William Liu, Eric Yang, Sarah Slack
BioEn 317 Lab 2 Report
April 3rd, 2018

**Electrocardiogram Signal Acquisition and Analysis - Lab Report**

## Introduction

The purpose of the lab was to build an understanding of how biological signals must be acquired and processed in an often more complex way for bioengineering approaches than for non-biological applications. The electrical signals produced by a human heart as it beats were used as a model signal for data acquisition and processing. An electrocardiogram (EKG) measures the electrical voltage produced by the heart over time, which is then plotted as an EKG graph that shows each heart beat with its P wave, QRS complex, and T wave components, which correspond respectively to atrial depolarization and contraction, ventricle depolarization and contraction, and then repolarization before the atrioventricular node generates the signal for the next beat. In order to capture these electrical signals within the heart, electrodes must be placed according to Einthoven's triangle.

## Methods

One teammate was chosen for all of the EKG measurements, and seven electrodes were placed on the subject's right shoulder, right elbow, right wrist, left elbow, left wrist, left hip and left ankle. The right wrist was always connected to ground, the positive lead to the right side of the body, and the negative lead to the left. One distal arrangement, right elbow left ankle, and two proximal arrangements, right shoulder left hip and right shoulder left elbow, were recorded for one minute to determine the ideal electrode placement. The three EKG measurements were plotted in Excel, and the right shoulder left hip was chosen as ideal due to its low noise and slightly greater amplitude and was used for all following measurements. Two more minute long EKG measurements were recorded while the subject remained still and then immediately following the subject running up six flights of stairs. Before the heart rate returned to resting, the subject performed the Valsalva maneuver by exhaling against closed airways while an EKG was recorded for ten seconds. One final EKG measurement was recorded by adjusting the $f_s$ until the QRS signal no longer showed up reliably in the EKG. All figures report the EKG in volts, due to the 1000 time magnification of the original mV signal.

## Results and Discussion

1. There were seven locations on the subject where electrodes were placed. These seven electrodes included the right shoulder, right elbow, right wrist, left elbow, left wrist, left hip and left ankle. During all conditions, the ground wire was connected to the right wrist and the locations of other active leads were varied. The location of the distal condition

was defined as right elbow and left ankle since they are the farthest away from the heart. The other two locations that were farther away from the heart were defined as proximal conditions. These were right shoulder-left hip and right shoulder-left elbow.
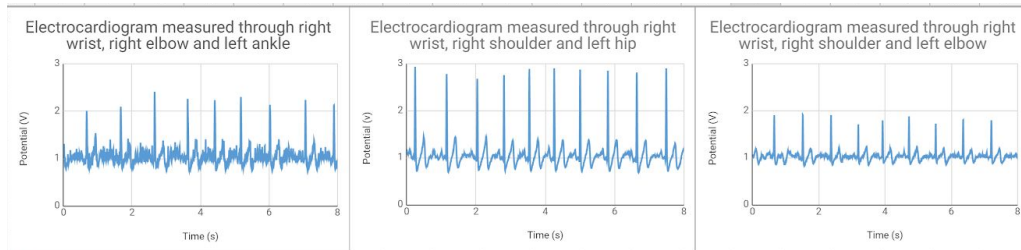


**Figure 1:** Plots of 5-10 cycles of the EKG signals measured at various locations
Most left: distal condition. Middle and right: proximal conditions.

