The ECG

How does it work, and why?

An infographic by Callum Cockburn

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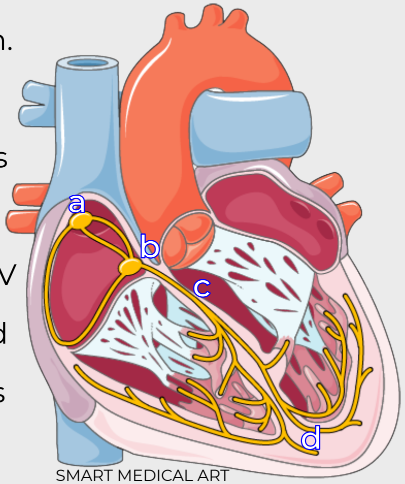
1) Electrical Anatomy and Physiology

The heart works by electrical conduction. Spikes of voltage are produced in the SA node (a) in the right atrium, which causes a wave of depolarisation to sweep across the heart, through the AV node (b), down the Bundle of His (c), and into the Purkinje fibres (d). This results in contraction of the cardiac muscle.

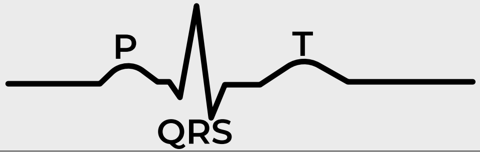


The ECG trace has different segments which represent the electrical equivalent of the different parts of the mechanical process.

i) P-wave - atrial depolarisation

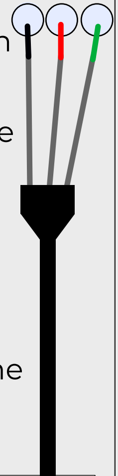
ii) QRS complex - ventricular depolarisation

iii) T wave - ventricular re-polarisation



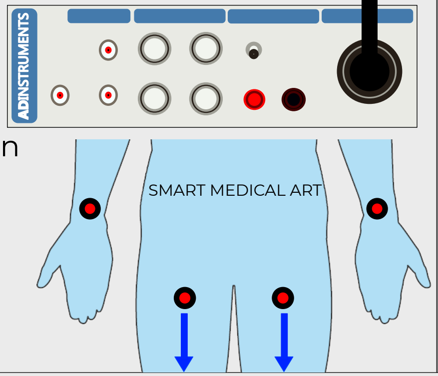
2) Capturing an ECG

In the Bristol Physiology teaching lab, the PowerAmp interface is used to capture the electrical activity of the heart through detecting voltage via surface electrodes.



The ECG is then viewed by comparing the differences in activity between these electrodes - to form a "lead". Common ECG types are the 1-lead, 3-lead, and 12-lead.

Using the PowerAmp interface to collect an ECG lead entails using two active electrodes (positive and negative) and one ground connection. The PowerAmp then collects the voltage readings, amplifies them, and exports them to the Lab Chart software for further analysis and processing.



Limb electrodes should be placed on the wrists and ankles (away from skeletal muscle). Make sure they are securely fastened and not likely to move.

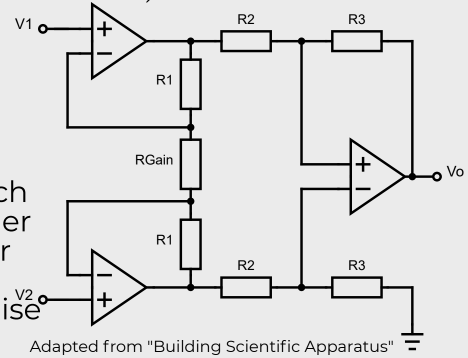
3) The ECG - Engineering Theory

The core engineering principle behind an ECG is the differential amplifier which compares two voltage readings and amplifies the difference between them.

The circuit diagram below uses resistors and a type of amplifier called an "Op Amp" (the triangle shaped component) to create an instrumentation amplifier. The benefit of this amplifier is that it has two stages of amplification, which allows the function of the amplifier to be maximised. The equation from the amplifier shows that the values of the resistors set the gain (how much the difference between the inputs is amplified).

$$V_{out} = \left(1 + \frac{2R_1}{R_{gain}}\right) \frac{R_2}{R_3}(V_2 - V_1)$$

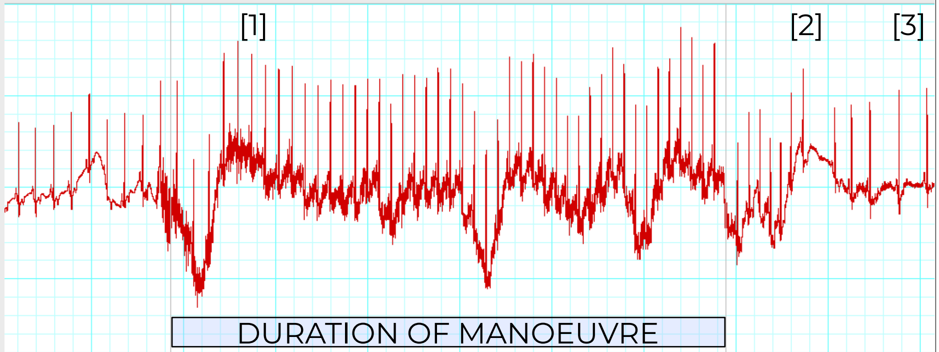
One key consideration in ECG electronic design is the CMRR, which reflects how much noise the amplifier removes. Resistor values will be picked to maximise the CMRR.



Adapted from "Building Scientific Apparatus"

4) The Effect of the Valsalva Manoeuvre on the ECG Waveforms

The Valsalva manoeuvre is an extended period of strained expiration against a closed glottis. It increases intrathoracic pressure, resulting in decreased venous return to the heart and decreased preload. By reducing preload, cardiac output is also reduced, and the arterial blood pressure falls. The arterial baroreceptors detect this change in blood pressure and stimulate the sympathetic nervous system, leading to tachycardia [1]. However, when the strain is released, a transient bradycardia then occurs as the intrathoracic pressure suddenly drops [2]. The heart rate then returns to baseline as the blood pressure normalises [3]. This is a example of physiology in action.



ECG captured by Dr Andy James

References and Further Reading: