

Electrocardiogram and Heart Sounds

Introduction

The beating of the heart is accompanied by both electrical activity and sound. The pattern of electrical activity produced by each heart beat cycle is called the electrocardiogram or ECG. The aim of this session is to record and analyze an ECG from a student volunteer, and to examine the relationship between the ECG and the characteristic sounds of the heart.

Background

The heart is a dual pump that pushes blood around the body and through the lungs. Blood enters the atrial chambers of the heart at a low pressure and leaves the ventricles at a higher pressure; it is this high arterial pressure that provides the energy to force blood through the circulatory system. Figure 1 shows the organization of the human heart and the circulatory system, in schematic form. Blood returning from the body arrives at the right side of the heart and is pumped through the lungs to pick up oxygen and release carbon dioxide. This oxygenated blood then arrives at the left side of the heart, from where it is pumped back to the body.

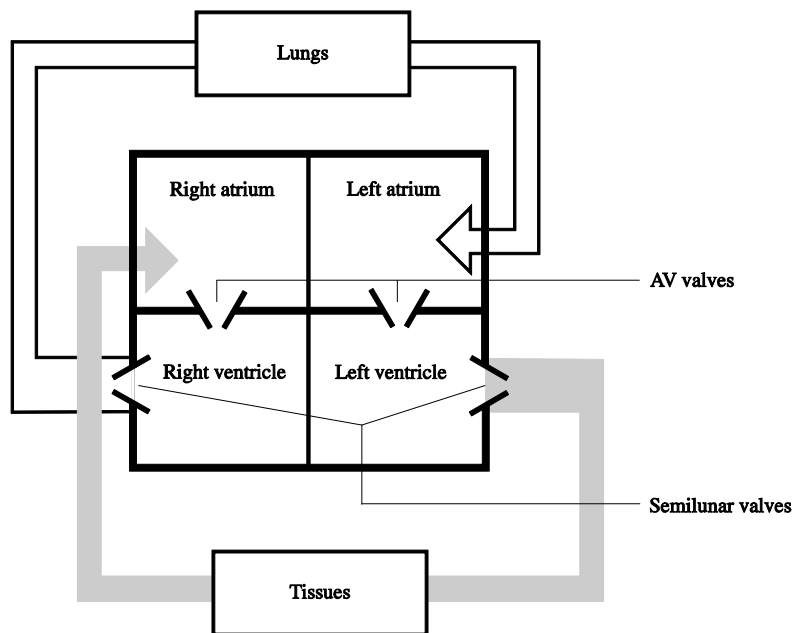


Figure 1. A schematic diagram of the human heart and circulatory system.

Cardiac contractions are not dependent upon a nerve supply. A group of weak muscle cells (sinoatrial or sinuatrial node, SA node) acts as the pacemaker for the heart (Figure 2). These cells rhythmically produce action potentials that spread through the fibers of the atria. The resulting contraction pushes blood into the ventricles. The only electrical connection between the atria and the ventricles is via the atrioventricular (AV) node. The action potential spreads slowly through the AV node (thus giving a time delay for ventricular filling) and then rapidly through the AV bundle and Purkinje fibers to excite both ventricles. The large muscle mass of the ventricles allows powerful contractions.

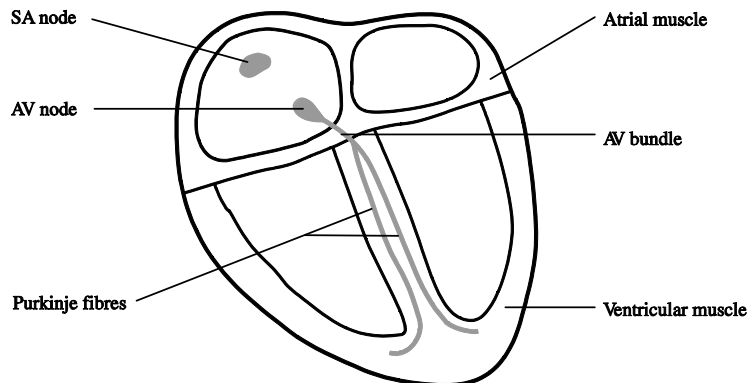


Figure 2. Components of the human heart involved in conduction.

