
# Lab 2: BIOPOTENTIAL MEASUREMENTS

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## 1.0 INTRODUCTION

In this lab we were tasked with taking several measurements including: electroencephalogram, galvanic skin response, electrooculogram, electromyogram, and the electrocardiogram. We used Ag/AgCl skin electrodes to take all of our measurements. These biopotential measurements are a representative portion of widely used and very important measurements used in the biomedical engineering field as well as in medicine. This lab paper details the results we obtained in taking these measurements from our group members, as well as some of the problems we faced and how we overcame them. Also, during some of the measurements that we took, we had a circuit board problem which caused several measurements to be overly noisy. This was corrected for the EEG (since it has such a large gain) and it should not effect the observable results for the other measurements.

## 2.0 ELECTROOCULOGRAM (EOG)

The electrooculogram measures eye position using a steady electric dipole that is created by the corneal-retinal potential. The EOG is capable of measuring both horizontal and vertical eye movements. The horizontal measurement can be made by placing surface electrodes on the temple to the right and left of the eye and on the forehead. The relationship between the horizontal angle of gaze and the EOG voltage should be approximately linear for +/- 30 degrees of arc. The EOG output typically ranges from 50-3500 uV and the signal frequency from dc to 50 Hz. The electrooculogram is frequently the method of choice for recording eye movements in sleep and dream research, in recording eye movements from infants and children, and in evaluating reading ability and visual fatigue[1]. It is also useful for the detection of RPE diseases.

Our horizontal EOG measurements were taken on Matt McClintock. For the first measurement, the positive electrode was connected to the right temple and the negative electrode was connected to the forehead. Matt began by looking straight ahead, which resulted in a steady signal around 1.5mV. Next, he moved his eyes to the right and continued to look that direction. The voltage increased to almost 7mV as he moved his eyes and then steadied at the original

voltage after the eye movement stopped. Then, he moved his eyes back to the center which caused the voltage to decrease to almost -7mV and then return to around 1.5mV. These results are shown in Figure 1.

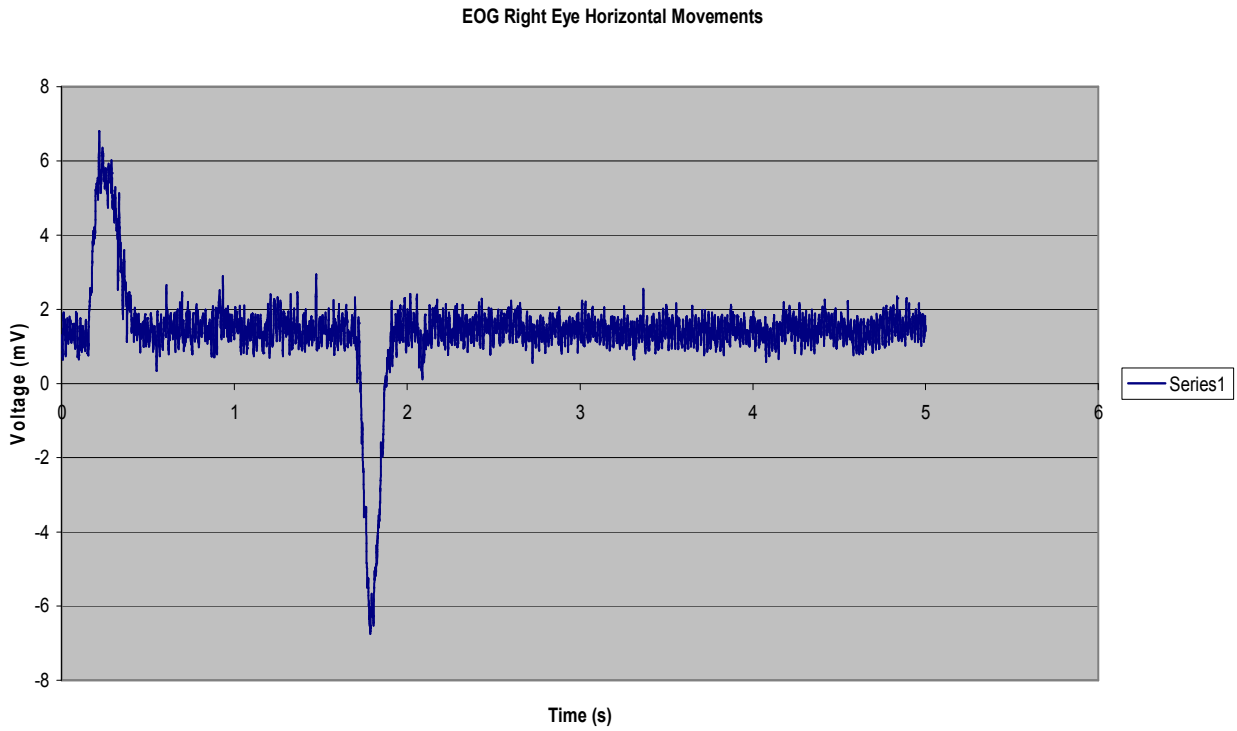


**Figure 1: EOG Right Eye Horizontal Movements**

The next measurement was made with the positive electrode connected to the left temple and the negative electrode still connected to the forehead. The results of this measurement (Figure 2) were very similar to the first except that instead of looking to the right, Matt looked to the left. The motion artifact that can be seen in these figures was caused by Matt blinking. Both of these measurements were taken with ground connected to the right leg and the bandpass filter set to .05-100 Hz.

