

The heart, ventilation and exercise

Revision notes · How the heartbeat is coordinated and monitored, how heart and ventilation rates are controlled in exercise, adrenaline, and spirometer data.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

The heart, ventilation and exercise

Spec 7.12-7.15

A Level only

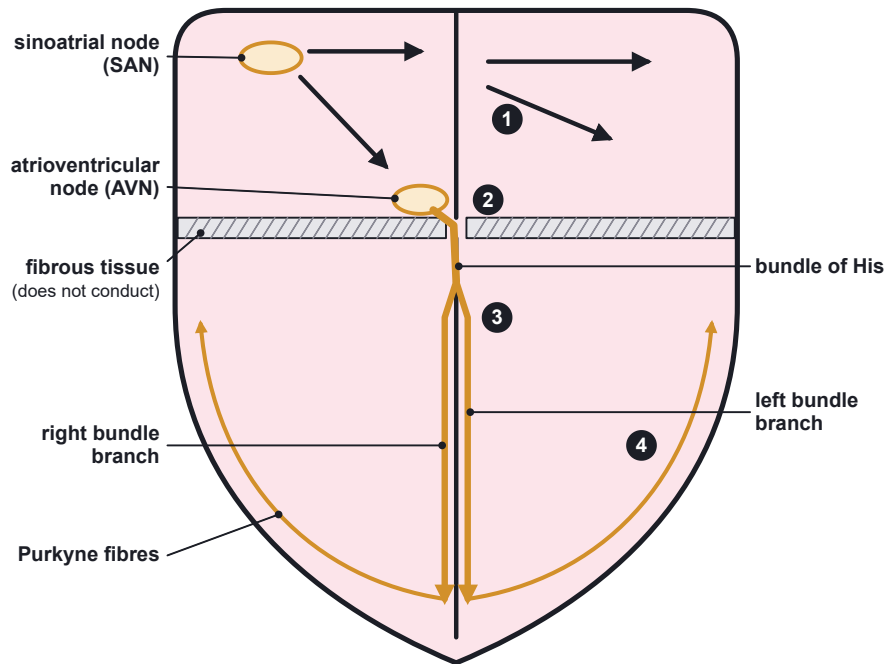
Cardiac muscle and the coordination of the heartbeat

Spec 7.12(i), 7.12(ii)

Cardiac muscle is **myogenic**: it can initiate its own contraction without a nerve impulse, so the heart beats even if its nerves are cut. Nerves only change the rate.

1. The **sinoatrial node (SAN)**, a patch of cardiac muscle cells in the wall of the right atrium, is the pacemaker. It generates a wave of depolarisation (excitation) at regular intervals.
2. The wave spreads across the walls of both atria, which contract together (atrial systole).
3. A layer of non-conducting fibrous tissue between the atria and the ventricles stops the wave passing directly to the ventricles.
4. The wave reaches the **atrioventricular node (AVN)**. The AVN delays it for about 0.1 s, giving the atria time to empty and the ventricles time to fill.
5. The wave then passes down the **bundle of His**, which runs through the septum to the apex (bottom) of the heart.
6. The bundle divides into **Purkyne fibres**, which carry the wave up the walls of both ventricles. The ventricles contract from the apex upwards (ventricular systole), forcing blood out through the arteries.

Exam tip: Explain the delay at the AVN: it makes sure the atria have finished contracting before the ventricles contract, so the ventricles fill fully.



- ① impulse spreads over both atria from the SAN: atria contract
- ② delay of about 0.1 s at the AVN: atria finish contracting first
- ③ impulse passes down the bundle of His and its branches in the septum
- ④ Purkyne fibres carry it up the ventricle walls: ventricles contract from the apex

The wave of excitation: SAN, then a 0.1 s delay at the AVN, then the bundle of His, branches and Purkyne fibres.

Electrocardiograms (ECGs) Spec 7.12(iii)

An **electrocardiogram (ECG)** is a trace of the electrical changes produced by the heart, recorded by electrodes on the skin. One heartbeat gives a repeating pattern of waves.

