system.
- Role of haemoglobin and myoglobin in the transportation of oxygen to muscles.
- Neuro-muscular; the role of chemoreceptors, proprioceptors, thermoreceptors and baroreceptors; changes in blood pH, stretch, temperature and pressure.
- How these systems work at different intensities; steady state and VO₂ max.

B. Knowledge and Understanding

Introduction

Primary purposes of the cardiovascular and respiratory systems are to deliver adequate amounts of oxygen and remove waste from working muscles.

The pulmonary circulatory system is between the heart and the lungs. It transports deoxygenated blood from the heart to the lungs to be re-oxygenated through gaseous exchange. At the lungs CO₂ is removed from the blood and O₂ enters. The blood then returns to the left side of the heart via the pulmonary vein.

As with the cardiovascular system, as exercise intensity increases, minute ventilation increases proportionally to the intensity.
Ventilation values:

**Tidal volume (TV)** is the volume of air that is inhaled and exhaled with every breath (similar to stoke volume).

**Breathing frequency (Bf)** is the number of breathes in a minute (similar to heart rate).

**Minute ventilation (ME)** is the volume of air breathed in or out every minute (similar to cardiac output).

Minute Ventilation mL/min = breathing frequency (beats/min) × tidal volume (mL).

- ME = Bf × TV

An average person has a resting breathing frequency of 12 breathes/minute and a resting tidal volume of 500 mL/breathe. The minute ventilation for this person at rest is:

Minute Ventilation = 12 × 500 = 6,000 mL/minute.

ME = 6 Litre/minute

Similar to cardiac output, minute ventilation will increase proportional with exercise intensity.
Aerobic exercise

<table>
<thead>
<tr>
<th>Individual</th>
<th>Breathing frequency (breathes/min)</th>
<th>Tidal volume (ml)</th>
<th>Minute ventilation (ml/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>12</td>
<td>500</td>
<td>6000</td>
</tr>
<tr>
<td>Exercise</td>
<td>25</td>
<td>1,000</td>
<td>25,000</td>
</tr>
</tbody>
</table>

Anaerobic exercise

<table>
<thead>
<tr>
<th>Individual</th>
<th>Breathing frequency (breathes/min)</th>
<th>Tidal volume (ml)</th>
<th>Minute ventilation (ml/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise</td>
<td>40</td>
<td>2,500</td>
<td>100,000</td>
</tr>
</tbody>
</table>

The most commonly used measure of maximal oxygen consumption during exercise is known as VO$_2$. VO$_2$ max refers to the amount of oxygen the body can take up and utilise.

With continuous aerobic exercise VO$_2$ increases linearly with increases in exercise intensity. This is due to an increasing need of oxygen to help provide energy as exercise continues. There will be a maximum point where the body can no longer utilise anymore oxygen, this is known as VO$_2$ max.

VO$_2$ max is used as a measure of an individual's aerobic fitness. The multi-stage fitness test estimates an individual's VO$_2$ max.

At Steady State exercise the need for oxygen is proportional to the consumption of oxygen, therefore ME increases linearly to the need for oxygen.
Gaseous Exchange

The main function of the respiratory system is gaseous exchange. This refers to the process of Oxygen and Carbon Dioxide moving between the lungs and blood. This occurs because of the process of diffusion.

Diffusion occurs during gaseous exchange as the air in the alveoli has a higher concentration of $O_2$ than in the capillaries and therefore diffuses across into the red blood cells. Similarly there is a greater concentration of $CO_2$ in the capillaries than in the alveoli and therefore the $CO_2$ diffuses across. There is an increased rate of diffusion during intense exercise due to the increase in concentration gradient.

The role of haemoglobin is to transport oxygen in the blood to the working muscles and then the oxygen diffuses into the muscle cell where myoglobin transports it to the mitochondria.
Control Mechanisms of Breathing

The rate of inspiration and expiration is controlled by the respiratory control centre (RCC) found within the Medulla Oblongata in the brain. Inspiration increases due to a firing of inspiratory nerves within the intercostals and diaphragm muscles.

Expiration occurs due to a sudden stop in impulses along the inspiratory nerves.