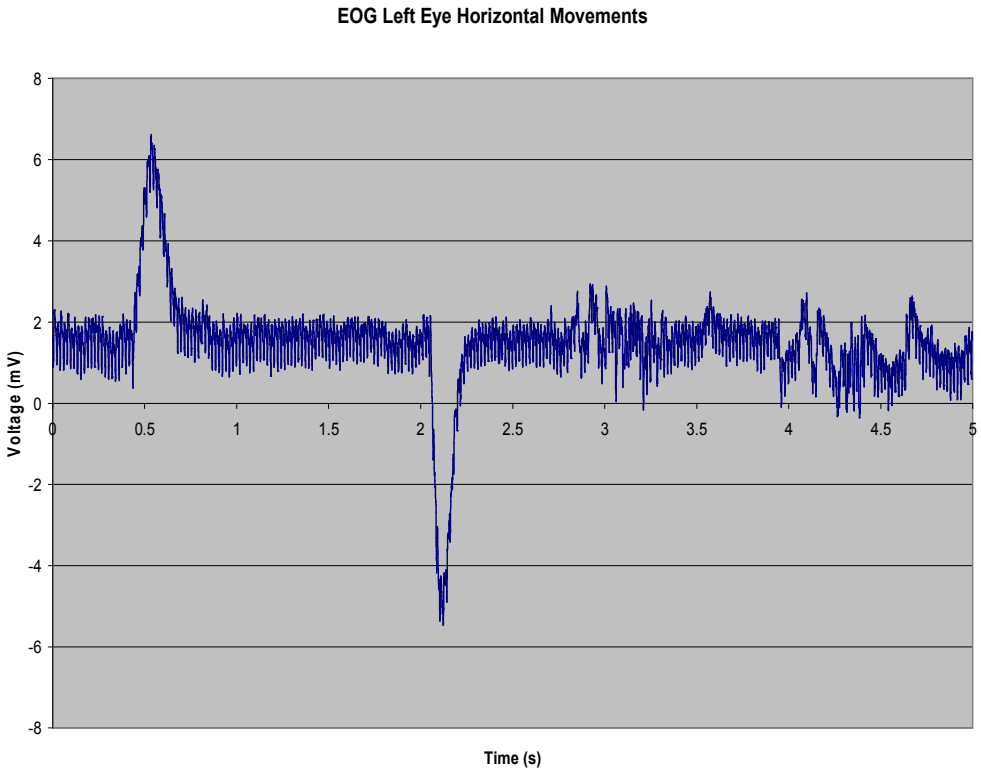


**Figure 2: EOG Left Eye Horizontal Movements**

A limitation of the electrooculogram is the inaccuracy of measurements for small and large eye movements. Noise from the EEG and the EMG that is equivalent to approximately 1 degree of eye movement appears on the signal [1]. Therefore, eye movements that are less than 1 or 2 degrees are difficult to record using the EOG. Also, eye movements that are greater than approximately 30 degrees do not produce amplitudes that are strictly proportional to eye position.

Since we had already completed taking the EOG measurements before we received the grading requirements for the lab (the day before the lab was due), we did not take measurements on the light and dark adaptation. However, if we had taken these measurements, we would have found that the EOG signal is twice as large in light adaptation as it is in dark adaptation.

## 3.0 GALVANIC SKIN RESPONSE (GSR)

The galvanic skin response measures changes in the electrical resistance of the skin caused by an individual's psychological state. These changes are specifically caused by the sweat glands and ducts, which create a potential difference between the lumen of the sweat duct and the dermis and subcutaneous layers of the skin. As a person sweats, the resistance of the skin decreases, causing the potential difference to decrease. The GSR measurement varies from 1-500k Ohms and over the frequencies .01-1 Hz. The main use of the galvanic skin response has been as a lie detector test.

We took GSR measurements on Nathan Shepard by placing four electrodes in a row on his left forearm, approximately two inches apart. The outer two electrodes were connected to an alternating 10 Hz current source that we built and the inner two electrodes were connected to the biopotential amplifier. Ground was connected to his right leg. The bandpass filter was set to .5-300 Hz. The first measurement we took was with the normal electrical resistance of the skin. The GSR for the dry skin has a voltage of around .35mV as can been seen in Figure 3. Next, we placed salt water on the skin to simulate sweat and took another measurement. The voltage for the salty skin was approximately .2mV (Figure 4). The decrease in potential from the dry skin to the salty skin indicates that the resistance of the salty skin was less than that of the dry skin, as we expected.

