Electrocardiography-EKG*
Spring 2024

Introduction

The purpose of this experiment is to determine the dipole moment of a heart using electrocardiography EKG.

Theory

You will recall that during the second experiment of the semester, you measured the equipotential surfaces due to a dipole by measuring the potential difference between a ground wire and various points around the dipole. In today's experiment you will measure potential differences around the heart and use those to determine magnitude and direction of the maximum dipole moment of the heart. This is called an *electrocardiogram (EKG)*: the time-dependent potential difference that the heart generates between selected points on the surface of the body which results from the discharging of the cell membranes of the cells making up the heart muscle.

Why does the heart have a time-dependent electric dipole moment? If you were to watch a heart beat in slow motion, you would see that the entire heart does not contract simultaneously. Instead, the contraction moves across the heart in a wave, starting with the small chambers (atria) and then moving across the large chambers (ventricles). The heart is made up of muscle cells. When resting (not contracting), these cells have oppositely charged layers of ions on either side of the cell membrane, and the net dipole is zero. When contracting, these cells have specialized proteins crossing their membranes called "ion channels" that open up pathways that allow positive ions to flow across the membrane inward, changing the potential difference across the membrane. This process in a capacitor would be called discharging; the physiological term is "depolarization". The contraction travels from cell to cell, so the edge of the depolarized region likewise travels across the heart muscle. The traveling edge of the depolarized region moves as the depolarization spreads across the heart's muscle as it undergoes its regular cycles of contraction and pumping. The traveling edge is equivalent to a moving electric dipole. It is this moving electric dipole that is observed with the electrocardiogram. Any changes in heart function, such as diseased regions of the heart muscle that fail to contract properly, will change the moving dipole moment – hence its diagnostic utility. In today's lab we will focus on just one item of the standard EKG analysis: identifying the direction of the heart's peak dipole moment within the "frontal plane" (the plane parallel to the front of the torso).

Figure 1 shows a schematic of voltage as a function of time for a single heart beat with the different features labeled using electrocardiography nomenclature. The peak labeled P corresponds to the spreading of the depolarization across the atria and is typically very small because the atria include only a small fraction of the muscle mass of the heart. The interval from Q to S, called the "QRS complex," comes from contraction of the ventricles of the heart; these chambers accomplish most of the pumping. The QRS complex is usually the largest feature in the EKG. Finally, the T peak is associated with the repolarization, or recharging, of the ventricles in preparation for the next cycle. (Repolarization of the atria occurs during the contraction of the ventricles and is hidden by the QRS complex.)

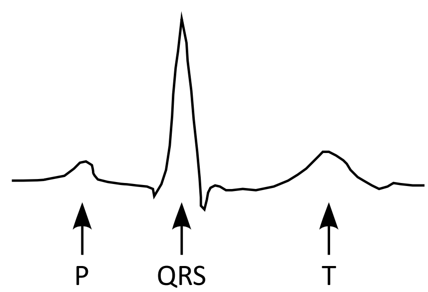

Figure 1: Schematic of a single cycle in an EKG. The vertical direction is voltage, and the horizontal is time.

Apparatus

We will use an EKG sensor box that has three wires (red, black, and green) with clips on the end to make our measurements. The sensor measures the potential difference between the green and red wires, with the red lead as the positive side. If the red wire is at higher potential than the green, the reading will be positive; if the red is at lower potential than the green, the reading will be negative. The black lead serves as the reference point of potential, equivalent to the "ground" terminal, so that multiple sensors can be used simultaneously, all with the same zero. Each sensor measures a single potential difference between the red and green wires. In clinical electrocardiography, twelve potential differences are measured where each one is called a "Lead". We will measure two potential differences called "Lead I" and "Lead II", shown in **Figure 2**, to determine the approximate dipole moment of the heart in the frontal plane. *Lead I and Lead II will be connected to the 'patient' at the same time*.

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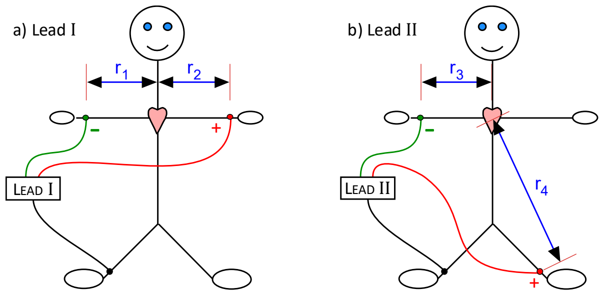

Figure 2: a) shows the Lead I configuration and b) shows the Lead II configuration. The distance between each electrode and the heart is approximately the average of the four distances, *r*. The "–" shows where the green wires are connected, and the "+" shows where the red wires are connected. The black wires are connected to the right ankle.