Parts of a normal ECG

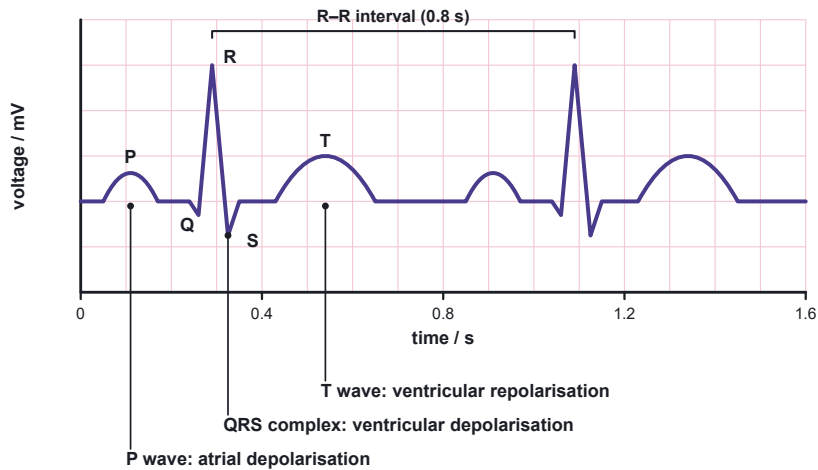
Feature	What it shows
P wave	Depolarisation of the atria (just before atrial systole)
QRS complex	Depolarisation of the ventricles (just before ventricular systole)
T wave	Repolarisation of the ventricles (as they relax)
R-R interval	Time for one complete heartbeat

heart rate (beats per minute) = $60 \div \text{time for one heartbeat (R-R interval, in seconds)}$

Abnormal rhythms shown on an ECG

Condition	ECG appearance
Tachycardia	Regular pattern, but a rapid heart rate (above 100 beats per minute): short R-R intervals
Bradycardia	Regular pattern, but a slow heart rate (below 60 beats per minute): long R-R intervals
Ectopic heartbeat	An extra or early beat, then a longer gap before the next normal beat
Atrial fibrillation	Irregular, rapid atrial activity: no clear P waves and an irregular R-R interval

Maths skill: To find heart rate from an ECG, measure the time between two R peaks from the scale given, then divide 60 by it. For example, an R-R interval of 0.8 s gives 75 beats per minute.



Tachycardia

fast heart rate: short R-R intervals



Bradycardia

slow heart rate: long R-R intervals



Ectopic beat

early extra beat, wide QRS, no P wave



Atrial fibrillation

irregular R-R, no clear P waves



A normal ECG, and what **abnormal rhythms** look like.

Cardiac output and the control of heart rate and ventilation Spec 7.13

cardiac output = stroke volume × heart rate

Stroke volume is the volume of blood pumped out of a ventricle in one beat (cm^3). Heart rate is in beats per minute. Cardiac output is in $\text{cm}^3 \text{ min}^{-1}$ (or $\text{dm}^3 \text{ min}^{-1}$).

Cardiac output

At rest, a person's stroke volume is 75 cm^3 and heart rate 70 beats per minute. During exercise, stroke volume is 120 cm^3 and heart rate 150 beats per minute. Calculate the change in cardiac output.

1. Resting cardiac output = $75 \times 70 = 5250 \text{ cm}^3 \text{ min}^{-1}$
2. Exercise cardiac output = $120 \times 150 = 18\,000 \text{ cm}^3 \text{ min}^{-1}$
3. Change = $18\,000 - 5250$

Answer: $12\,750 \text{ cm}^3 \text{ min}^{-1}$ ($12.75 \text{ dm}^3 \text{ min}^{-1}$) increase. An increase of 243% ($12\,750 \div 5250 \times 100$).

Maths skill: Write the unit with every answer and check the units match (cm^3 with $\text{cm}^3 \text{ min}^{-1}$).

Percentage change = $\text{change} \div \text{original} \times 100$.

Controlling heart rate

The **cardiovascular control centre** in the medulla oblongata of the brain receives information from receptors and signals to the SAN along two nerves:

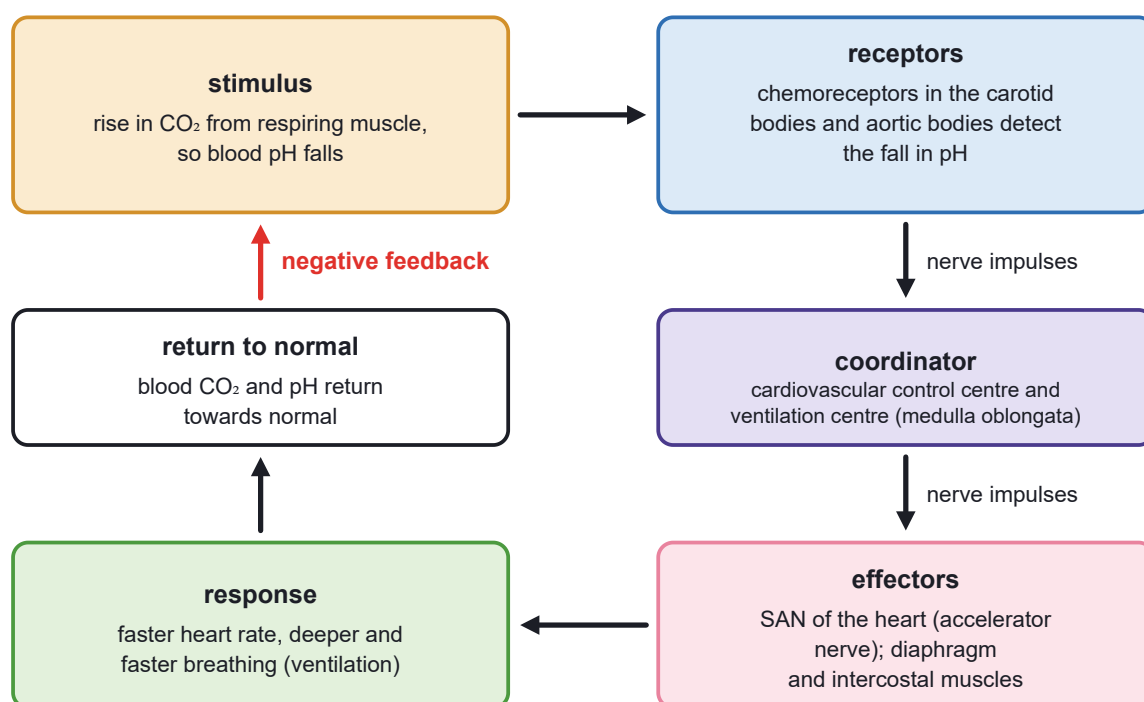
- Chemoreceptors in the carotid arteries and aorta, and in the medulla, detect a fall in blood pH (caused by a rise in CO_2 concentration, which forms carbonic acid). Baroreceptors in the aorta and carotid arteries detect blood pressure.

- A rise in CO₂ (low pH) in exercise: impulses along sympathetic nerves (the accelerator pathway) to the SAN increase heart rate and stroke volume.
- A rise in blood pressure, or low CO₂: impulses along the vagus (parasympathetic) nerve to the SAN decrease heart rate.
- During exercise, stretch receptors in the muscles and joints also detect movement and send impulses to the cardiovascular control centre, so heart rate rises as soon as exercise starts. Adrenaline released into the blood increases heart rate as well.

Controlling ventilation

The **ventilation centre** (breathing centre) in the medulla oblongata controls the rate and depth of breathing. During exercise, more CO₂ is made by respiration, and chemoreceptors detect the fall in pH. The ventilation centre sends more frequent impulses along nerves to the diaphragm and the external intercostal muscles, so breathing becomes faster and deeper. Stretch receptors in the lungs send impulses back to the centre to stop over-inflation.

The combined increase in ventilation and cardiac output delivers oxygen to the muscles quickly and removes CO₂ rapidly from them, keeping the blood CO₂ concentration and pH within narrow limits. This is a negative feedback system.



Control of heart rate and ventilation in exercise is **negative feedback**.

Adrenaline and the fight or flight response Spec 7.14

In a threatening situation, the brain stimulates the adrenal glands (above the kidneys) to release **adrenaline** into the blood. It reaches its target cells, which have specific receptors on their cell surface membrane. This prepares the body for **fight or flight**.

- Heart: increases heart rate and stroke volume, so cardiac output rises and more oxygen and glucose reach the muscles.
- Lungs: widens the bronchioles and increases ventilation rate and depth, so more oxygen enters the blood.
- Liver: stimulates the conversion of glycogen to glucose, raising blood glucose concentration as a substrate for respiration.

- Blood vessels: dilates arterioles supplying skeletal muscles and constricts arterioles to the gut and skin, redirecting blood to muscles.
- Eyes: dilates the pupils so more light enters.
- Metabolic rate increases.

Exam tip: Link each effect to its purpose: for example, 'increases heart rate, so more oxygen and glucose are delivered to muscles for aerobic respiration'.

Core practical 17: exercise and spirometer traces Spec 7.15

Core practical: Core practical 17: investigate the effects of exercise on tidal volume, breathing rate, respiratory minute ventilation, and oxygen consumption using data from spirometer traces.

A spirometer is a chamber containing air or oxygen, with a lid that rises and falls as the person breathes in and out through a mouthpiece. The movements are recorded as a trace. Soda lime in the circuit absorbs the CO₂ breathed out, so the total volume of gas in the chamber falls as oxygen is consumed and the trace slopes downwards.