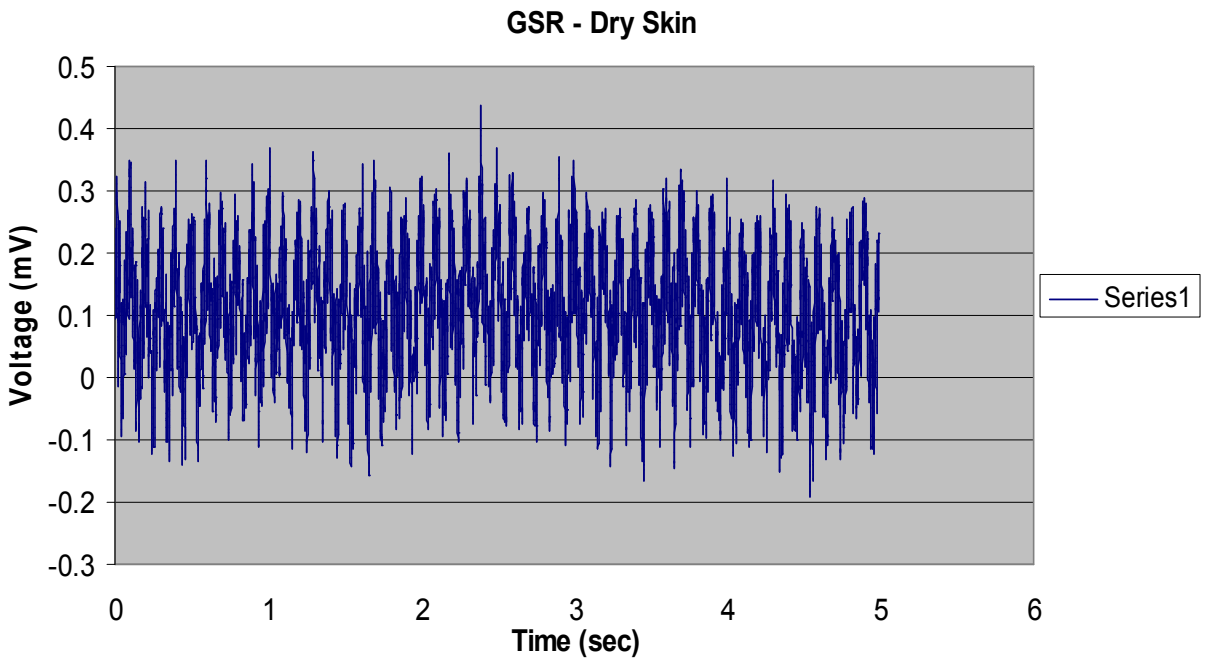


**Figure 3: GSR - Dry Skin**

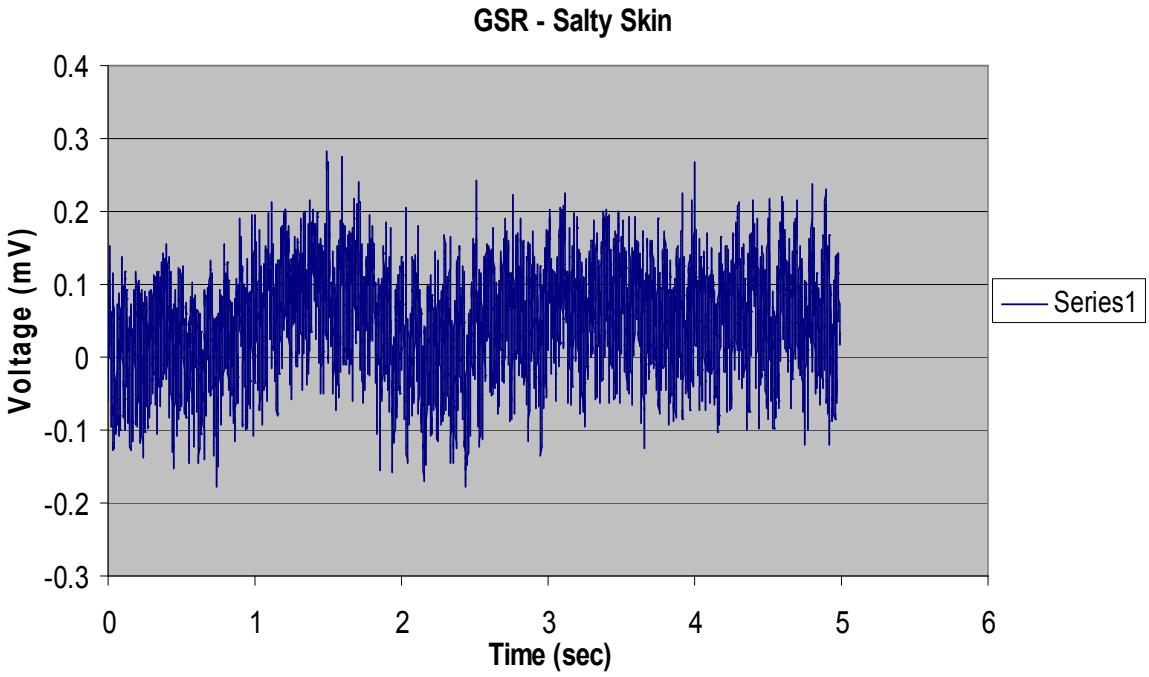


**Figure 4: GSR - Salty Skin**

## 4.0 ELECTROENCEPHALOGRAM (EEG)

The electroencephalogram is used to record the electrical activity within the brain. The intensity and patterns of this activity are called brain waves. These waves vary greatly between when a person is awake and asleep. General patterns of these waves that are observed in normal people can be classified into four wave groups, alpha, beta, theta, and delta. Other abnormal patterns can help detect seizure disorders such as epilepsy. EEG measurements are also used for the legal definition of brain death.

The 10-20 electrode system is most often used for placement of the EEG electrodes. The EEG can be measured on the surface of the brain or the scalp. The magnitude of the surface measurement may be as large as 10mV, while the scalp measurement has a lower amplitude of approximately 100uV. The frequencies of the signal range from .5 to 100 Hz.

The electrode placement for our EEG was done in two different ways. The first method employed an electrode attached below the ear and one on the on the occipital lobe, with driven ground attached to the right leg. This yielded some interesting results and we obtained a gain of 200,000. However, as we researched further we decided right leg driven ground was generating a lot of noise from muscle and heart contractions which limited us from achieving a gain of 1,000,000. Therefore, we decided to rearrange our electrode placement. We placed one electrode on the right occipital lobe and the other one the left occipital lobe with driven ground connected right below the ear. We were able to see a signal with our biopotential amplifier gain set to 1,000,000. These results were actually quite surprising to our group. The main problems we had when taking these measurements were muscle action potential interference, voltage transients, and poor contact with the head. To solve these problems we eventually ended up taking these measurements while laying flat on the ground to achieve complete muscle relaxation. Then we placed a board under the head which pressed very firm (with insulation in between the electrodes and the board) which helped our electrodes make good contact with the head. With this technique we were able to see some interesting results as shown below. The graphs labeled EEG center are the ones measured using the first technique and the ones labeled EEG differential are the ones measured with the second technique. The gain of the graph is shown in the label. It is

quite difficult to analyze these results, but they did contain a large amount of signal in the 1-40 Hz region which is indicative of an EEG signal. There were some obvious changes in the signal when the eyes were open and closed as well. The band pass used for the EEG was .05 Hz to 100 Hz.