Each side of the heart is provided with two valves, to convert rhythmic contractions into a unidirectional pumping. The valves close automatically whenever there is a pressure difference across the valve that would cause backflow of blood. Closure gives rise to audible vibrations (heart sounds). Atrioventricular (AV) valves between the atrium and ventricle on each side of the heart prevent backflow from ventricle to atrium. Semilunar valves are located between the ventricle and the artery on each side of the heart, and prevent backflow of blood from artery to ventricle. The cardiac cycle involves a sequential contraction of the atria and the ventricles. The combined electrical activity of the different myocardial cells produces electrical currents that spread through the body fluids. These currents are large enough to be detected by recording electrodes placed on the skin. The regular pattern of peaks produced by each heart beat cycle is called the electrocardiogram or ECG (Figure 3).

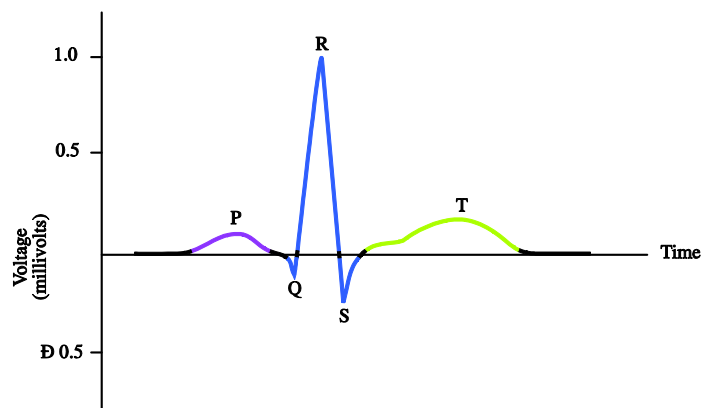


Figure 3. A typical ECG showing the fundamental parts that make up the signal.

The action potentials recorded from atrial and ventricular fibers are different from those recorded from nerves and skeletal muscle. The cardiac action potential is composed of three phases: a rapid depolarization, a plateau depolarization (which is very obvious in ventricular fibers), and a repolarization back to resting membrane potential.

The components of the ECG can be correlated with the electrical activity of the atrial and ventricular muscle:

- the P-wave is produced by atrial depolarization
- the QRS complex is produced by ventricular depolarization; atrial repolarization also occurs during this time
- the T-wave is produced by ventricular repolarization.

The characteristic sound produced by the heart is usually referred to as a 'lub-dup' sound. The lower-pitched 'lub' sound occurs during the early phase of ventricular contraction and is produced by closing of the atrioventricular

valves (the mitral valve and tricuspid valve), which prevent blood from flowing back into the atria. When the ventricles relax, the blood pressure drops below that in the artery and the semilunar valves (aortic and pulmonary) close, producing the higher-pitched 'dup' sound.

Required Equipment

The experiment has been designed for and tested on a PowerLab 4/25T system, although it can easily be adapted for other PowerLab systems.

This general setup is used for all the exercises in this experiment. The PowerLab 4/25T should already be connected to the computer and turned on. The equipment required for these exercises is:

A computer system

Chart software

PowerLab (with built-in Bio Amp or PowerLab and Bio Amp front-end)

Five-lead Shielded Bio Amp Cable & snap-connect Lead Wires

Three reusable clamp electrodes or disposable adhesive electrodes

Electrode cream (for use with the clamp electrodes)

Alcohol swabs (70% ethanol on cotton wool or paper tissue); optional

Ballpoint pen

Abrasive pads/gel

Push-button switch

Stethoscope

Procedures

Subject preparation

The student volunteering for the experiment should remove any watch or jewelry from their wrists and ankles.