Experiment

1. The EKG measurements are made using LoggerPro. Open the LoggerPro file *EKG.cmbl* from the Phys104 folder on the *Teaching Drive* (T:)
2. Choose one person in your group to be the patient. Use alcohol wipes to clean the skin on the inside of each ankle behind the ankle bone and the inside of each wrist. This will remove the skin oils that can degrade the electrical contact.
3. Put four sticky gel electrodes on the skin of the "patient," in the places cleaned with alcohol.
4. Have the patients hold their arms out horizontally, then measure and record the distance between each of the four electrodes (two red and two green) and the approximate position of the heart, as shown in Figure 2 above. Average these four values to find the average distance between the electrodes and the heart, *r*.
5. *Attaching the leads:* You will clip each wire from the sensors onto the black tab on each electrode: (a) Connect the wires from the EKG sensor in Channel 1 as Lead I (**Figure 2a**): red lead on the left wrist, green lead on the right wrist, black lead on the right ankle. (b) Connect the wires from the EKG sensor in Channel 2 as Lead II (**Figure 2b**): red lead on the left ankle, green lead on the right wrist, black lead on the right ankle. *Double check with **Figure 2** to be sure the electrodes are all in the correct place.*
6. The "Doctor" will hold the EKG boxes for the patient. Have the patient hold their arms out horizontally, and Zero the sensors in Logger Pro by going to the *Experiment* menu and choosing "Zero". Zeroing the sensors should bring the baseline close to zero, but it will not be exactly zero. *It is important that the sensors are zeroed before each measurement, and data collection starts immediately after (next step).*
7. With the patient's arms still stretched out horizontally, press the green "Collect" button to measure an EKG. Your Lead I or Lead II data (or both) should look something like that shown in **Figure 3** below. The repetition in the signal reflects the heart's repeated contraction. Make sure the baseline is close to zero; if it isn't, zero the sensors again, and collect a new data set.

Figure 3: A typical EKG scan.

8. Have your instructor check your graphs. When the data set looks good, store the data by choosing "Store latest data run" under the *Experiment* menu. Hide any other data sets using the "Data" menu, then "Hide".
9. Print the graphs for Lead I and II as follows: first, choose "Page Setup" from the "File" menu, and click the button next to "Landscape"; next, print the graphs by choosing "Print" (*NOT Print Graph*) under the "File" menu, adding your names to the Footer. **KEEP LOGGERPRO OPEN WITH YOUR DATA SAVED.**
10. Switch the Lead I set of electrodes on the wrists so that the green and red leads are reversed; this is called *lead reversal*. Collect another data set and print it as before. You may now remove this data run from view: under the "Data" menu choose "Hide Data Set" and then select the latest run. Save your data so you can reopen it if something is amiss. *At this point, the patient may remove the electrodes and throw them away.*

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Analysis

1. What happened to the EKG scan when you reversed the leads? Describe what changed.
2. You will now zoom in on one cycle (peak) from your original Lead I and Lead II data. Select the region to magnify as follows: Position the cursor in the upper-left corner of the area you want to magnify on the Lead I graph, above a nearby tic mark on the time axis (**Figure 4a**). *Click & drag the cursor diagonally to the opposite corner*, creating a dark gray selection region (**Figure 4b**). Click the + magnifying glass in the toolbar once to zoom in on the dark gray region selected. Repeat these steps for the same peak, *over the same time interval*, on the graph for Lead II (**Figure 4c**).

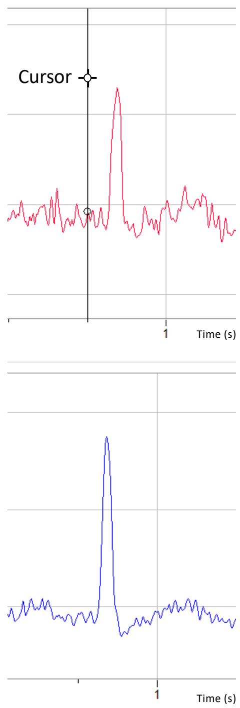

Figure 4a: Position cursor at upper left of a cycle in Lead I, as shown above (top graph). You'll find it easier to start at a time interval indicated by a tic mark on the Time axis.

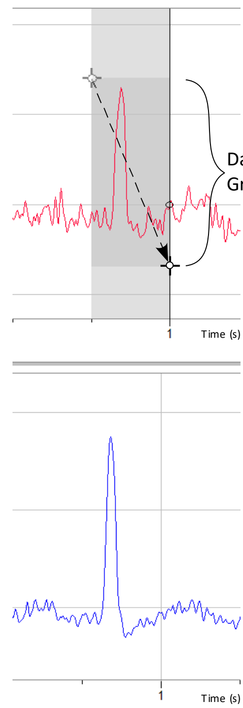

Figure 4b: Click and drag the mouse diagonally as shown, then click the + magnifying glass once. The zoom will occur in the dark gray selection area.