Control of Breathing

As with the control of heart rate, breathing rate is controlled by:

- Proprioceptors (detect movement)
- Chemoreceptors (detect chemical changes)
- Baroceptors (blood pressure)
- Thermoreceptors (detect temperature change).

These receptors detect changes that occur during exercise and adjust breathing rates accordingly.
Mechanics of Breathing –Inspiration (inhalation) and Expiration (exhalation)
C. Overview - short term effects of exercise on the cardiorespiratory system

- Two of the major functions of the respiratory system are to:
  - Provide oxygen ($O_2$) to the working muscles
  - Remove carbon dioxide ($CO_2$) from the body.

- Mechanics of breathing influenced by the diaphragm and intercostal muscles.

- The main function of the respiratory system is gaseous exchange. This refers to the process of Oxygen and Carbon Dioxide moving between the lungs and blood (between the alveoli and capillaries).

- This occurs because of the process of diffusion. Diffusion occurs when molecules move from an area of high concentration to an area of low concentration until equilibrium is reached.

- The rate of inspiration and expiration is controlled by the respiratory control centre (RCC) found within the Medulla Oblongata in the brain.

- The respiratory values vary depending upon intensity and duration of exercise: ME = TV × Bf.

- As with the control of heart rate, breathing rate is controlled by:
  - Chemoreceptors (detect chemical changes)
  - Proprioceptors (detect movement)
  - Thermoreceptors (detect temperature change).
1. Exercise physiology, performance analysis and training

Long-term adaptations to exercise

Question
Assess the long term adaptations that have supported the athletes in finishing this endurance event. (AO3)

A. Content

- Musculo-skeletal system; changes to bone density, articular cartilage and ligaments (linked with mobility training), muscular hypertrophy, changes to fibre types, thickening of tendons and increased force of muscular contractions.
- Cardio-respiratory system; bradycardia, cardiac hypertrophy and stroke volume (ejection fraction), changes in lung volumes, pulmonary diffusion and the effects on VO$_2$ max.
- How different methods of training (aerobic and anaerobic) cause long term adaptations to body systems and the physiological changes caused by training and links to improvements in performance.

B. Knowledge and Understanding

Introduction

After we exercise over a period of time, adaptations take place within the body. The main adaptations take place in the:-

1. Musculo-skeletal system
2. Cardio-respiratory/vascular systems

For the sports performer it is important to understand how the actual physiological adaptations affect sporting performance.
Example 1

Cardiac hypertrophy can help increase stroke volume and maximal cardiac output. This increase in oxygen reaching the muscle will increase the VO$_2$ max of an individual, which will increase the anaerobic threshold allowing the athlete to work in the aerobic zone for longer, therefore during a hockey match they will be able to work at a higher intensity for longer without fatiguing.

Example 2

Muscular hypertrophy, which can increase the force exerted by a muscle, thus allowing faster contractions allowing greater sprint speed or increasing leg power, therefore a sprinter can get out of the blocks quicker and generate more speed on the track.
Physiological adaptations from Aerobic Training

Following at least a 12 week continuous training programme the following adaptations were observed:

**Musculo-skeletal**

- Larger numbers of capillaries around muscles increasing diffusion of oxygen into the muscles.
- Larger number of **Mitochondria** (which converts oxygen and food into energy) in the muscle cell.
- Increased amounts of myoglobin (concentrated form of haemoglobin that transports the oxygen into the mitochondria from the blood).
- Increase in the efficiency of Type I muscles fibres and the utilisation of Type IIa.
Bones and Joints

- Exercise stimulates deposition of calcium which makes the bones stronger.
- Tendons and ligaments increase in strength and flexibility/mobility of joints.
- Increase in the amount of synovial fluid in the joint capsule, reducing the friction between the bones.

Cardio-respiratory

After training aerobically over a sustained period of weeks their adaptations will include:

- Increased capillarisation of the lungs, where oxygen diffuses from the alveoli into the blood.
- Improved strength of the diaphragm and intercostal muscles.
- Increased utilisation of the alveoli and therefore reducing breathing frequency.
- Increased tidal volume and minute ventilation.

This means that more oxygen can be consumed and transported from the alveoli into the capillaries and into the red blood cells. The remaining systems then transport the oxygen to the working muscles and eventually back out as CO$_2$.