2. The ideal condition the group picked was the electrocardiogram measured through the right wrist, right shoulder and left hip as the Q-R-S complexes were the most distinguishable. The second condition was the ideal condition when the subject is calm and still. The third condition was measured after the subject ran up and down six floors of stairs. The fourth condition was measured after the subject performed the Valsalva maneuver immediately after the third condition. The fifth condition was measured after the fourth condition with a sampling frequency of 2 Hz.
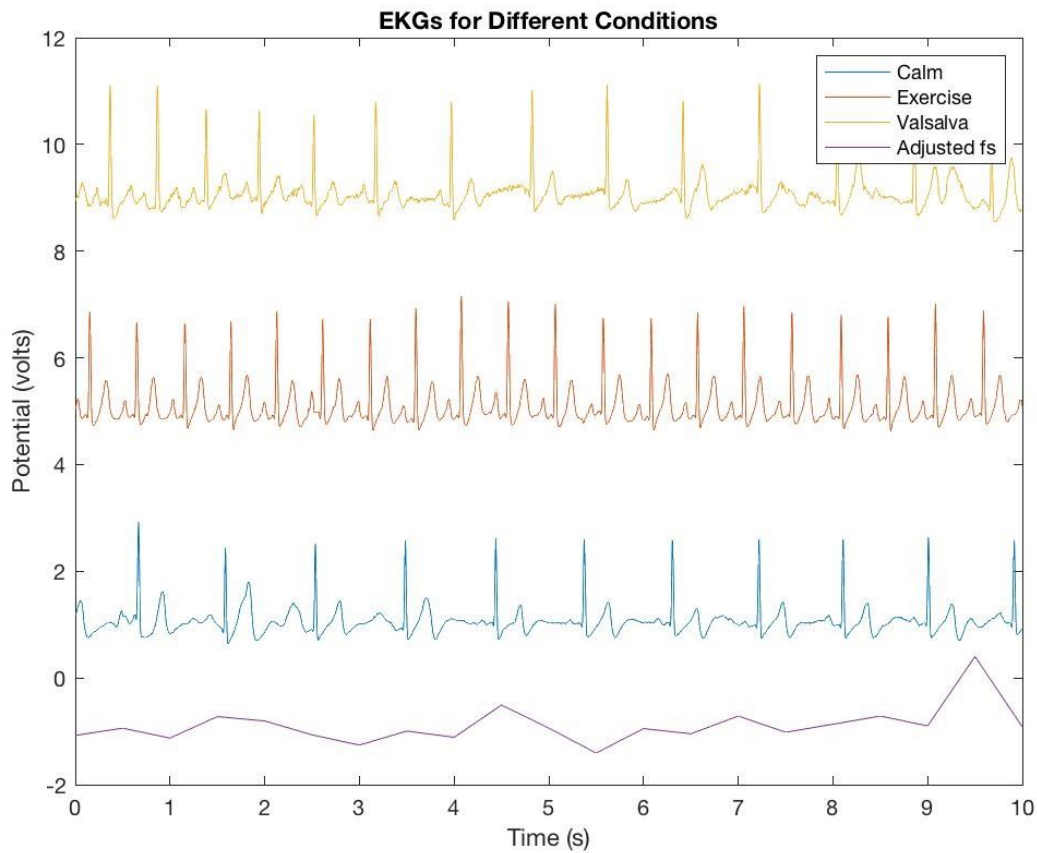
**Figure 2:** EKG's for four different conditions. Offsets in increments of two and four were added to each condition to distinguish the plots from each other in one figure.

