Electrocardiogram

How to work as a group

This lab involves three parts – reusing your lab equipment from the sEMG lab, taking ECG measurements and writing a report. You only need to turn in one report per group. However, part of the fun (hopefully!) is building things and hooking up your body to your equipment.

As usual, you only need to turn in one report. But feel free to have fun and each collect your own data and compare the readings with each other. If there are substantial discrepancies, feel free to put the graphs for multiple people in the same report (you don't have to tell me whose pictures are whose unless you want to).

ECG terminology: electrodes and leads

Each wire that you connect to your body is called an *electrode*. Basic physics says that voltage is defined as the difference between the electric potential at two different points, and so any particular reading that you see on a screen is the voltage difference between two electrodes. Each of these readings is called a *lead*. I don't know why it's called a lead – but that's standard medical terminology, even if it usually sounds a bit strange to engineers at first.

A typical ECG in a doctor's office attaches 10 electrodes to your body and displays 12 leads. With 10 electrodes, it would only take 9 leads to fully represent the data, and so we have some redundant readings – the redundant readings make it easier for a clinician to quickly diagnose issues.

The particular two readings we will perform in this lab are called Lead I and Lead III in cardiologist-speak.

Noise in ECGs

The signals that your heart produces are quite strong enough (> 60mV) in your heart, which is plenty to travel to the next cardiomyocyte and cause a contraction. By the time they travel through your body to our electrodes, though, the signal is only a few mV. It is easy for environmental noise to overwhelm an ECG, and the most common source of environmental noise is the 60Hz noise from power distribution and appliances in homes and buildings.

The ECG amplifier is a *differential amplifier*; if the same noise is applied to both electrodes of any lead, then the lead (which measures the difference between its two electrodes) will not show the noise. Thus, the main source of noise that we see in our readouts is noise that affects the two electrodes differently.

You may wonder why, if a lead only involves two electrodes, our experimental setup uses three electrodes rather than two. The third electrode is used to minimize noise. It uses a system called *right-leg drive*(RLD), where the AD8232 board tries to dynamically find noise that is common to both electrodes and then drive it back to your body (via your right leg) to cancel it out.

Hooking up the pads to your body

Our lab setup has three electrodes:

- The red RLD electrode should always be attached to your right leg.

- The blue electrode is the positive input.
- The black electrode is the negative input.

First two readings: lead I

For lead I, connect the positive-input electrode to the left arm and the negative-input electrode to the right arm. There's a video on the course web page showing you just where on your arms/legs to put them. Record a picture with this setup.

Next, reverse the blue and black electrodes so that positive electrode reads the right arm and the negative electrode reads the left arm. Record a picture with this setup as well.

Lead-III reading

For lead III, the positive electrode connects to the left leg and the negative electrode to the left arm.

Readings with muscular involvement

Our first bodily-measurement lab read a surface EMG by using a very similar experimental setup to the one we're using today. So why does today's lab display our ECG signal and not an EMG? Why didn't our EMG lab display an ECG waveform? Let's run some experiments to find out why.

Use either lead I or lead III, but this time hold your left arm in the air rather than resting it on a table. Capture the waveform. Next, perform a maximal static contraction – i.e., clench the muscles of your left arm (specifically, the muscles near the electrode) as hard as you can. Again, capture the waveform.

Manipulating the noise level

See if you can manipulate the level of noise by changing your experimental setup. A few interesting things that you might try:

- Twist the electrode wires together for as much of their length as possible. To minimize the length of wire that is untwisted, you may want to do a bit of yoga and place your left leg physically as close to your left arm as possible 😊
- Move to a different portion of your living space; perhaps close to a large appliance. Or perhaps turn off all electricity in the house.
- Wrap a piece of aluminum foil around the cable, and tie it to the negative battery terminal (*not* to a house ground, for safety reasons).

Capture pictures of whichever experiments seemed to have interesting results.