Cardio-vascular

The adaptation of the cardiovascular system work in tandem with the respiratory system. These adaptations include:

- Increase in myocardium (heart muscle) – cardiac hypertrophy.
- The ventricles can hold a greater volume of blood, increased diastolic phase of cardiac cycle.
- Reduced resting heart rate – bradycardia due to increase the stroke volume.
- Reduced/similar systolic phase.
- Increased blood pressure whilst exercising, a reduced resting blood pressure.
• Increased cardiac output.
• Vasomotor control – more efficient vasoconstriction and dilation. Smooth of blood vessels becomes stronger.
• Increased number of red blood cells and therefore more haemoglobin.

Improved cardiovascular system has real health benefit by reducing the potential impact of hypertension (high blood pressure), CHD and artherosclerosis.

Overall the athlete is able to work for longer in the aerobic zone (taking longer to reach anaerobic threshold) as the exercise intensity increases. This reduces the effects of fatigue and the build-up of waste products.

**Improvements to sporting performance**

All of the above adaptations mean more oxygenated blood can be transported to the working muscles allowing the performer to:-

• Have a higher \( \text{VO}_2 \text{Max} \) (the unit of measurement of aerobic fitness).
• Work aerobically for longer raising the **Anaerobic Threshold**, reducing the onset of blood lactate (OBLA) and conserving glycogen and CP stores.
• Reduced recovery times after intense exercise will be shorter due to the transportation system that removes waste produces as well as delivering oxygen and fuel.
• Faster recovery means the body can replenish **CP stores** and **glycogen** at a faster rate and removal of lactic acid.
• **Lactic acid** will be removed faster.
• **Myoglobin stores** will be re-saturated at a faster rate because of increased oxygen uptake.
Adaptations to the Body after Anaerobic Exercise

Anaerobic exercise includes such activities as sprinting, weight training, plyometrics and anything where a sportsperson is working close to their maximum. Even though there are specific adaptations from anaerobic exercise research suggesting that there is a significant contribution to the adaptations from aerobic exercise.

Training at a high intensity for short duration using predominantly the ATP-PC system, power and strength training may achieve the following adaptations:

- Muscle hypertrophy (increase in size of the muscles).
- Increased Creatine Phosphate stores in the muscles.
- Increased bone density and tendon thickening and strengthening.
- Development of Type IIb muscle fibres and utilisation of Type IIa.
- Neural system improves i.e. the firing patterns speed up, reducing response time.
Training at a high intensity for a slightly longer duration whilst predominantly using the anaerobic system, training which includes interval sprints could produce the following adaptations:

- Greater tolerance to **lactic acid** (also known as **buffering** capacity of the muscles)
- Increase in muscle glycogen stores
**Improvements to sporting performance**

All of the above adaptations mean:

- The performer will be able to increase the amount of force, power output, speed and strength within the sporting context.
- The performer can tolerate more lactic acid and therefore be able to remain in the anaerobic zone for longer.
- When using high intensity activity over a longer duration then similar improvements in performance will occur. E.g. Increased VO$_2$ max, higher anaerobic threshold.
B. Overview - long term adaptations of exercise on the cardiovascular system

After a period of prolonged aerobic training (up to 18 weeks) adaptations to the body's system include:

- **Musculo-skeletal**: mobility at joints, increased bone density, muscular hypertrophy, efficiency of muscle fibre types, increased force and length of contractions and capillarisation, increases in myoglobin and mitochondria in the muscle cell.

- **Cardiorespiratory**: changes to resting values of Bf, TV, diffusion rates, capillarisation and haemoglobin content. Values of ME and diffusion when exercising.

- **Cardiovascular**: changes to resting values of SV, HR, BP, (bradycardia, hypertrophy) compared with the changes when exercising.

- Increased **elasticity (Vasomotor control) of arteries and arterioles** (allows greater volume of oxygenated blood to pass through the vessels).

- Increased **CP** and **glycogen** stores and increased **tolerance to lactic acid**.

- Increased capacity of the training zones and energy systems.