3.  The minimum heart rate recorded while the subject remained still was 63 beats per minute, or 1.05Hz.  The maximum heart rate recorded after the subject performed vigorous exercise was 120 beats per minute, or 2Hz.  These were calculated by generating the MATLAB plots below and counting the number of EKG R wave peaks that occured over 20 seconds.
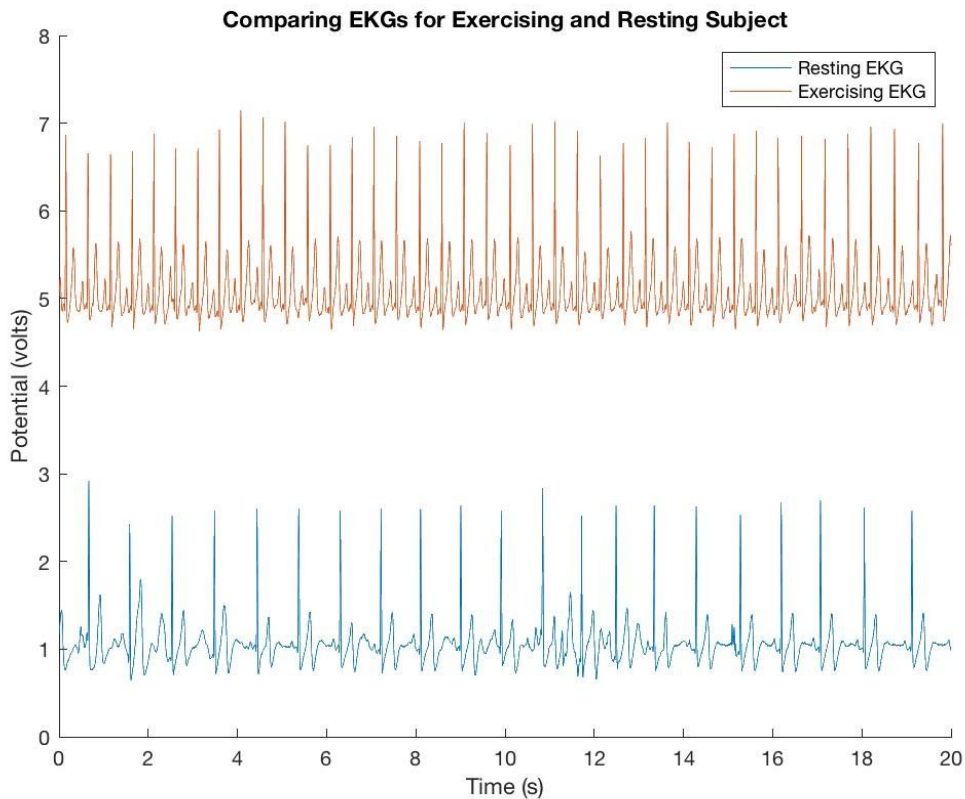
**Figure 3**: EKG's measured after subject had exercised (Condition 3) compared to when the subject was resting (Condition 2).

When targeting maximum heart rate for safe exercise, it is generally advised to stay under a heart rate of 220 beats per minute minus the person's age. However, heart rate can physiologically increase to about 300 beats per minute before becoming limited by the absolute refractory period of the atrioventricular junction.[1]

4. Following vigorous exercise, which increased heart rate, the Valsalva maneuver was performed, which almost immediately decreased heart rate (Figure 2). The heart rate of 2Hz following exercise decreased to 1.4Hz in the 10 seconds the Valsalva maneuver was performed. Because the Valsalva involves exhaling against a closed airway, the pressure inside the chest is dramatically increased. This increased pressure compresses the aorta, straining its ability to pump blood from the heart to the body, which is reflected by a decreased heart rate.

5. The amplitudes of the EKG's of the subject were generally constant around 2.5V. Nick's group's EKG amplitude was also constant, but had a lower average around 1.75V. The amplitudes were constant within one individual because the ion flow causing the

depolarization in the heart muscle cells always reaches the same maximum and minimum voltages due to its regulation by voltage gated channels. Therefore the heart voltage will not increase or decrease according to the conditions tested in lab, instead the rate of beats, or depolarizations, will adjust. The difference in amplitudes across individuals could be due to measuring conditions such as skin perspiration, lead connectivity, and machine settings. Dryer skin produced lower amplitudes as there was more resistance. The difference in where the leads were connected and different settings on the computer software also contributed to the difference in amplitudes.