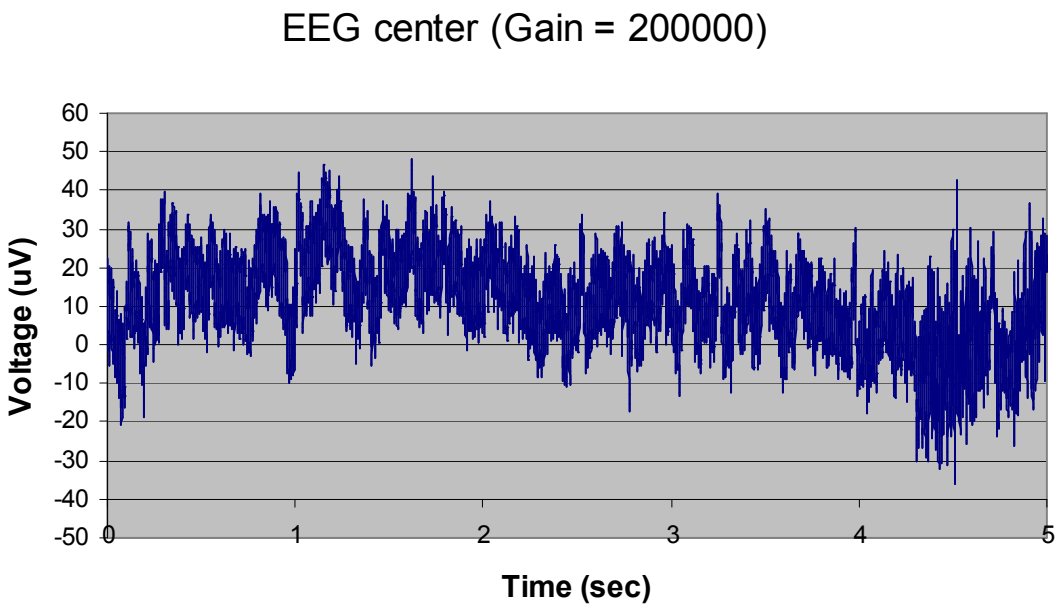


**Figure 5: EEG Center with Gain = 200000**

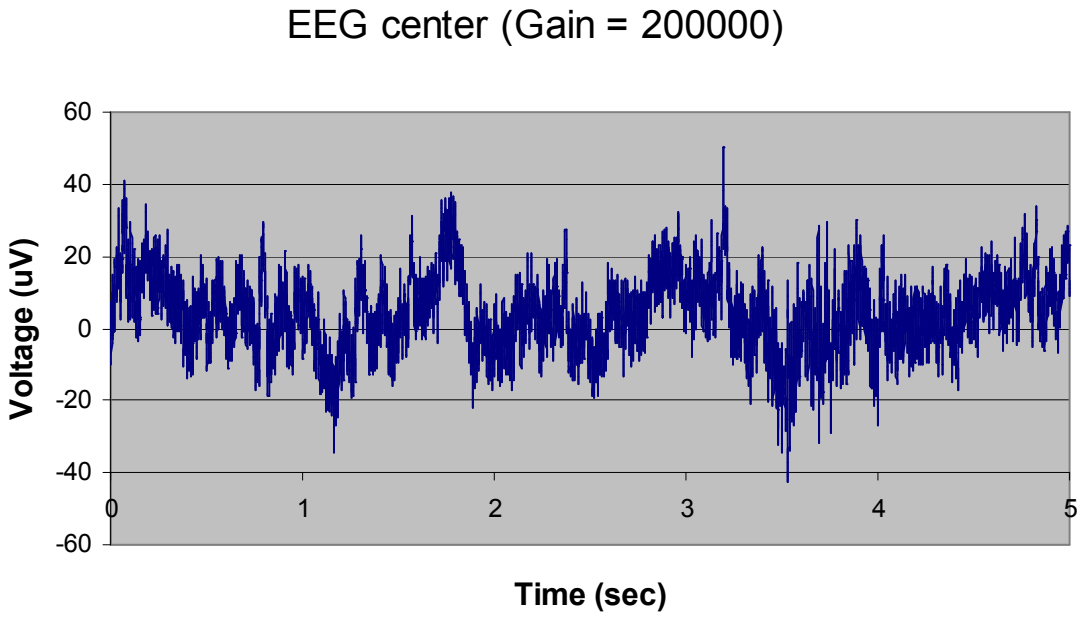


**Figure 6: EEG Center with Gain = 200000**

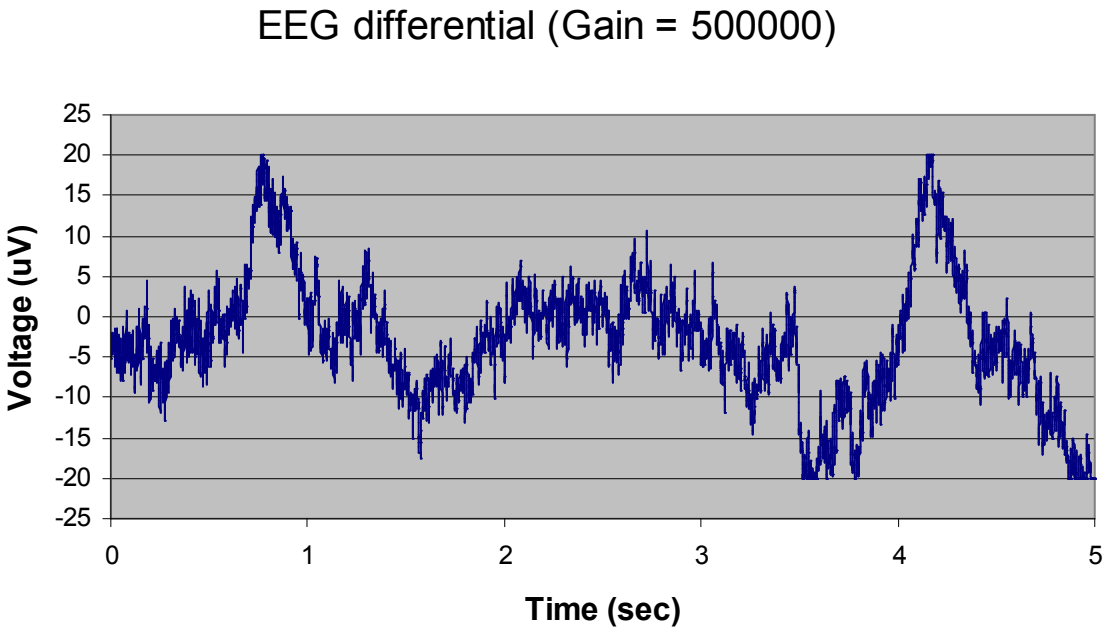


**Figure 7: EEG Differential with Gain = 500000**

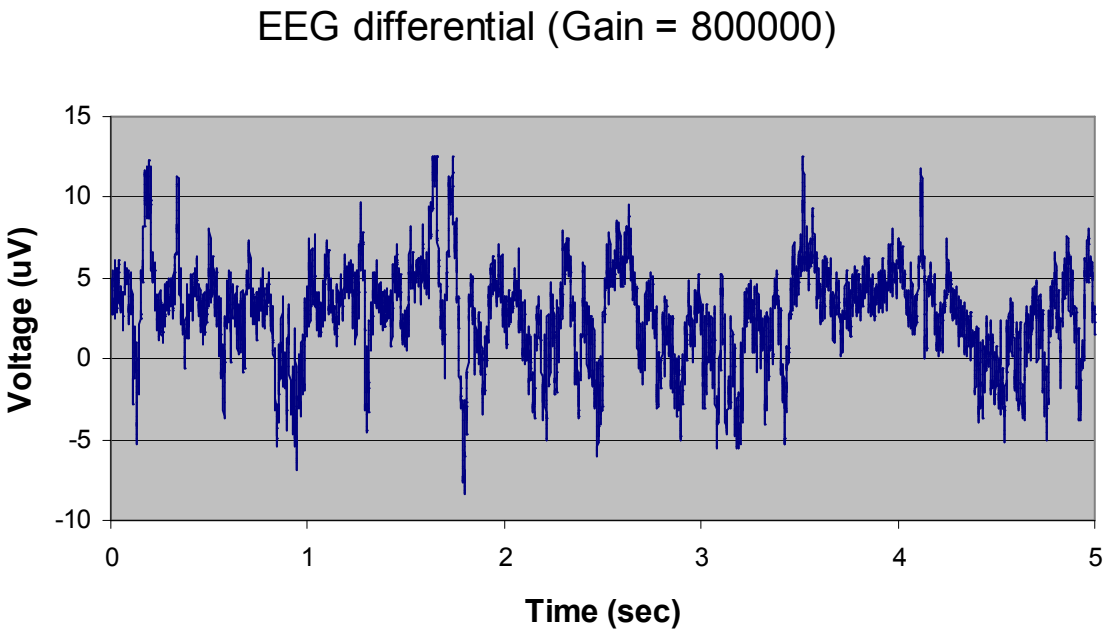


**Figure 8: EEG Differential with Gain = 800000**

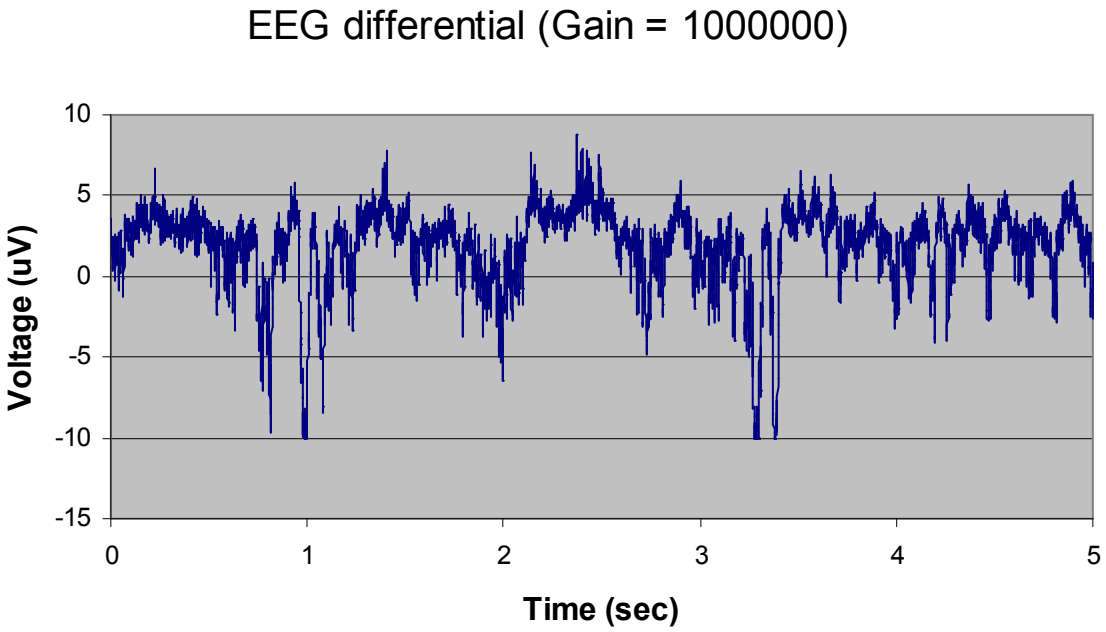


**Figure 9: EEG Differential with Gain = 1000000**

## 5.0 ELECTROMYOGRAM (EMG)

The electromyogram measures the electrical potential generated by muscle cells when the cells contract. The potential of this measurement ranges from .1-5 mV and between the frequencies dc-10,000 Hz. The mean frequency of muscle fatigue is approximately 200 Hz. There is a nonlinear relationship between the potential and the force of the contraction. The RMS amplitude of the signal is approximately equal to logarithm of the force of the contraction. The EMG can be used to detect problems and diseases such as Myasthenia Gravis, Muscular Dystrophy, and denervation of the muscle.

We did two tests, one where we contracted none, light, medium, and hard. These values are arbitrary but represent relaxation, 45° arm angle, 90° arm angle, and full tetanus contraction. These were the measurements we took before we read the requirements which indicated we need to use specific weights (which were not available in the lab). See Figure 10 and 11 below.

The other set of measurements we took involved a subject holding a weight for as long as they could at a 90° arm angle. We took several epochs of EMG data as they fatigued. Upon analyzing this data we recorded that the median frequency of the EMG was in fact decreasing due to decreases in muscle fiber conduction velocity as the muscle fatigued. See Figures 12-24.