1. Connect the push-button switch to the BNC socket for Input 2 (see
2. *Figure 4* for the equipment setup).
3. Plug the Bio Amp cable into the Bio Amp socket.
4. Connect the leads to Earth, CH1 negative and CH1 positive, on the Bio Amp cable.
5. If alcohol swabs are available, firmly swab the skin with them in each area where electrodes will be placed (Figure 5). Using a pen, mark each area with a small cross. Lightly abrade the skin at these areas with an abrasive pad/gel. This decreases the electrical resistance of the outer layer of skin and ensures good electrical contact.
6. If using the reusable clamp electrodes, apply a small amount of electrode cream to the electrodes, attach the electrodes to the subject as described below and connect the electrodes to the leads. If using the disposable electrodes (which have electrode gel on them already), just attach the electrodes to the subject as described below and connect the electrodes to the leads.
7. Ensure the volunteer is relaxed and sits as still as possible to minimize any signal artifacts from movement.

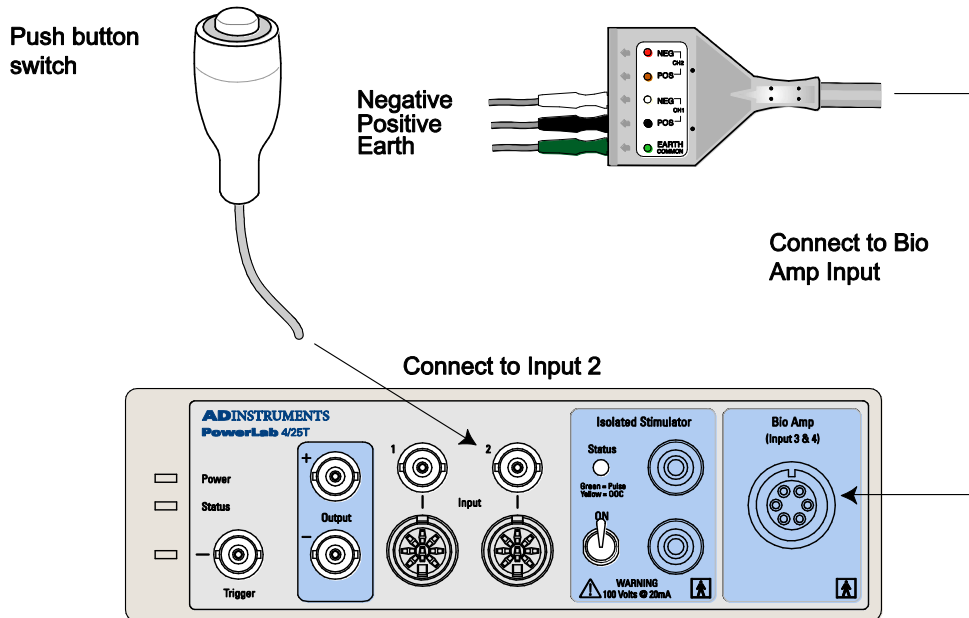


Figure 4. The equipment setup for this experiment.

Attaching the electrodes

1. **Standard connection:** attach the positive electrode to the left wrist, the negative to the right wrist, and the ground to the right leg. If after looking at the signal in the Bio Amplifier dialog window during the first exercise, this does not produce a good signal, the alternative method shown in *Figure 5* can be used.
2. **Alternative connection:** attach the positive electrode to the left upper arm, the negative to the right upper arm and the ground to either wrist. **NOTE: Do not place the electrodes over the major muscles of the upper arm because muscle activity interferes with the signal recorded from the heart.** Attach the electrodes on the outer side of the arm, midway between the elbow and the shoulder.