6. The noisiest EKG signal recorded was condition one, likely because the subject did not remain still and the electrocardiogram was not covered and therefore exposed to the noise in the room. For all subsequent conditions, the subject made no extraneous movements and the electrocardiogram was covered, limiting noise. None of the EKG signals recorded exhibit drift, or low frequency interference. Test subject conditions such as changes in breathing, movement, or perspiration at the electrode site can all contribute to drift, meaning the test subject was fairly constant during measurement.[2] Before processing, the EKG signals exhibited an offset of about 1V, which corresponds to 1mV before amplification, likely due to noise.
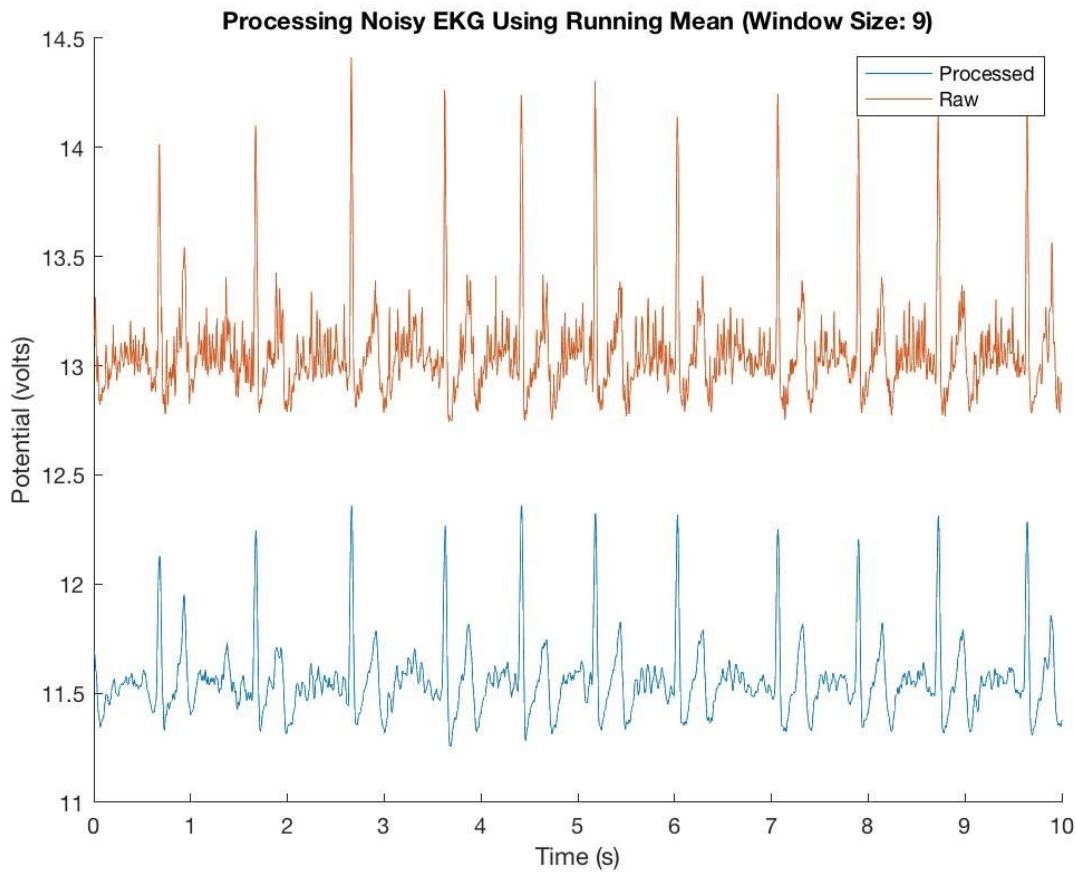
**Figure 4**: Raw and processed (running average function) EKG's of condition 1.

The running average function was used to remove noise carefully due to the its potential to remove valuable information encoded by the signal. The MatLab function "movmean" was applied to the voltage data from condition one with a range of 9. Many different values for window size were applied, but 9 offered the best compromise between noise filtering and signal integrity. As the window size was increased, the limitations of the filtering method became very apparent. With a range of 100, the signal had no discernible peaks; it was approaching a straight line. When the range was increased to 1000, the signal appeared to be a completely flat line, all information was lost. This highlights the trade-off that is inherent when using the running mean as a filter, noise can be reduced but some information will always be lost in the process.