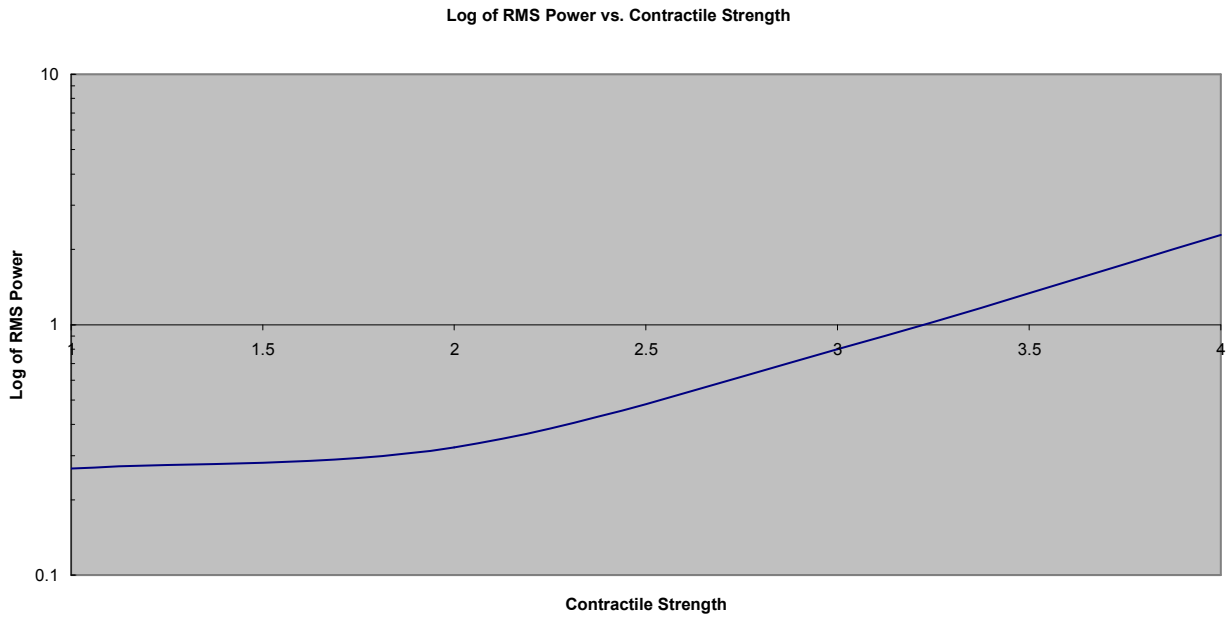


**Figure 10: Log of RMS Power vs. Contractile Strength**

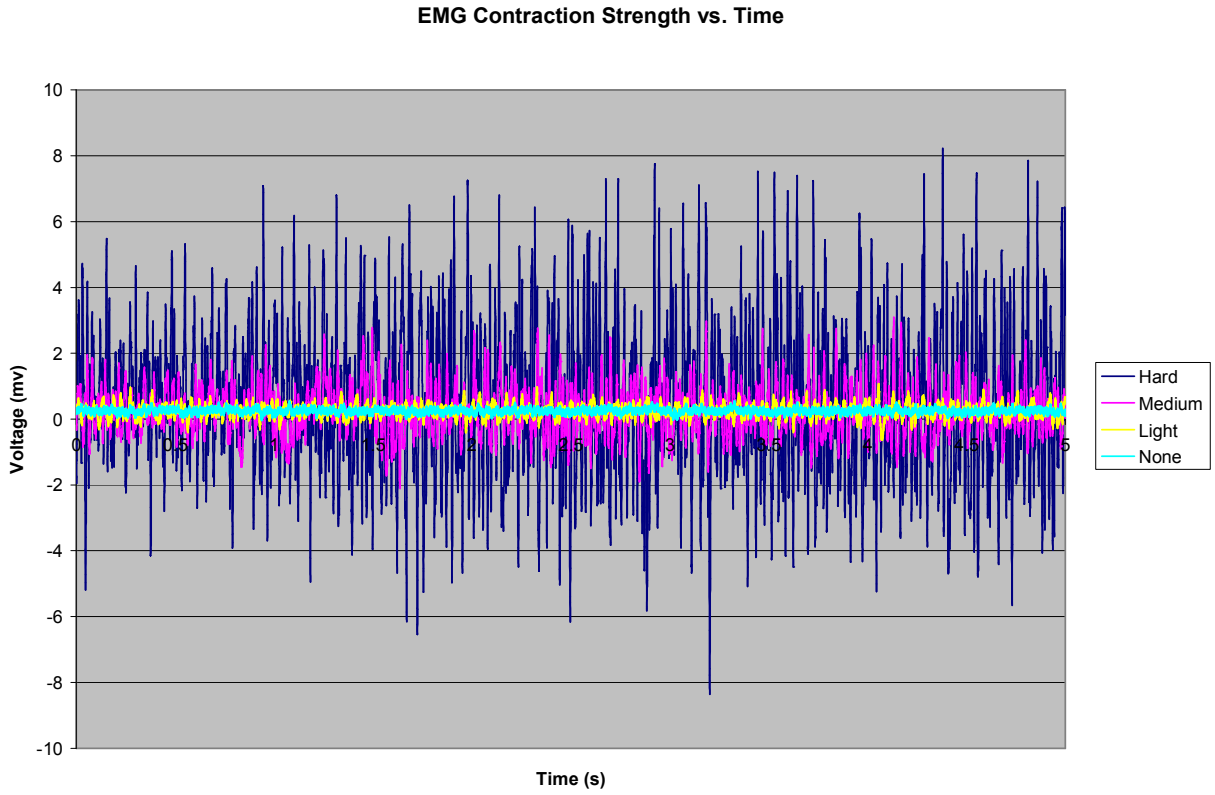


**Figure 11: EMG Contraction Strength vs. Time**

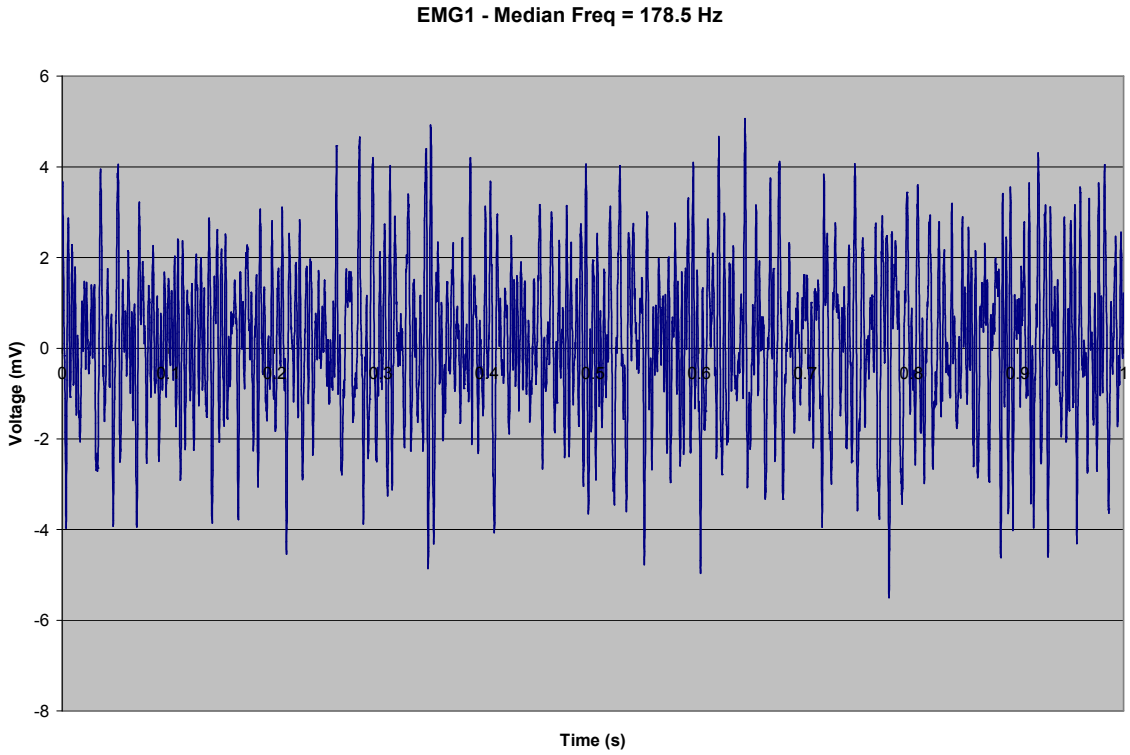