- Higher VO₂ max and an increase in anaerobic threshold.
1. Exercise physiology, training and performance

<table>
<thead>
<tr>
<th>Diet and nutrition and performance</th>
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**Question**

Discuss the use of diet and supplementation to improve performance. (AO3)

**A. Content**

- Carbo-loading and the importance of depletion, tapering and repletion/loading.
- The methods to deplete glycogen stores, e.g. training, tapering of training and loading phases (use of appropriate GI foods in these processes).
- The role of supplementation in sport, both positive and negative aspects.
- Illegal aids – anabolic steroids, erythropoietin (EPO), stimulants (ephedrine), human growth hormone and blood doping. The impact these have on performance and the potential long-term risks.
- The use and misuse of supplements and ergogenic aids to training: Protein (whey and casein), Creatine, Caffeine.

**B. Knowledge and Understanding**

**Introduction**

**Nutrition and Performance**

As with nutrition and health it is vital for a sportsperson to have a sufficient diet to meet the needs of their sport, event or activity. E.g. a marathon runner would have a different diet to that of a sprinter because of the differing energy demands. Nevertheless the primary source of energy for their training and competing regimes would come from carbohydrate.
**Fuelling the Energy Systems**

Carbohydrate are generally the main source of energy fuelling exercise of a moderate to high intensity, with fat providing energy during exercise that occurs at a lower intensity.

As exercise intensity increases, carbohydrate metabolism takes over. It is more efficient than fat metabolism, but has limited energy stores. This stored carbohydrate (glycogen) can fuel about 2 hours of moderate to high level exercise depending on an individual's level of fitness. After that, glycogen depletion occurs (stored carbohydrates are used up) and if that fuel isn't replaced athletes may hit the wall. An athlete can continue moderate to high intensity exercise for longer by simply replenishing carbohydrate stores during exercise (High GI foods, isotonic drinks/gels etc.) This is why it is critical to eat easily digestible carbohydrates during moderate exercise that lasts more than a few hours.

**The Glycaemic Index and Exercise**

The glycaemic index is the rate at which carbohydrate releases energy (glucose) into the bloodstream. Carbohydrates vary greatly with regard to how quickly they increase blood sugar levels. Some types of carbohydrate release energy quickly and increase blood glucose levels very quickly ('high GI' foods) while others release glucose at a slower rate, ('low GI' foods).

It is important to understand that not all high GI foods are bad e.g. jacket potato is considered in the high category but is healthy, also milk chocolate is considered medium to low GI but because of the high fat content found in the milk then the calorie content is higher. It is important to get a balance of the GI foods in your diet to provide both immediate and long term energy. Too much of any food or over consumption will result in a positive energy balance and subsequent weight gain if sufficient exercise is not carried out. Such unproductive weight gain is not beneficial to sportspeople.
How the Glycaemic Index is used in sport

An athlete participating in an endurance event should consume a low GI meal between 3-4 hours prior to exercise consisting of foods such as brown bread, fruit, vegetables, porridge (see other items on the index below). During the event high GI foods such as isotonic drinks and gels, jelly babies, jaffa cakes are often consumed.

Carbo-loading

Carbo-loading is a diet or process of increasing carbohydrate consumption and storage of glycogen usually prior to an endurance event. There are numerous ways to carbo-load but all follow a similar principle. The Shearman technique has three stages:

- Depletion
- Tapering
- Loading stage

Depletion stage

This stage involves the reducing muscle glycogen stores. The training intensity continues or in some instances increases but the carbohydrate intake is reduced. The theory is that the body will store more carbohydrate when it’s available.

Tapering stage

At this stage the amount of training is reduced with the same amount of carbohydrate consumption. There is a preparation for the event and a replenishment of glycogen stores within this stage.
Loading stage

Finally the intensity has decreased to almost no training and there is an increase in the consumption of carbohydrates. This allows the body to overload the systems with glycogen.

At the end of day three, the body will think that there is a problem with its glycogen stores and that it should store more glycogen than normal. In the last three days, when the athlete consumes carbohydrate, the body will replenish the glycogen stores and top them up with extra glycogen. This process is called Super compensation.
For example: A marathon runner’s typical week.