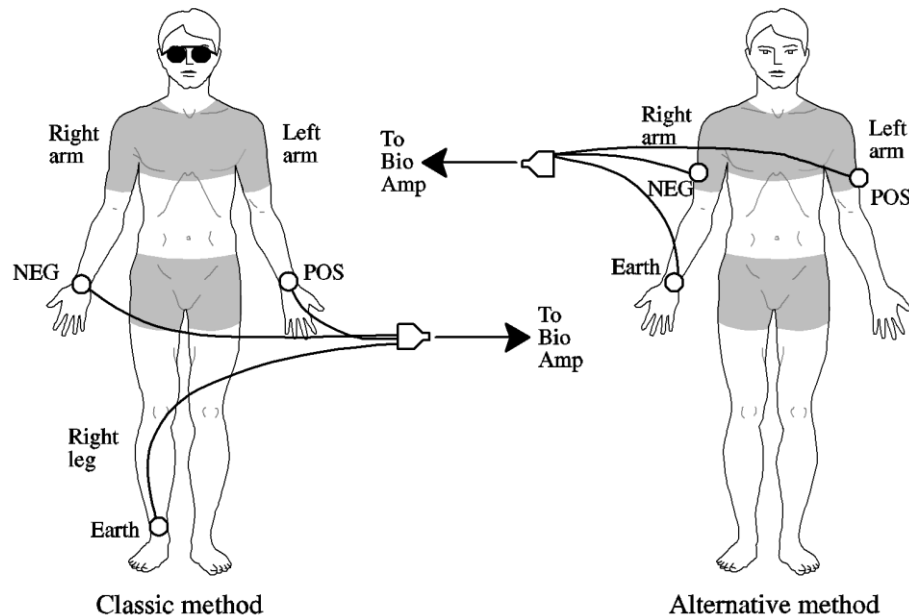


Figure 5. Connecting the electrodes to the volunteer: two alternative methods.

Starting the software

- Before beginning the exercises remember to ensure that the volunteer is relaxed and sits as still as possible, arms at rest, hands in lap, to minimize any signal artifact from movement. The Bio Amp cable has a clip that can be used to fasten the cable and leads to the volunteer's clothing.

Exercise 1: ECG in a resting volunteer

Objectives

To measure the ECG in a resting volunteer, and analyze the resultant signal. Also, to observe the effects of slight movement on the signals.

Procedure

Everything should be set up as described in the general notes above.

1. Observe the signal.

If the ECG cannot be seen, check that all three electrodes are correctly attached. Adjust the range if necessary. If the signal is noisy and indistinct, make sure that the volunteer is relaxed; consider using the alternative attachment positions shown in *Figure 5*.

2. Ask the volunteer to open and close their hands, and then move both arms across the chest. Note that the trace moves all over the place, and the ECG becomes distorted. This should demonstrate why it is necessary to keep still and relaxed when recording the ECG.
3. With the volunteer sitting quietly, click the Start button. When a suitable trace has been recorded, type 'Resting ECG', and the volunteer's name, and press the Return/Enter key on the keyboard to enter the comment.

4. Click the Stop button to stop Chart recording.
5. Choose Save from the File menu to save the recording.

Exercise 2: ECG for a range of volunteers

Objectives

To compare the resting ECG signal from different volunteers.

Procedure

Everything should be set up as described in the general notes above. Record and analyze the ECG signals of other volunteers in the group as described in Exercise 1.

Exercise 3: ECG and heart sounds

Objectives

To measure and correlate the ECG and heart sounds in a resting volunteer.

Using a stethoscope

The tutor will briefly demonstrate how to use the stethoscope. *Figure 6* shows the essentials.