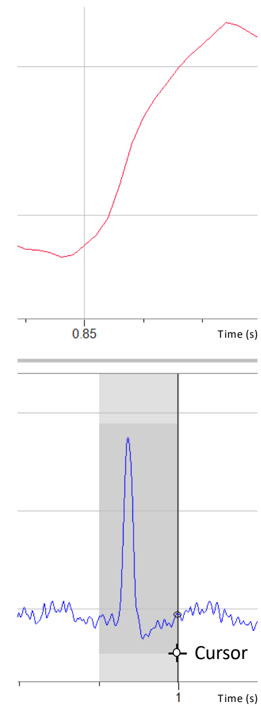

Figure 4c: Repeat the same steps for the corresponding cycle in Lead II (bottom graph). Note the zoom on the cycle in the Lead I graph.

3. Align the time axes in each graph by positioning the cursor over the axis of one graph, then clicking and dragging left or right until they both are in the same position. Then print the graphs as before.
4. You want to find the voltage and time duration of the QRS peak. Create Table 1 in your report to organize your measurements. Choose the "Examine" tool under the *Analyze* menu, and move the cursor along *the same peak* for from each lead. Record the time and potential difference (voltage) for the following three points for each lead – see **Figure 5**: 1) where the peak begins, 2) the top of the peak, 3) where the peak ends (the times for *Point 4* will be determined on the next page).

		Lead I		Lead II	
Point	QRS	Time (s)	Potential (*mV*)	Time (s)	Potential (*mV*)
1	Q				
2	R				
3	S				
4					

Table 1: Voltage and time durations for the QRS peak. *The times bordered in red will be explained on the next page*

5. Calculate the time duration using points 1 and 3 from each lead, and then calculate the maximum potential difference for the QRS peak using point 2 and point 3 from each lead. Label the magnified peaks of your printed Lead I and II graphs with the peak voltage and time duration. Typical time duration is 60-80 *ms*. Are your data consistent with this?

6. Copy the time where Lead II has its peak voltage (point 2, **Figure 5**) into the time value for point 4 in *Table 1* (the times bordered in red in the table will be *the same*).

7. Now find the voltage of Lead I at the time value just determined and record it as the voltage of point 4 in Table 1. The voltages of point 4 (Lead I) and point 2 (Lead II) will next be used to calculate the dipole moment.

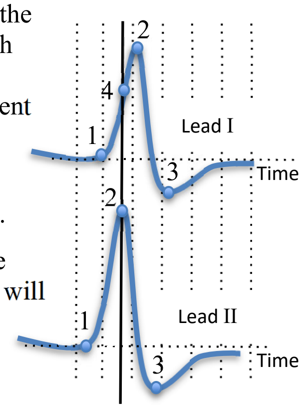

Figure 5: Determining the time for Lead I, point 4

8. *Calculating the maximum dipole moment*: The dipole moment of the heart rotates in time and its magnitude changes. We are going to estimate the maximum dipole moment of the heart using the point in time when Lead II gives a maximum voltage. So, we will use point 4 from Lead I and point 2 from Lead II as recorded in your data table.

   a. As shown in **Figure 2**, Lead I is horizontal, and we can use this to find p_x, the x-component of the dipole moment.

   $$\Delta V_x = \Delta V_{Lead\ I} = \frac{p_x}{2\pi\varepsilon_o \kappa_{water} r^2}$$

   where κ is the dielectric constant $(\kappa_{water} = 80)$ and $\varepsilon_o = 8.85\times10^{-12} C^2/(N{\bullet}m^2)$, which is the permittivity of free space. Algebraically solve for p_x and calculate its numerical value using the voltage found for point 4. Include the units, showing how they are determined $\left\{\text{Recall: } N = \frac{CV}{m}\right\}$

   b. **Figure 2** also shows that Lead II has a potential difference that is part vertical, and part horizontal. By subtracting the horizontal piece we can find the vertical piece. Note that the horizontal part of the voltage is over approximately half of the distance as measured in ΔV_{LeadI} and therefore corresponds to about half of the voltage (see **Figure 1**). Now you can algebraically solve for p_y and calculate its value with the following equation, using the potential found for point 4:

   $$\Delta V_y = \Delta V_{Lead\ II} - \frac{1}{2}\Delta V_{Lead\ I} = \frac{p_y}{2\pi\varepsilon_o \kappa_{water} r^2}$$

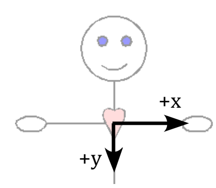

Figure 6: Our coordinate system

   c. Now that you have the two components of the maximum dipole moment, calculate the magnitude and the direction of the dipole moment. Create a sketch (*scale: 1 grid boxes =* 1×10^{-12} *C·m*) showing the two components and the direction of the maximum dipole moment using the coordinate system shown in **Figure 6**, where +x points the right and +y points down. Why is this the case?

Discussion

- Report the maximum potential difference found for each lead, as well as the magnitude and direction of the dipole moment.
- It is expected that your measurements of the dipole moment for the heart will be on the order of 10^{-12} *C·m*. How well did your value agree?
- A typical angle for the dipole moment is about 30° from the +x-axis to the +y-axis. How did your value compare?
- What about the EKG changed when you switched leads. Why did it change in this way?
- Describe a few of the approximations we have made in this experiment that may cause a discrepancy between your measured EKG and typical clinical EKGs.