Overview

Your body has a strong electric nature. The transmission of nerve impulses in the axons, the long fibers that connect nerve cells, depends on the movement of electric charges across membranes leading to a voltage signal that travels along the axon. When muscles contract, they create an electrical signal as well.

The electrical signal of your heart, in particular, is quite strong, and easily measurable. A measurement of the pattern of voltages produced by the action of the muscles in the heart, an electrocardiogram, abbreviated ECG, can be used to diagnose illness.

In this set of investigations, you’ll use an ECG device to record the voltage signal produced by your heart, but this is not a medical investigation. The ECGs we measure will all be different; the results are highly variable, and there is a wide range of what is normal. So your ECG, no matter how it appears, is probably just fine. But if you are concerned about the signal, please check with a medical professional who is qualified to make a judgement.

Theory

A muscle cell has ion channels in the cell membrane that allow specific ions to move into or out of the cell, and ion pumps that move specific ions into or out of the cell. At rest, a muscle cell will have an excess of positive charges on the outside of the cell membrane, and an excess of negative charges on the inside, leading to a potential difference—a voltage—across the cell membrane.

When a muscle cell contracts, ion channels open in the cell membrane, and the motion of ions across the membrane reverses the voltage—the cell is now negative on the outside, positive on the inside.

The contraction of skeletal muscle cells is induced by signals from the nervous system, conducted by axons that connect to the muscle cells. A voltage signal from the axon triggers the contraction of the muscle cell. But the contraction of the muscle cell produces its own signal, and this is a signal that can be measured. The contraction of muscles in your body produces voltages that are measurable on your skin. A measurement of the voltage signal from muscles is an electromyogram, abbreviated EMG.

When you contract a muscle in your arm, say, or another skeletal muscle, not all muscle cells contract at once; if you measure the voltage on the surface of your skin, if you take an EMG, you’ll get a messy signal. It’s very noisy, with little overall structure, because different cells are contracting and then relaxing and then contracting, not in synchrony with each other.

Necessary materials:

- Electrocardiogram unit
- Smartphone to connect to eletrocardiogram unit
When your heart contracts, it’s a different story. Cardiac cells, unlike skeletal muscle cells, aren’t always electrically insulated from each other. The contraction of one muscle cells can provide a signal that causes neighboring cells to contract as well. A signal from the sinoatrial node in the heart starts the heartbeat by triggering a contraction in one part of the heart. A wave of voltage, and thus a wave of contracting muscle, goes through the heart, causing the contraction of one chamber of the heart after another. This wave of contraction isn’t coordinated by the nervous system; if your heart were removed from your chest, it would continue to beat, as waves of electricity—and contraction—passed through it. Electrically, the heart is a free-running electrical oscillator.

Since the cardiac cells trigger contactions in their neighbors, all of the cells in a region of the heart will either be relaxed (with positive charges on the outside) or contracted (with negative charges on the outside). As a result, your heart will produce a strong voltage signal.

The signal evolves with time over one heart beat, as shown in the diagram below. (Note that the convention in medicine is to have a human figure facing you—so the left side of the person is on the right side of the diagram.) The tissue colored green is contracted (or depolarized) and thus negative; the tissue colored red is relaxed, and thus positive. As the wave of contraction moves through the heart, the voltage between different parts of the heart varies. The voltage signal produced by the heart is large enough that it can be detected well away from the heart. If you measure the voltage between two points on your torso—or between your left and your right hand—you’ll see that the voltage alternates between being positive and negative.

There is more detail here than you really need, but notice these key points: As your heart beats, the positive and negative charges on different parts of the heart lead to a voltage that can be measured with electrocardiogram electrodes placed on the body.

The largest signal happens when all of the tissue of the heart is depolarized save the left ventricle, the largest chamber of the heart, that pumps blood through the body. At this moment, there is a big difference between the two sides of the heart, with the left side positive and the right side negative. This is the source of the biggest spike in the electrocardiogram, labeled c in the graph above.

The electrocardiogram unit you will use for this exercise has two electrodes. It is designed to be used with a finger of the left hand on the left electrode, and a finger of the right hand on the right electrode. When you place your fingers on the electrodes as noted, you’ll measure an ECG that is apt to look quite a bit like the one in part (d) of the figure.
But not necessarily! The orientation of the heart in the chest is quite variable. We have seen people who get a very small voltage between their left and right sides during ventricular depolarization. This is likely because the heart is tipped so that the “left” side of the heart is directly below the “right” side. In such cases, there will be a very large voltage between top and bottom. Such people will be a large signal not with the left and right electrodes connected to left and right fingers—but with one electrode connected to a finger of the left hand and the other on the left knee or the left ankle.

**Doing the activity**

Connect the device to your smartphone, and download the necessary app to record voltage signals. (Details are given in the documentation with the device.)

Now, set the device on a table and gently rest one or two fingers of your left hand on the left electrode, one or two fingers of your right hand on the right electrode. Start recording, and note the appearance of the resulting ECG. The device needs to be very close to your phone; the information is transmitted acoustically. And to get the best results, you'll need to stay very still, to keep electrical signals from other muscles from interfering with that from your heart.

A typical measurement is shown at right—but your reading might well look quite different! We want to try some different electrode arrangements to see how this affects the recording.

To do this, take ECG measurements with different electrode orientations:

- Switch the orientation of the two electrodes—put your left hand on the right electrode, and your right hand on the left electrode. How does the signal appear now? Explain.
- Now, try measuring the potential difference between your left arm and your left leg.
  - Given the appearance of these two measurements, you can determine how your heart is orientated in your chest. Think about how you would do this.
- Try measuring your ECG with different electrode placements, and share your findings.

Finally, we want to look at the difference between the signal produced by cardiac muscle and that produced by skeletal muscle:

- Place the device on your upper arm so that the two electrodes contact two points on your arm. Start an ECG recording, and contract and relax your biceps. How does muscle contraction / relaxation change the voltage?
- Try using the device to measure different muscles in this way. Bigger muscles should, all things being equal, create bigger signals.
Summing up

Every muscle in your body produces electrical signals, and nerve impulses move along axons as an electrical signal. Your body has a very strong electrical nature—which is why electricity can be dangerous. Electricity can trigger involuntary contraction of muscles—an electric shock can trigger muscle contraction just as the signal from a nerve cell can. But the most dangerous electric currents are those that go across the torso, and so can affect the heart. An electric current through the heart can disrupt the very precise sequence of signals necessary for proper beating of the heart, with potentially disastrous consequences.

This sequence can be started by a signal from the sinoatrial node, or, if the body is having difficulty maintaining a steady rhythm, from a pacemaker. And the signal is conducted through electrical channels in the heart. For some arrhythmias, it's possible to tweak these channels to tune the sequence of contractions that is a heartbeat.

For more information

Little Shop of Physics: https://www.lsop.colostate.edu

Colorado State University College of Natural Sciences: https://www.natsci.colostate.edu