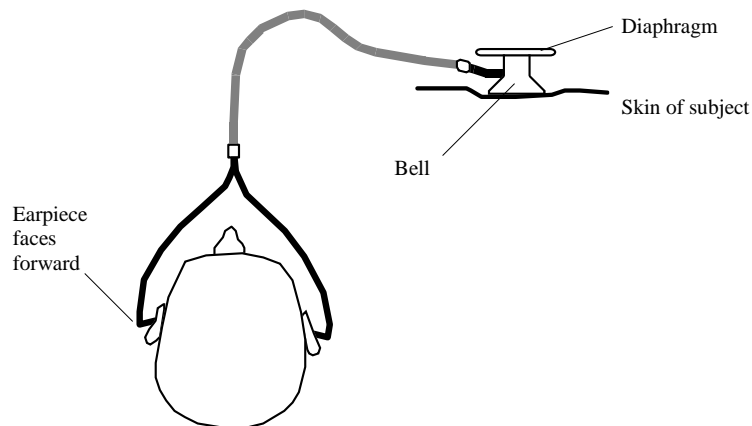


Figure 6. The correct use of a stethoscope: note the angle of the connection to the endpiece; it shows that the bell is currently selected.

Procedure

Everything should be set up as described in the general notes above. The stethoscope bell is better than the diaphragm for this exercise because it blocks off room noise. It still helps if everyone tries to keep the noise to a minimum. The bell (the cup-shaped end) of the stethoscope should be placed directly on the skin over the heart to hear the heart sounds clearly. One student should listen using the stethoscope and do the recording, while the volunteer whose heart sounds are being listened to places the stethoscope bell.

1. Press and release the push-button switch several times. An obvious deflection should be seen. If not, adjust the range to obtain a deflection that is at least 25% of full scale.

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2. The volunteer should place the bell of the stethoscope on the left side of their chest, using the right hand (It is easy enough to do this under one's shirt). The stethoscope should be moved to different positions until the student listening using the stethoscope hears clear heart sounds. The sounds are soft and therefore room noise must be kept to a minimum. Once clear heart sounds are heard, the volunteer should hold the stethoscope in place with the right hand while the student using the stethoscope listens and conducts the recordings.
3. Click the Start button to start recording, and press the push-button switch on hearing 'lub' and release it on 'dup'.
4. After a few heart beat cycles, click the Stop button to stop recording. A recording similar to that in *Figure 7* should be observed.
5. Choose Save from the File menu to save the recording.

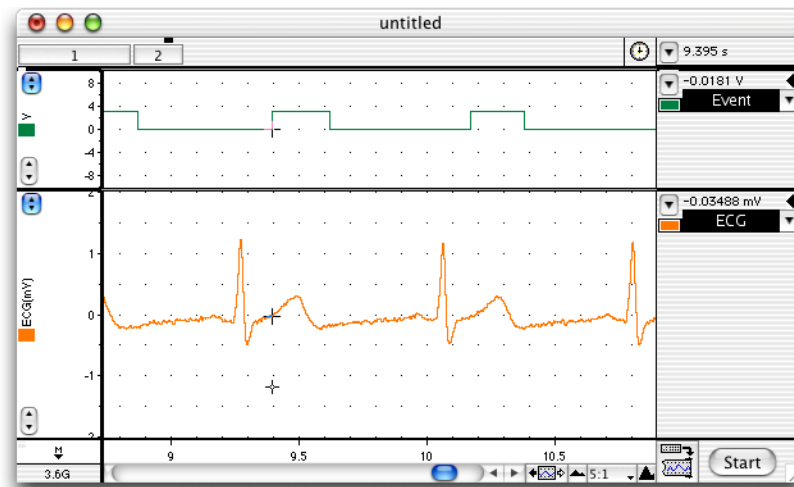


Figure 7. An ECG recording, with timed pulses from the push-button switch showing when the heart sounds were heard.