What to measure from a spirometer trace	
Measurement	How to find it from the trace
Tidal volume	Volume of air breathed in or out in one breath (at rest or during exercise): the height from a trough to the next peak
Breathing rate	Number of peaks (breaths) per minute
Respiratory minute ventilation	Tidal volume × breathing rate (dm ³ min ⁻¹)
Oxygen consumption	The gradient (slope) of the trace over a set time, drawn through the peaks or troughs (dm ³ min ⁻¹)

minute ventilation = tidal volume × breathing rate

Spirometer trace

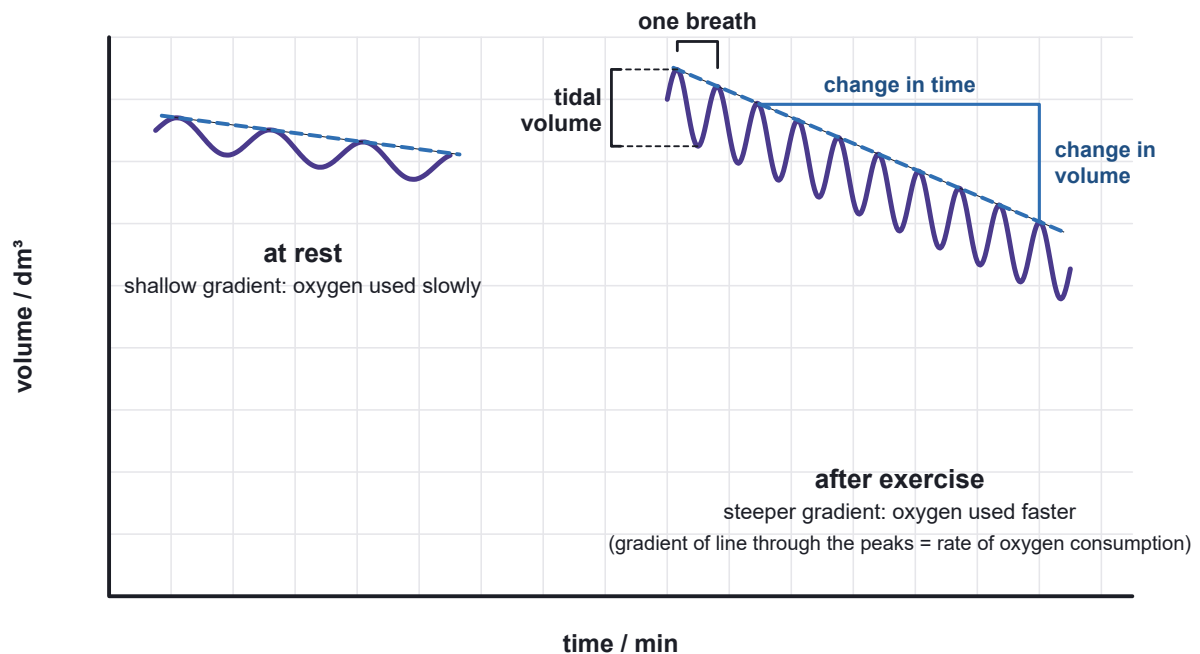
At rest, a spirometer trace shows a tidal volume of 0.5 dm³ and 14 breaths per minute. The trace falls from 3.0 dm³ to 2.4 dm³ in two minutes. Calculate the minute ventilation and the rate of oxygen consumption.

1. Minute ventilation = $0.5 \times 14 = 7.0 \text{ dm}^3 \text{ min}^{-1}$
2. Fall in the trace = $3.0 - 2.4 = 0.6 \text{ dm}^3$
3. Rate = $0.6 \div 2 = 0.3 \text{ dm}^3 \text{ min}^{-1}$

Answer: Minute ventilation 7.0 dm³ min⁻¹; oxygen consumption 0.3 dm³ min⁻¹.

1. Fill the spirometer chamber with medical-grade oxygen, check the soda lime is fresh and the mouthpiece is sterilised. The volunteer wears a nose clip.
2. Record a trace at rest for a few minutes.
3. The volunteer exercises for a set time (for example stepping or cycling), then breathes through the spirometer again and a trace is recorded at once. Repeat with different levels of exercise, with a rest period between.
4. Process the traces for tidal volume, breathing rate, minute ventilation and oxygen consumption. Both ventilation and oxygen consumption increase with exercise.

- Safety and ethics: the volunteer gives informed consent and can stop at any time; check for asthma, heart conditions or other health problems before exercise; use a clean mouthpiece to avoid cross-infection; the soda lime is corrosive and oxygen is a fire risk, so keep flames away.
- Control variables: the same person, the same type and duration of exercise, the same starting volume in the chamber, the same time of day, and the same amount of rest.



The gradient of a line through the **peaks** gives the rate of oxygen consumption.

Quick check

1. What does myogenic mean?
2. Where is the sinoatrial node?
3. What does the QRS complex on an ECG show?
4. How do you calculate cardiac output?
5. Which part of the brain contains the ventilation centre?

Quick check answers

The heart, ventilation and exercise

1. The heart muscle can contract and relax on its own, without nerve impulses.
2. In the wall of the right atrium.
3. Depolarisation of the ventricles.
4. Stroke volume $\times$ heart rate.
5. The medulla oblongata.