Discussion questions:

1. Look up the shape of a "normal sinus rhythm." Which of your two main readings (Lead I and Lead III) looks more like the "normal sinus rhythm?" You should be able to look up the expected shape of Lead I and Lead III rhythms; are they mostly as expected?
2. Given your images, can you read the numbers for:
    a. Heartrate
    b. PR interval
    c. PR segment (i.e., the delay across the AV node)

3. Can you explain the results of any of your noise-manipulation experiments?
4. When you raised your arm or clenched a muscle, how did that change the ECG waveform? Any explanations for why that might be? Given that your muscles are much closer to our electrodes than year heart is, it's not obvious why an ECG doesn't pick up signals that look a lot more like an EMG! Can you come up with any ideas for why? Consider that:
    a. Your heart has many, many cells firing synchronously. However, as you found with your sEMG lab, many motor neurons fire at fairly uncorrelated times.
    b. A bit more physics than we will do in this course would predict that the amplitude of the voltage we read at the skin surface from a neuron or cardiomyocyte firing is proportional to the area under the action-potential curve. Why might this make it easier to pick up an ECG all the way from the heart than an EMG from a much closer muscle?

What to turn in

Turn in your pictures for the three regular measurements (Lead I, Lead 1 reversed and Lead III). Also turn in your pictures for any noise-measurement experiments you did, and your muscle-involvement readings.

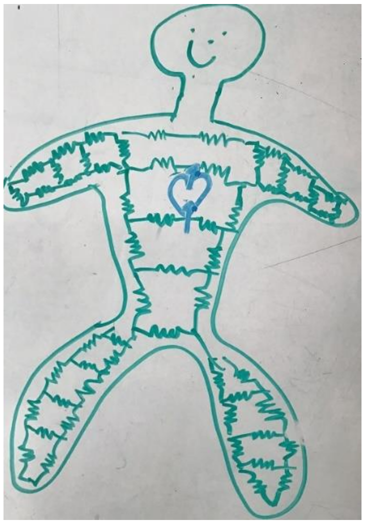
Finally, turn in your answers to the discussion questions.

Extra credit

For both our Lead I and Lead III measurements, it turns out that attaching an electrode near your wrist gives almost identical results to our upper-arm location. However, the reasons for this are not always intuitive. In fact, it's not even obvious why sticking electrodes in your legs and arms would pick up signals that originate in your heart in the first place! The answer to both these questions comes from better understanding the physics of electrocardiograms.

A simple but reasonable model of the heart replaces all of the cardiomyocytes firing at any given time by their single summed action potential. This looks like a *current dipole* – two equal and opposite current sources a short distance away from each other. At any time, one supplies current into the body and the other sinks the returning current.

The body can be modeled as a big network of reasonably-conductive material, which we can break into a large grid of resistors:

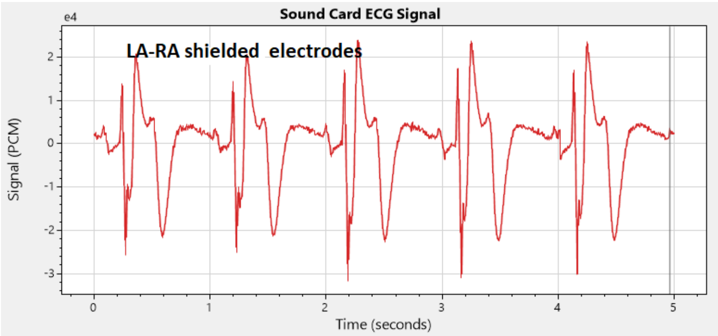


With all due apologies for CardioMan's total lack of artistic merit, the two barely-visible blue arrows represent the current dipole. Given this model, can you explain why there is so little voltage drop between his left shoulder and his left wrist?

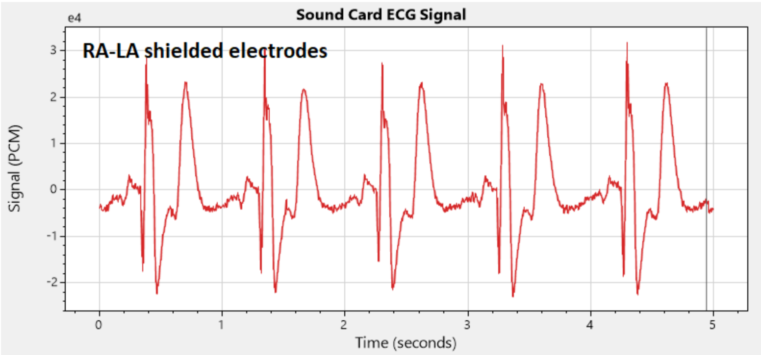
If CardioMan were to jump into a swimming pool (which we do not recommend – remember, electricity and water do not mix!), would there still be almost no voltage drop between his left shoulder and his left wrist?