Analysis

Exercise 1: ECG in a resting volunteer

1. Use the View buttons in the Chart window to set the horizontal **compression** to 5:1.
2. Scroll through your data and observe the regularly occurring ECG cycles.
3. Measure the amplitudes of four P waves, QRS complexes and T waves from the ECG trace. Move the Waveform Cursor to the peak of the wave, and read off the amplitude value from the Range/Amplitude display directly above the 'ECG' channel title. Record the average amplitude in Table 1 or a table like it.
4. Using the **Marker** and **Waveform Cursor**, measure the durations of four P waves, QRS complexes and T waves from the ECG trace. Place the Marker on the ECG trace immediately before the wave of interest, move the Waveform Cursor to the end of the waveform, and read off the time from the Rate/Time display (as shown in *Figure*). The ' Δ ' symbol indicates that the value is the difference in time between the positions of the Marker and Waveform Cursor.
5. Place the Marker before a QRS complex and use the View buttons in the Chart window to compress the view horizontally to 50:1. Move the Waveform Cursor to the right until roughly a 15-second difference is shown in the Rate/Time display (this should appear as ' $\Delta 15s$ '). Count the number of QRS complexes between the Marker and the Waveform Cursor. Multiply this number by four to calculate resting heart rate in beats per minute (bpm).
6. Use the View buttons in the Chart window to set the horizontal compression to 10:1. Measure the time interval (in seconds) between three pairs of adjacent R waves using the Marker and Waveform Cursor. For each interval, calculate the heart rate using the equation below, and record these results in Table 2 of the Data Notebook.

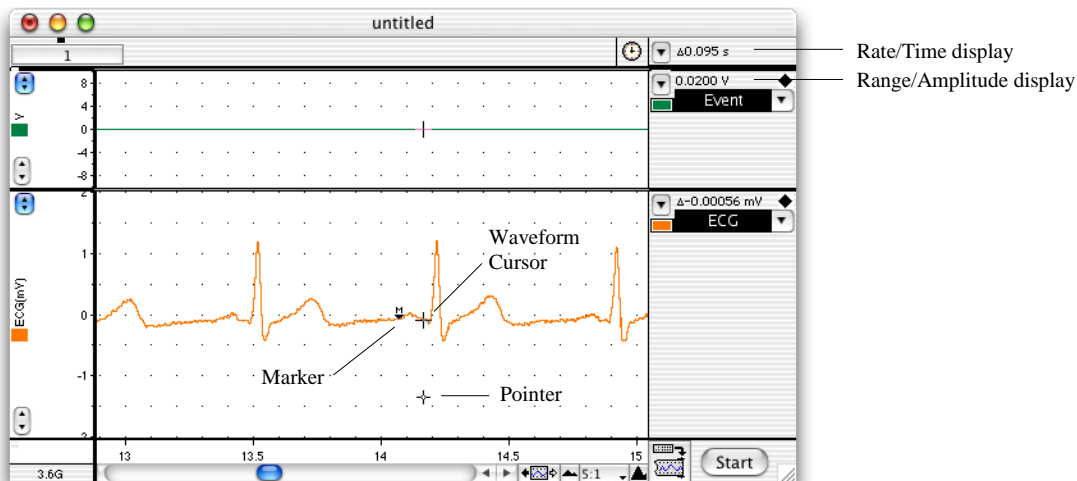


Figure 8. A typical recording of Exercise 1: the Marker and Waveform Cursor are set to measure the duration of the P wave.

- Calculate the average duration for each waveform from four separate ECG cycles and record these results in Table 1 or a table like it.

$$\text{Heart rate (beats / minute)} = \frac{60}{\text{time interval (seconds)}}$$

Exercise 2: ECG for a range of volunteers

Compare the duration and amplitude of the P waves, QRS complexes and T waves between those in the group and with other members of the class. Record these results in Table 3 of the Data Notebook. It may help to note down the sex and apparent fitness levels of the volunteers.

Exercise 3: ECG and heart sounds

1. **Select** a region of data with two or three cardiac cycles, by clicking and dragging in the Time axis area (this will select both of the displayed channels).
2. Select Zoom Window from the Window menu. The Zoom window appears with the Event and ECG signals overlaid.
3. Note the correlation between Event and ECG signals.

If the instructions given earlier were followed, the Event signal should go high (signaling the 'lub' sound) very soon after the QRS complex, and the Event signal should go low (signaling the 'dup' sound) at or shortly after the T wave.