<table>
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<tr>
<th>Day/s</th>
<th>Diet</th>
<th>Training</th>
<th>Stage</th>
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<tr>
<td>Sunday</td>
<td>Balanced diet</td>
<td>Light</td>
<td>Recovery</td>
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<tr>
<td>Monday/Tuesday</td>
<td>Balanced diet</td>
<td>High intensity</td>
<td>Depletion</td>
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<tr>
<td>Wednesday</td>
<td>Balanced diet</td>
<td>Medium intensity</td>
<td>Tapering</td>
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<tr>
<td>Thursday</td>
<td>Medium/High Carbohydrate (Low/medium GI foods)</td>
<td>Light</td>
<td>Tapering/Loading</td>
</tr>
<tr>
<td>Friday</td>
<td>High Carbohydrate 80% of diet. (Low/medium GI foods)</td>
<td>Light</td>
<td>Loading</td>
</tr>
<tr>
<td>Saturday</td>
<td>Low-Medium GI meal 3-4hrs prior to competition</td>
<td>Competition</td>
<td>Loading</td>
</tr>
</tbody>
</table>

The method of carbo-loading is to deplete glycogen stores on day prior to competition with a short burst of high intensity activity, no more than 15 minutes in duration. The loading phase would begin immediately after exercise consuming 80% carbohydrate.
Supplementation in Sport

Sports supplementation is also called **ergogenic aids**. These are products used to enhance athletic performance that may include vitamins, minerals, proteins (amino acids), or any concentration, extract and are generally available over the counter without a prescription. Sports supplements tend to be dietary supplements, however lots of organisations including the International Olympic Committee (IOC) have developed policies on their usage and guidelines on illegal aids.

The most common supplements of protein, caffeine and creatine all have different effects on the body.

Proteins are required for growth and repair. Proteins are broken down into amino-acids and are used by the muscle to repair any damaged tissue after intense exercise e.g. help repair microfiber tears in the muscle and therefore rebuilding bigger, stronger structures – muscular hypertrophy.

Caffeine's main physiological impact is the maintenance of alertness in the brain. It blocks adenosine, and slows down other brain signals making us feel less fatigued and more focused. Research suggests there is a positive impact on sports that are; high intensity, strength, multiple sprints, and can aid recovery. Caffeine's main effect is muscular (neuro-muscular). It also suggests that it allows the metabolism of fatty acid rather than glycogen stores.

Creatine which is naturally occurring in meats and fish can also be produced in the body. There is also a manufactured product that is available over the counter.

Sports people who take creatine do so to improve strength however there are no long term studies to look at the physiological impact of the supplementation. Similarly the improvements in strength and power may also be a placebo (psychological rather than
physiological). Some research suggests that creatine is most effective for athletes doing intermittent high-intensity exercise with short recovery intervals, such as sprinting and power lifting.

The most common side effect of creatine supplementation is weight gain. It is also suggested that people with kidney problems should not use creatine because it may affect kidney function.

**Illegal aids**

Doping means athletes taking illegal substances to improve their performances. There are five classes of banned drugs, the most common of which are stimulants and hormones. There are health risks involved in taking them and they are banned by sports’ governing bodies.

According to the UK Anti-Doping Agency, substances and methods are banned when they meet at least two of the three following criteria:

- Enhance performance,
- Threat to athlete health, or
- Violate the spirit of sport.

The most commonly used substances are androgenic agents such as anabolic steroids. These allow athletes to train harder, recover more quickly and build more muscle, but they can lead to kidney damage and increased aggression. Other side effects include baldness and low sperm count for men, and increased facial hair and deepened voices for women.
Anabolic steroids are usually taken either in tablet form or injected into muscles. Some are applied to the skin in creams or gels.

Then there are stimulants, which make athletes more alert and can overcome the effects of fatigue by increasing heart-rate and blood flow. But they are addictive and, in extreme cases, can lead to heart failure.

Diuretics and masking agents are used to remove fluid from the body, which can hide other drug use or, in sports such as boxing and horse racing, help competitors “make the weight”.

Human Growth Hormone (HGH) is a natural testosterone booster that's produced on its own in the pituitary gland and plays a vital role in cell regeneration, growth and maintaining healthy human tissue, including that of the brain and various vital organs.

Human growth hormone can be injected in larger doses to promote weight loss and increase muscle size while a small doses can be used for general recovery, health and ignite the anti-aging process. Two main impacts are:

1. Increased Muscle Strength
2. Increased the risk for cardiovascular disease.

Blood doping is the misuse of certain techniques and/or substances to increase one's red blood cell mass, which allows the body to transport more oxygen to muscles and therefore increase stamina and performance. Erythropoietin (EPO) is the most common synthetic oxygen carrier.
EPO is released from the kidneys and acts on the bone marrow to stimulate red blood cell production, which increases bulk, strength and red blood cell count and gives athletes more energy.

An increase in red blood cells improves the amount of oxygen that the blood can carry to the body's muscles. It may also increase the body's capacity to buffer lactic acid.

EPO causes the blood to thicken, leading to an increased risk of several deadly diseases, such as heart disease, stroke, and cerebral or pulmonary embolism.

Beta blockers, meanwhile, which may be prescribed for heart attack prevention and high blood pressure, are banned in sports such as archery and shooting because they keep the heart-rate low and reduce trembling in the hands.

C. Overview of diet nutrition and supplementation

- The primary source of energy for their training and competing regimes would come from carbohydrate.
- Carbohydrate are generally the main source of energy fuelling moderate to high intensity exercise, with fat providing energy during exercise that occurs at a lower intensity.
- The glycaemic index is the rate at which carbohydrate releases energy (glucose) into the bloodstream.
- Carbo-loading is a diet or process of increasing carbohydrate consumption and storage of glycogen usually prior to an endurance event.
- There tends to be three stages to carbo-loading: depletion, tapering and loading.
- Sports supplementation is also called **ergogenic aids**.
- The most common supplements of protein, caffeine and creatine all have different effects on the body.
• Proteins are required for growth and repair.
• Caffeine main physiological impact is the maintenance of alertness in the brain.
• Sports people who take creatine do so to improve strength, however there are no long term studies to look at the physiological impact of the supplementation.
• Doping means athletes taking illegal substances to improve their performances.
• The most commonly used substances are androgenic agents such as anabolic steroids.
• Human growth hormone can promote weight loss and increase muscle size.
• Blood doping is the misuse of certain techniques and/or substances to increase one’s red blood cell mass, therefore increase stamina and performance.
• Erythropoietin (EPO) is the most common synthetic oxygen carrier.
1. Exercise physiology, performance analysis and training

### Biomechanical principles

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<td>Evaluate the techniques used to help improve performance. (AO3)</td>
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#### A. Content

- Newton’s three laws of motion; Laws of inertia, acceleration and action/reaction and their application within sport.

- Momentum, impact and impulse; Defining the terms momentum (a product of a moving object’s mass and velocity), impact and impulse. Force – time graphs; how to interpret information from a force/time graph.

- Stability; Stable, unstable and neutral equilibrium link with base of support and centre of mass. Factors affecting stability; mass, size of base, height of centre of mass, points of contact.

- Linear and angular motion; Position, distance, displacement, speed, velocity, acceleration and their application to sport. Moment of inertia and conservation of angular momentum.

- Projectile motion; Gravity and weight: factors affecting the flight of an object - velocity, height of release and air resistance. The different between parabolic and asymmetric flight paths. Lift forces; Spin: Magnus effect, Bernoulli principle; boundary layers.
• Fluid mechanics; Fluid friction: factors affecting fluid resistance; laminar flow and turbulent flow and its effect on drag. Importance of streamlining in sport; air resistance.
B. Knowledge and Understanding

Newton’s Laws of Motion

Knowledge of the factors that cause movement are based on forces and underpinned by Newton’s laws of motion. Knowledge of these Laws help us to understand the demands of performance on the body and explain how successful performance can be developed through the training principles and analysing technique.

There are three laws of motion:

Newton’s 1st Law:

A body continues in its state of rest or motion in a straight line unless acted upon by an external force.

Application to sport

A winger will continue to run in a straight line to cross the ball unless the opposition comes across to tackle them.

Newton’s 2nd Law:

The rate of change of momentum of a body is directly proportional to the force causing it and the change takes place in the direction in which the force acts.

Application to sport

If a rugby player, during the execution of penalty applies a force to a ball, it will move in
the direction that this force is applied, and acceleration of the ball will be in proportion to the force applied.

**Newton's 3rd Law:**

To every action there is an equal and opposite reaction.

**Application to sport**

In the start blocks in athletes, a force is applied to the blocks by the athlete, at the same time an equal force and opposite force comes back from the blocks resulting in the athlete moving forward out of the blocks.

**Momentum, impact and impulse**

Momentum allows us to understand how mass and velocity influence movement of athletes. Impulse allows us to explain how force and time can cause the athlete to start moving or change direction.

Definitions:

**Momentum** can be defined as the quantity of motion. This is a product of mass and velocity (velocity is the speed something is moving in a given direction)

In sport momentum can be increased by using a heavier bat in cricket or running faster with the ball.

**Impulse** is the product of force and the time it takes to apply the force.

In sport the follow through of the racket in tennis allows the racket to have the longest
contact (impact) with the ball and therefore apply force to the ball for a longer time. This maximises the time that the force is applied.

**Application to sport**

If a hammer thrower wants to increase impulse they can do it one of two ways:

1. Apply a greater force – moving the arm faster therefore becoming stronger.

2. Apply the force for a longer time – do more spins and release the hammer at the last possible moment.
For example:

An 18 year old hammer thrower applies a force of 25N (Newton's) for 1 second during 1 turn.

Impulse = force x time

\[ I = 30 \times 1 \]

\[ I = 30 \text{ Ns} \]

If the hammer thrower achieves 4 spins in 3 seconds:

\[ I = 30 \times 3 \]

\[ I = 90 \text{ Ns} \]
**Force time graphs**

Force time graphs are often used to demonstrate impulse. The area of the graph is the impulse.

Force is measured in newtons and will increase and then decrease over time.

![Force time graph](image)

**Stability**

In many sports, athletes need to be balanced and stable in order to perform successfully. Understanding of the factors that affect balance and stability allow for understanding of performance. Balance and stability can be understood through knowledge of a person's centre of mass.
An object with a larger base of support is more stable:

An object with a lower centre of mass is more stable:
These concepts are vital when getting into the correct body position to maintain or reduce stability.

**Application to sport:**

A sprinter in the blocks wants to reduce their stability so that they fall out of the blocks, this is achieved by reducing the base of support – weight just on fingers. However a canoeist wants to increase their stability to reduce the chances of capsizing they achieve this by lowering their centre of mass down into the boat.

**Linear and angular motion**

Understanding motion allows us to explain how an athlete moves as a whole object in the performance. The human body moves due to rotations at joints, as such human movement is not only linear, but involves angular motion (rotation).

**Linear motion** allows us to understand how quickly the athlete or object is travelling and in which direction.

\[ \text{SPEED} = \frac{\text{DISTANCE}}{\text{TIME}} \]

Understanding how much speed a player can travel at can offer valuable information for training and even team selection.

**Angular motion** relates to rotating movements at joints. A cyclist will produce angular movement at the legs pushing the peddles to achieve linear motion.
**Moment of Inertia** is the body’s resistance to motion, where the mass is widely distributed the moment of inertia is larger, compared with the concentrated mass closer to the mass centre the moment of inertia is smaller.

**Application in sport**

A speed is vital to sporting performance in cycling, the faster a cyclist can pedal the greater the linear motion. This will be produced from angular motion. The contact area of the tires reduces the moment of inertia. A wider wheel in mountain biking increases the moment of inertia requiring more force to overcome it but it increases stability allowing more control for the cyclist.

Another example of reducing moment of inertia is tighter tucks in diving and gymnastics.

**Projectile motion**

Understanding projectile motion and the factors that influence objects or athletes in flight allows us to explain technique and skill performance.

Knowledge of projectile motion allows for us to maximise performance in sports that require objects or athletes to travel maximum distances. A projectile is any object or body that is in flight. The flight path (trajectory) of the object is influenced by gravity and air resistance.

There are three key factors that determine the path of the projectile:

1. Angle of projection
2. Height of projection
3. Velocity of projection

It is sometimes easier to consider projectile motion without the following factors; air resistance, friction, spin and air flow around the object being thrown.