Free pictures

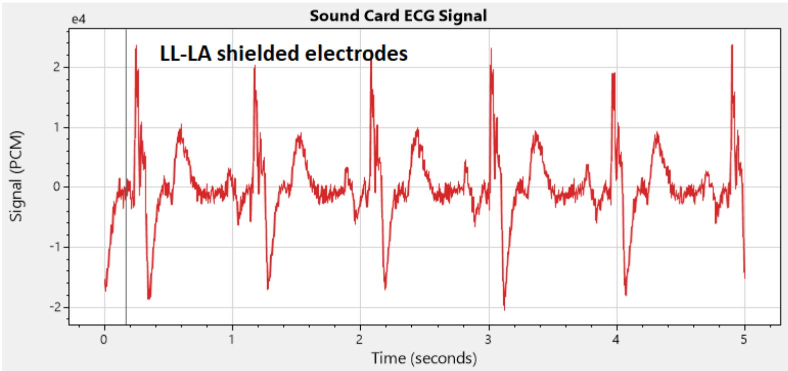
You may choose to hand in the pictures below; either because you have not been able to get waveforms to display on your laptop, or because your own ECGs are confidential medical information.



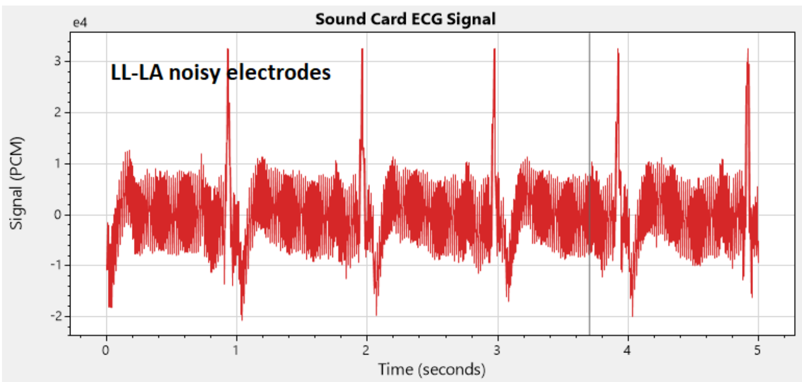
Lead I; left arm=+, left leg=- . Nice shielded electrodes



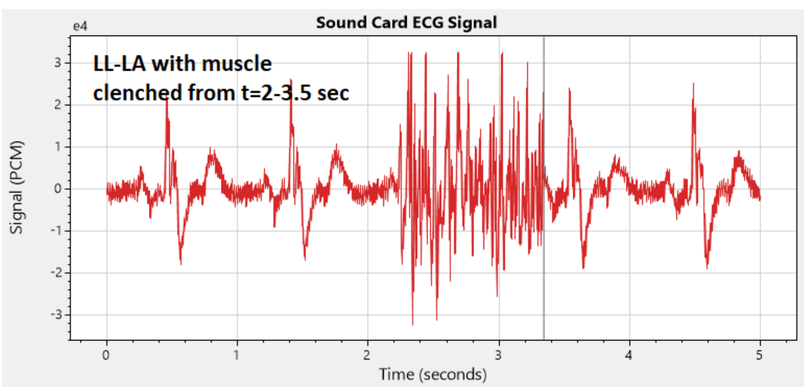
Lead I reversed. Nice shielded electrodes



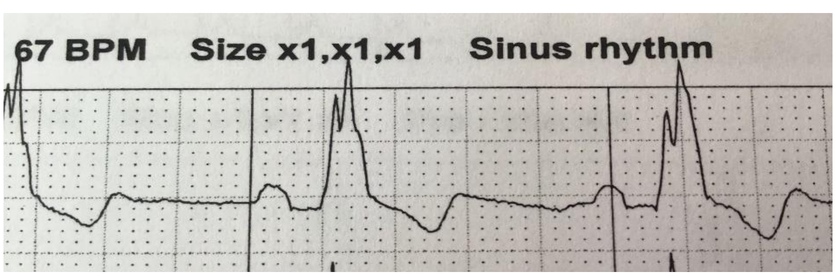
Lead III; left leg=+. Left arm = -. Nice shielded electrodes



Lead III, but with noisy (i.e., unshielded) electrodes



Lead III with shielded electrodes again. But now, clench left biceps from about t=2s to t=3.5s



A professionally-done picture of a sinus rhythm; the same person as the rest of the pictures.