Note any differences from the expected timing of the Event signal.

Data Notebook

Table 1. Results table for the data analysis from Exercise 1.

Component	Amplitude (millivolts)	Mean	Duration (seconds)	Mean
P wave				
QRS complex				
T wave				

Table 2. Results table for the heart rate calculation in Exercise 1.

Pair	Time Interval (seconds)	Heart Rate (beats per minute)
1		
2		
3		

Table 3. Group data results for Exercise 2.

Person's name	Mean P amplitude (mV)	Mean P duration (sec)	Mean QRS amplitude (mV)	Mean QRS duration (sec)	Mean T amplitude (mV)	Mean T duration (sec)

Study Questions

Write a paragraph in the space defining the components of an electrocardiogram, and how it relates to heart sounds. Explain briefly what you expect to learn from this experiment. Briefly describe the techniques you will use to measure heart sounds and the ECG.

Exercise 1

1. What can you say about the amplitude of the various waves in different cardiac cycles?
2. The P wave and the QRS complex represent depolarization of the atrial and ventricular muscle respectively. Why does the QRS complex have the largest amplitude?
3. In step 5 you calculated a heart rate averaged over 15 seconds whereas in step 6 you calculated 'instantaneous' heart rates. Explain any differences between these values.
4. The range for a normal resting heart rate is 60 to 90 bpm. A trained athlete could have a resting heart rate of 45 to 60 bpm. Why might a very fit person have a slower heart rate than someone of average fitness?

Exercise 2

1. Do you expect that the amplitudes and durations of the various waves in different individuals to be similar or very different?
2. What variations in heart rate do you expect to observe between individuals?
3. Is there any obvious correlation between heart rate and an individual's sex or apparent fitness?

Exercise 3

1. Explain why ventricular contraction (systole) and the 'lub' sound occur immediately after the QRS complex.
2. Explain why ventricular relaxation (diastole) and the 'dup' sound occur after the T wave.
3. Your recordings probably will show some differences from the correct timing of the heart sounds. How do you think such wrong results occur? What additional apparatus might improve the experiment and prevent errors in the recorded timing?

Results

Exercise 1: ECG in a resting volunteer

Attach a copy of the Zoom window of resting ECG. Indicate on the figure the P-wave, QRS complex, and the T-wave.

Fill in the results from Table 1 in the space below.

Component	Mean Amplitude (millivolts)	Mean Duration (seconds)
P wave		
QRS complex		
T wave		

Show the calculation for heart rate in the space below:

Exercise 2: ECG for a range of volunteers

Draw a column graph in the space below showing the average heart rate for:

- a) the entire class
- b) males
- c) females

Put error bars on each column representing (+/-) 1 standard error from the mean.

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Draw a column graph showing the average amplitudes of the P wave, QRS complex, and T wave for the class. Put error bars on the graph representing (+/-) 1 standard error from the mean value.

Draw a column graph showing the average duration of the P wave, QRS complex, and T wave for the class. Include error bars representing (+/-) 1 standard error from the mean.

Exercise 3: ECG and heart sounds

Attach a copy of the Zoom window in the space below showing the ECG and heart sounds trace. Indicate on the figure where the “lub” and “dup” sounds were heard.

Conclusions

Answer the following questions in complete sentences.

- 1) Describe the events that are occurring in the heart during the following times:
 - a. P wave
 - b. QRS complex
 - c. T wave
- 2) Did the amplitudes of the ECG waves vary greatly between individuals in your class?
- 3) Did the duration of the ECG wave vary greatly between individuals in your class?
- 4) Did heart rate vary between members of your class? Did sex appear to relate to heart rate?
- 5) Explain why the QRS complex appears *before* the "lub" sound.
- 6) Explain why the "dup" sound occurs *after* the T wave.
- 7) Explain why there may be errors in the timing of your heart sounds.