There is a relationship in projectile motion between the vertical velocity (red arrows) and the horizontal velocity (blue arrows). This relationship and distance is dependent upon the three factors above. As the object reaches the top of the parabola the vertical velocity decreases as demonstrated by the size of the arrows (similarly as the object comes closer to the ground the vertical velocity increases).

Parabola is a symmetrical curve, the path of a projectile follows this curve under the influence of gravity.

**Bernoulli Effect**

The Bernoulli principle refers to changes in fluid (water and air) speeds due to changes in pressure.
If a fluid flows around an object at different speeds, the slower moving fluid will exert more pressure on the object than the faster moving fluid. The object will then be forced toward the faster moving fluid (low pressure). A product of this event is either lift or down force.

e.g. air moves quickly over the top of a discus resulting in lift.

**Magnus Effect**

This is the Bernoulli principle applied to spinning objects. The side of the object that is spinning in the direction of the air will result in a high velocity air flow and therefore low pressure.

e.g. in the penalty kick, curling the ball in towards the posts rather than trying to kick it straight.
Fluid mechanics

It is important for us to understand the effects of fluid mechanics in order to understand how we can move better through air and water and therefore, ultimately improve performance. Bernoulli and Magnus effects work on the same principles.

Streamlining

To conserve energy and improve performance technological advancement in equipment and coaching has allowed companies and coaches to design or improve technique that presents very little resistance to fluid (gas or liquid), increasing speed and ease of movement.

Drag Force

Drag forces resist motion and therefore generally restrict sports performance. Performers need to overcome drag forces. There are three major factors that affect drag force:

- Cross sectional area – standing up on a bike compared with sitting down
- Surface properties – swimming caps and compression clothing
- Speed of the object – greater the speed the more air resistance

Laminar and Turbulent Flow

As fluid (liquid or gas) flows past an object, the fluid nearest the object slows down because of its viscosity. The region of fluid that is affected is called the boundary layer. By altering the boundary layer drag can be reduced. There is dramatic change in drag as flow transitions from laminar to turbulent, resulting in a 65% reduction in drag.
Application to sport

The majority of sports try to reduce drag and air resistance to help with the conservation of energy. Compression clothing in most sports reduces drag. Footwear in the majority of sports focuses on the increasing friction increasing impact and impulse.

Sports such as swimming analyse the laminar flow and attempt to alter boundary layers minimising the turbulent flow.

Sports such as cricket attempt to create more boundary layers on the ball creating more turbulent flow to generate swing in cricket – the uneven surface of the ball creates an asymmetrical wake and the ball moves in the direction of the turbulent flow.
C. Overview of Biomechanical principles

- Newton's three laws of motion:
  - Newton's 1st Law: A body continues in its state of rest or motion in a straight line unless acted upon by an external force.
  - Newton's 2nd Law: The rate of change of momentum of a body is directly proportional to the force causing it and the change takes place in the direction in which the force acts.
  - Newton's 3rd Law: To every action there is an equal and opposite reaction.
- Momentum allows us to understand how mass and velocity influences movement of athletes.
- Impulse allows us to explain how force and time can cause the athlete to start moving or change direction.
- Force time graphs are often used to demonstrate impulse.
- Balance and stability can be understood through knowledge of a person's centre of mass.
- Stability is increased by making the base larger and lowering the centre of mass.
- Linear motion allows us to understand how quickly the athlete or object is travelling and in which direction. \( \text{SPEED} = \frac{\text{DISTANCE}}{\text{TIME}} \)
- Angular motion relates to rotating movements at joints. A cyclist will produce angular movement at the legs pushing the pedals to achieve linear motion.
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- A projectile is any object or body that is in flight. The flight path (trajectory) of the object is influenced by gravity and air resistance.
- There are three key factors that determine the path of the projectile: Angle, Height and Velocity of the projection.
- The Bernoulli principle refers to changes in fluid (water and air) speeds due to changes in pressure.
• Magnus Effect this is the Bernoulli principle applied to spinning objects. The side of the object that is spinning in the direction of the air will result in a high velocity air flow and therefore low pressure.

• Fluid mechanics looks at the movement through air and liquid, applying the principles of increasing and decreasing, drag through streamlining and altering laminar flow.
## Acknowledgements

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