**Figure 12: EMG1 Median Frequency**

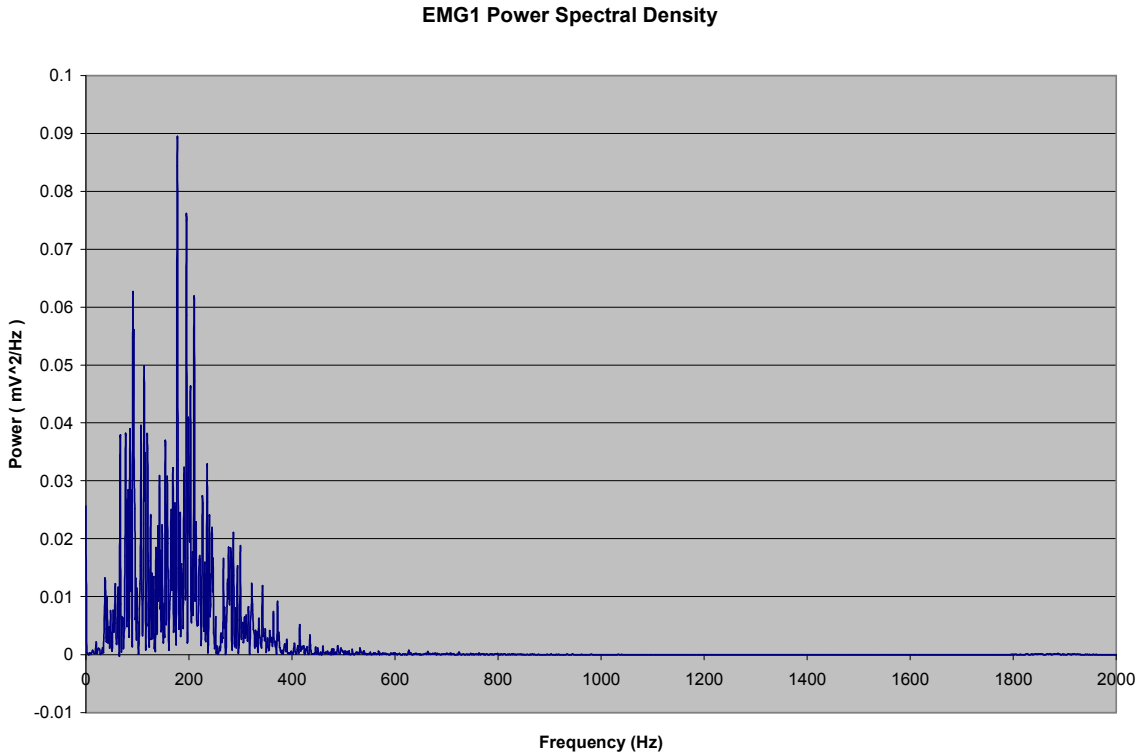


**Figure 13: EMG1 Power Spectral Density**

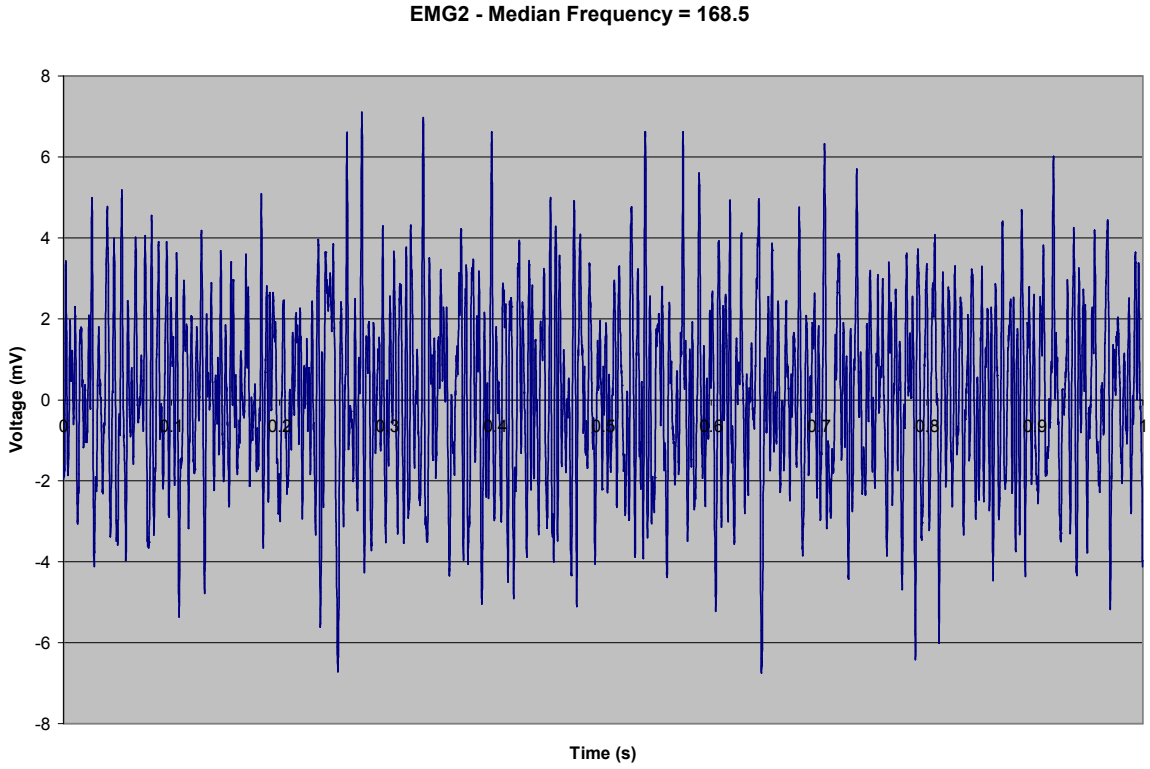


**Figure 14: EMG2 Median Freqency**

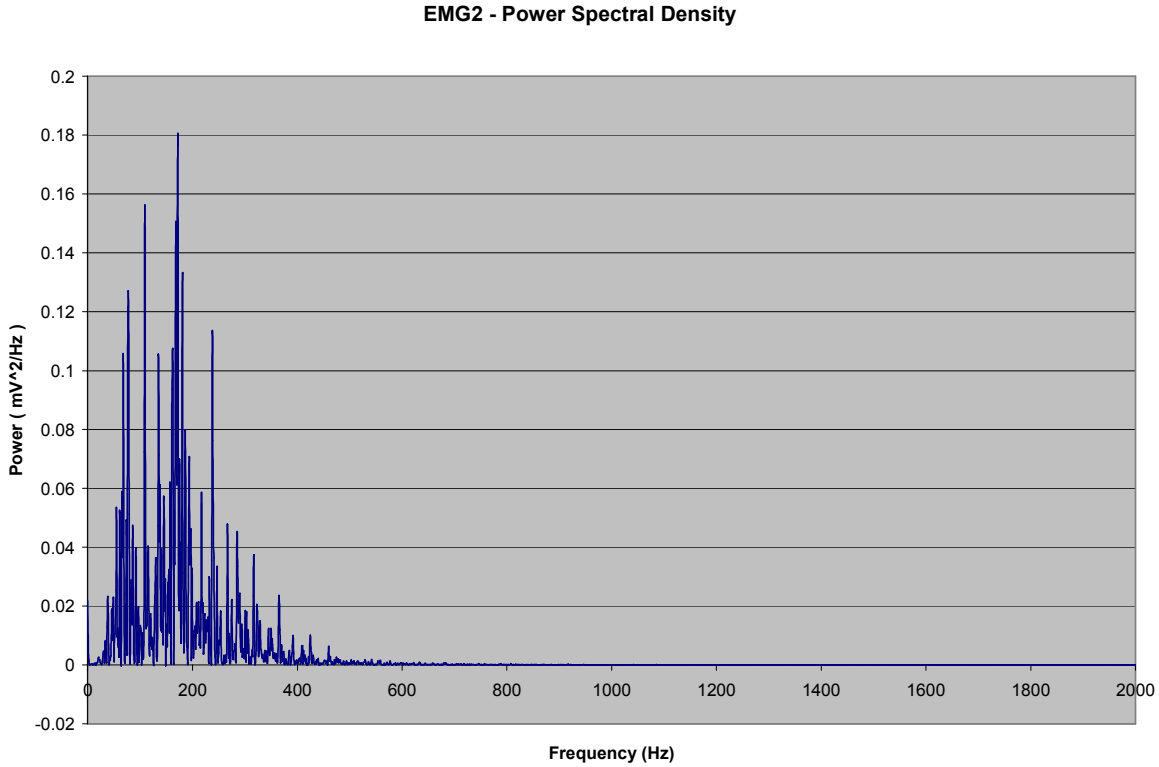