7. The Nyquist rate functions as the lower bound of the sample rate to achieve sampling without aliasing. In essence, sample rate frequency should be at least twice that of the signal you are measuring. When measuring EKGs, the sampling frequency was set to 250 Hz, while the calculated frequency of the heartbeat was only 2 Hz, ensuring an alias-free

signal. However, for measuring action potentials, whose maximum frequency can reach 1000 Hz, the $f_s$ used for the EKG experiment would not be sufficient. Given that the $f_s$ is ¼ of the signal frequency it does not conform to the Nyquist rate, and therefore aliasing would be present in the signal.
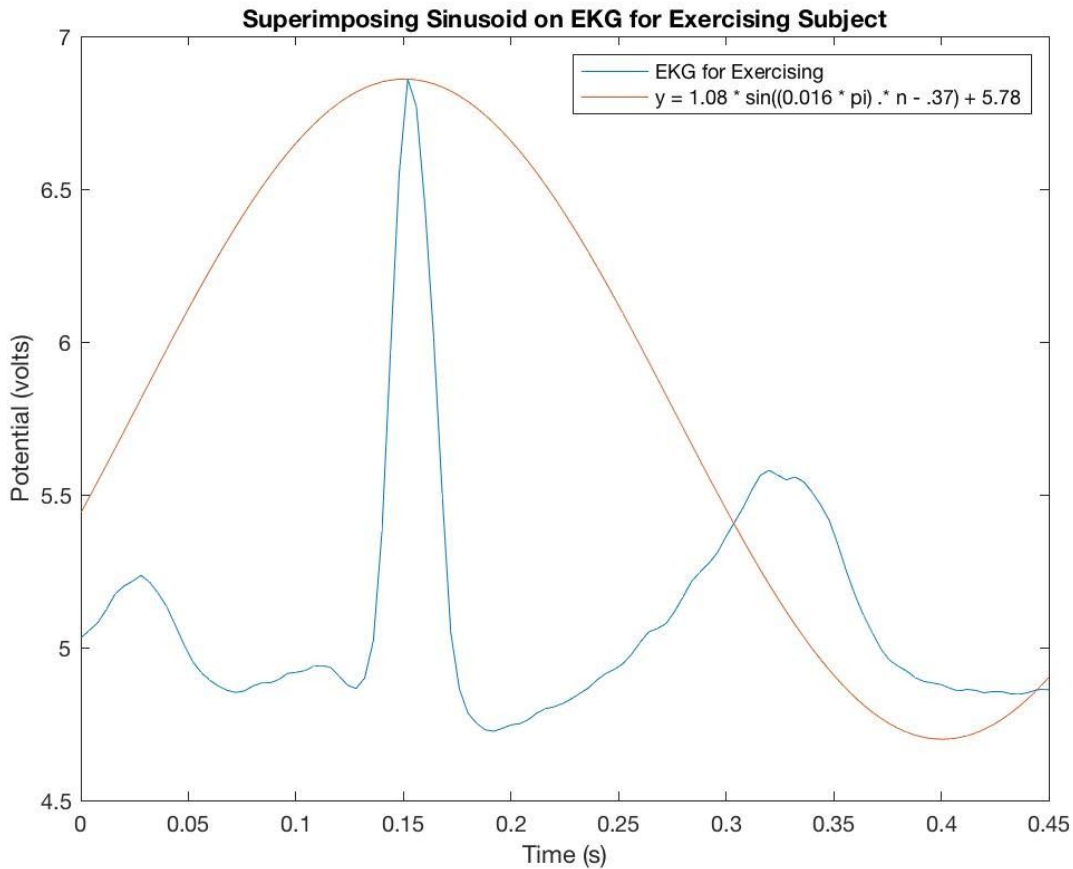


**Figure 5:** One cycle of the EKG after exercise imposed with the sinusoid generated by adjusting the Hertz experimentally collected to radians per second, and time to the discrete sampling time points created by the digitization of the analog signal.

