Control of the heart, ventilation and exercise

Myogenic stimulation of the heart, ECGs, cardiac output, control of heart rate and ventilation, adrenaline, and the core practical on exercise and spirometry.

The heartbeat is myogenic

Cardiac muscle is **myogenic**: it contracts and relaxes **without** nervous stimulation, because the signal starts within the heart itself.

The conducting system

1. The **sinoatrial node (SAN)**, the **pacemaker** in the wall of the **right atrium**, sends out a wave of **electrical excitation** across both atria, which causes them to **contract** (atrial systole).
2. A layer of **non-conducting tissue** between the atria and ventricles prevents the wave from passing directly to the ventricles.
3. The wave reaches the **atrioventricular node (AVN)**, which **delays** the signal (about 0.1 s), so the atria have time to empty before the ventricles contract.
4. The signal travels down the **bundle of His** in the septum.
5. It spreads along the **Purkyne fibres** in the walls of the ventricles, so they contract from the **apex upwards** (ventricular systole), pushing blood out into the arteries.

Electrocardiograms (ECGs)

An **ECG** records the heart's **electrical activity** with electrodes on the skin.

Feature	Represents
P wave	**Depolarisation** of the atria (atrial contraction)
QRS complex	**Depolarisation** of the ventricles (ventricular contraction)
T wave	**Repolarisation** (recovery) of the ventricles

ECGs diagnose abnormal rhythms:

- **Tachycardia**: heart rate faster than 100 beats per minute (closely spaced peaks).
- **Bradycardia**: slower than 60 beats per minute.
- **Atrial fibrillation**: a rapid, irregular activation of the atria; the P waves are absent or irregular.
- **Ectopic beats**: an extra beat.

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- **Heart block**: a long delay between P and QRS.

Heart rate = 60 / time between R peaks in seconds.

Cardiac output

$$\text{cardiac output} = \text{stroke volume} \times \text{heart rate}$$

Stroke volume is the volume of blood pumped by the left ventricle in one beat (cm^3), and **heart rate** is in beats per minute, giving a cardiac output in $cm^3\ min^{-1}$.

> **TRY IT**
>
> At rest, stroke volume is 70 cm^3 and heart rate is 72 bpm. In exercise they are 110 cm^3 and 150 bpm. Calculate both cardiac outputs.

Rest: $70 \times 72 = 5040\ cm^3\ min^{-1}$. Exercise: $110 \times 150 = 16\,500\ cm^3\ min^{-1}$.

Controlling the heart and ventilation

During exercise, **muscles respire** faster, so more CO_2 is produced and the **blood pH falls**. **Variations in ventilation and cardiac output** meet the demand for rapid delivery of oxygen and removal of CO_2.

The control centres in the medulla oblongata

- **Chemoreceptors** in the **carotid arteries and aorta** detect the rise in CO_2 (and fall in pH) in the blood.
- They send impulses to the **cardiovascular control centre** in the **medulla oblongata**, which sends impulses along **sympathetic nerves** to the SAN to **increase** heart rate (and along the **parasympathetic (vagus) nerve** to **decrease** it).
- The **ventilation (breathing) centre** in the medulla increases the rate and depth of breathing through impulses to the **intercostal muscles and diaphragm**.
- **Stretch receptors** in the lungs prevent over-inflation.
- **Baroreceptors** (pressure receptors) in the aorta and carotid sinus detect changes in blood pressure.

> **This is negative feedback: a rise in CO_2 leads to an increase in heart rate and ventilation, which removes CO_2 and restores the level.**

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Adrenaline: fight or flight

Adrenaline is released by the **adrenal glands** in response to stress. It binds to receptors on target cells and has these effects: it **increases heart rate** and stroke volume, **widens bronchioles** and **pupils**, **raises blood glucose** (by stimulating the breakdown of glycogen in the liver), **diverts blood** to muscles (vasodilation) away from the gut and skin (vasoconstriction). It prepares the body for action.

Core Practical 17: exercise and spirometer traces

A **spirometer** records the volume of air breathed in and out, as a **trace** (usually with a chamber and soda lime to absorb CO_2).

From the trace:

- **Tidal volume**: the volume of air in each breath (the peak-to-trough height).
- **Breathing rate**: the number of breaths per minute (the peaks).
- **Minute ventilation** = tidal volume × breathing rate.
- **Oxygen consumption**: from the **slope** of the trace (the downward trend), as the oxygen is used and the CO_2 absorbed.
- **Vital capacity** and **residual volume**.

During **exercise**: tidal volume, breathing rate and oxygen consumption all **increase**, so the minute ventilation rises. After exercise they return gradually.

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