**References**
[1] Chhabra, L., Goel, N., Prajapat, L., Spodick, D. H., & Goyal, S. (2012). Mouse Heart Rate in a Human: Diagnostic Mystery of an Extreme Tachyarrhythmia. *Indian Pacing and Electrophysiology Journal*, *12*(1), 32–35.
[2] Luo, Y. (2013). A Hierarchical Method for Removal of Baseline Drift from Biomedical Signals: Application in ECG Analysis. *TheScientificWorld*.

William Liu, Eric Yang, Sarah Slack
BioEn 317 Lab 2 Report
April 3rd, 2018

**Appendix/MATLAB**

```
clear all; close all; clc
%% Plotting Initial EKGs
%Right Elbow, Left Ankle
rightElbowLeftAnkle = csvread('Distale Right Elbow Left Ankle.csv', 1, 0);
rightElbowPotential = rightElbowLeftAnkle(:, 2) + 12;
time = rightElbowLeftAnkle(:, 1);
figure;
plot(time(1:2502), rightElbowPotential(1:2502));
title('Comparing Different EKGs');
legend;

%Condition 2: Calm
condition2 = csvread('Condition 2.csv', 1, 0);
potential2 = condition2(:,2);
plot(time(1:2502),potential2(1:2502));
hold on

%Condition 3: Exercise
condition3 = csvread('Condition 3.csv', 1, 0);
potential3 = condition3(:,2)+4;
plot(time(1:2502),potential3(1:2502))

%Condition 4: Valsalva
condition4 = csvread('Condition 4.csv', 1, 0);
potential4 = condition4(:,2)+8;
plot(time(1:2502),potential4(1:2502))

%Condition 5
condition5 = csvread('Condition 5.csv', 1, 0);
time5 = condition5(:,1);
potential5 = condition5(:,2)-2;
plot(time5(1:22),potential5(1:22))
legend('Calm', 'Exercise', 'Valsalva', 'Adjusted fs');
title('EKGs for Different Conditions');
```

```matlab
ylabel('Potential (volts)');
xlabel('Time (s)');
xlim([0 10]);
hold off

%% Calculating Heart Rate and Comparing between Conditions 2 and 3
figure;
hold on
plot(time(1:5004),potential2(1:5004));
plot(time(1:5004),potential3(1:5004));
xlim([0 20]);
ylabel('Potential (volts)');
xlabel('Time (s)');
title('Comparing EKGs for Exercising and Resting Subject');
legend('Resting EKG', 'Exercising EKG');
hold off

%% Finding Amplitude of EKG, using the Range
range2 = range(potential2);
range3 = range(potential3);
range4 = range(potential4);

%% Running Average
%Compute average about a point using a range of 4 values on either side
processedEKG = movmean(rightElbowPotential, 9);
figure;
hold on
plot(time(1:2502), processedEKG(1:2502)-1.5);
plot(time(1:2502), rightElbowPotential(1:2502));
xlim([0 10]);
title('Processing Noisy EKG Using Running Mean (Window Size: 9)');
xlabel('Time (s)');
ylabel('Potential (volts)');
legend('Processed', 'Raw');
hold off

%% Superimposed Sinusoid
figure;
plot(time(1:115),potential3(1:115))
```

```
hold on
n = [1:115];
y = 1.08 * sin((0.016 * pi) .* n - .37) + 5.78; %Equation for sinusoid
plot(time(1:115), y);
xlim([0 0.45]);
title('Superimposing Sinusoid on EKG for Exercising Subject');
xlabel('Time (s)');
ylabel('Potential (volts)');
legend('EKG for Exercising', 'y = 1.08 * sin((0.016 * pi) .* n - .37) + 5.78');
hold off
```