**Figure 15: EMG2 Power Spectral Density**

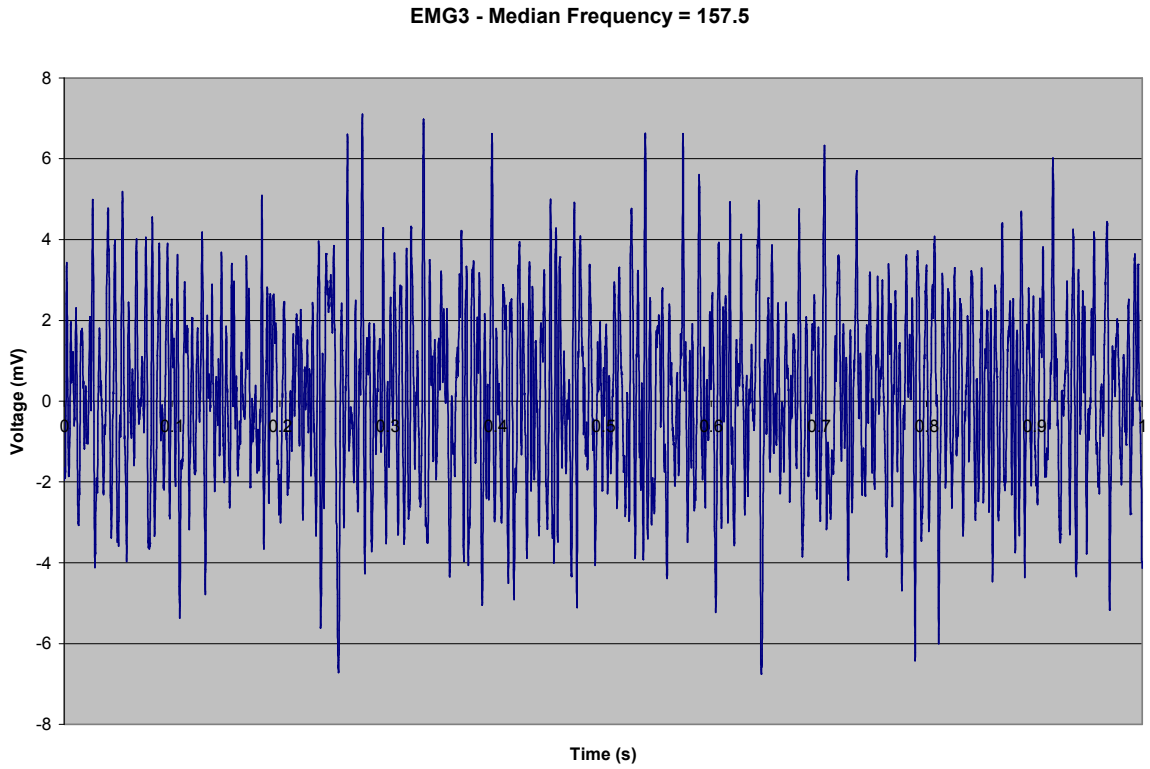


**Figure 16: EMG3 Median Frequency**

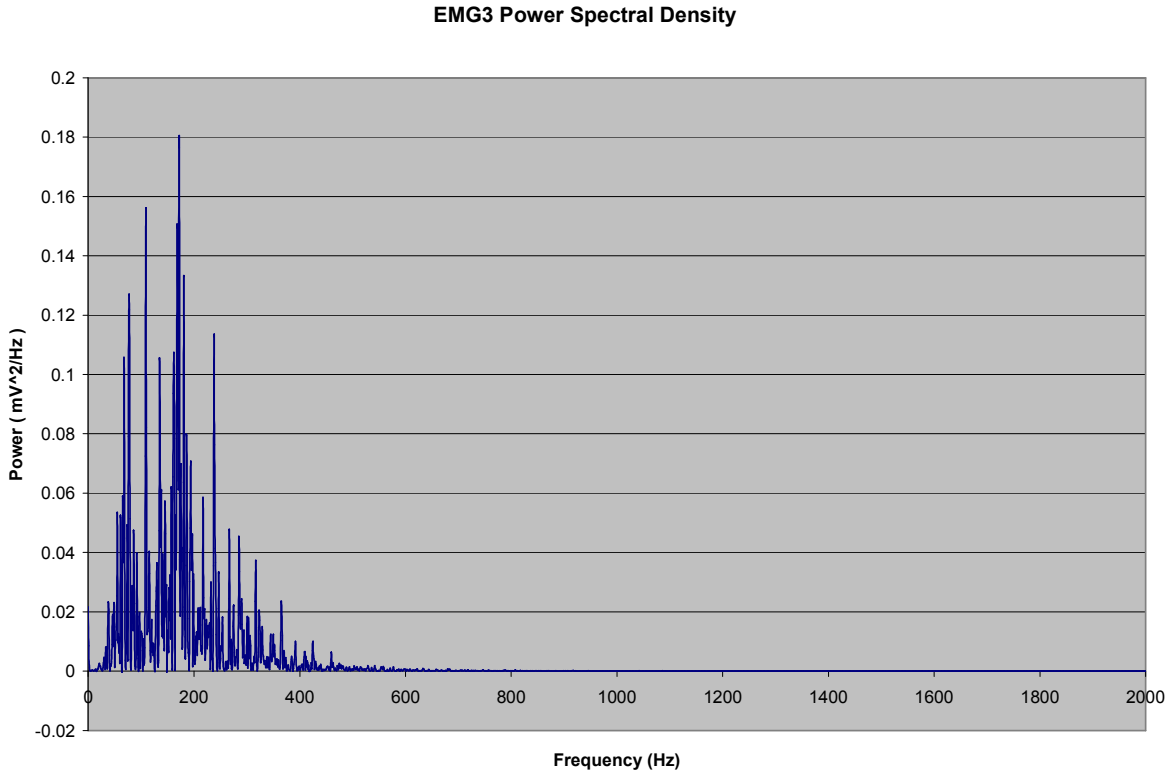


**Figure 17: EMG3 Power Spectral Density**

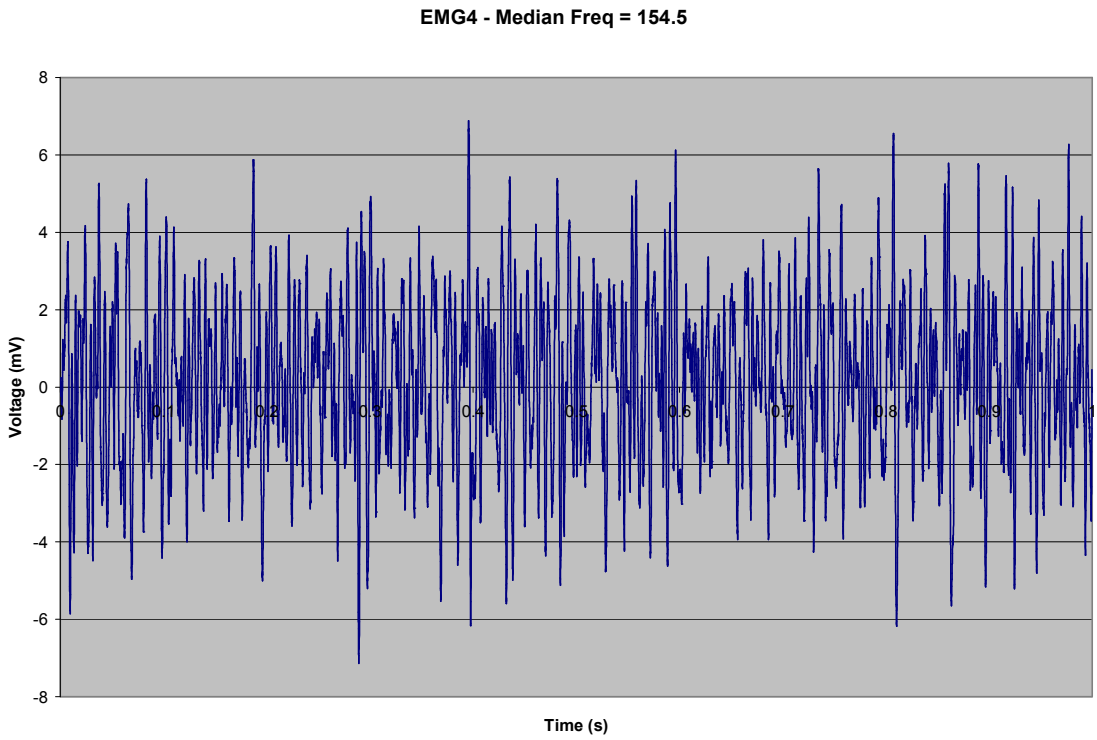


**Figure 18: EMG4 Median Frequency**

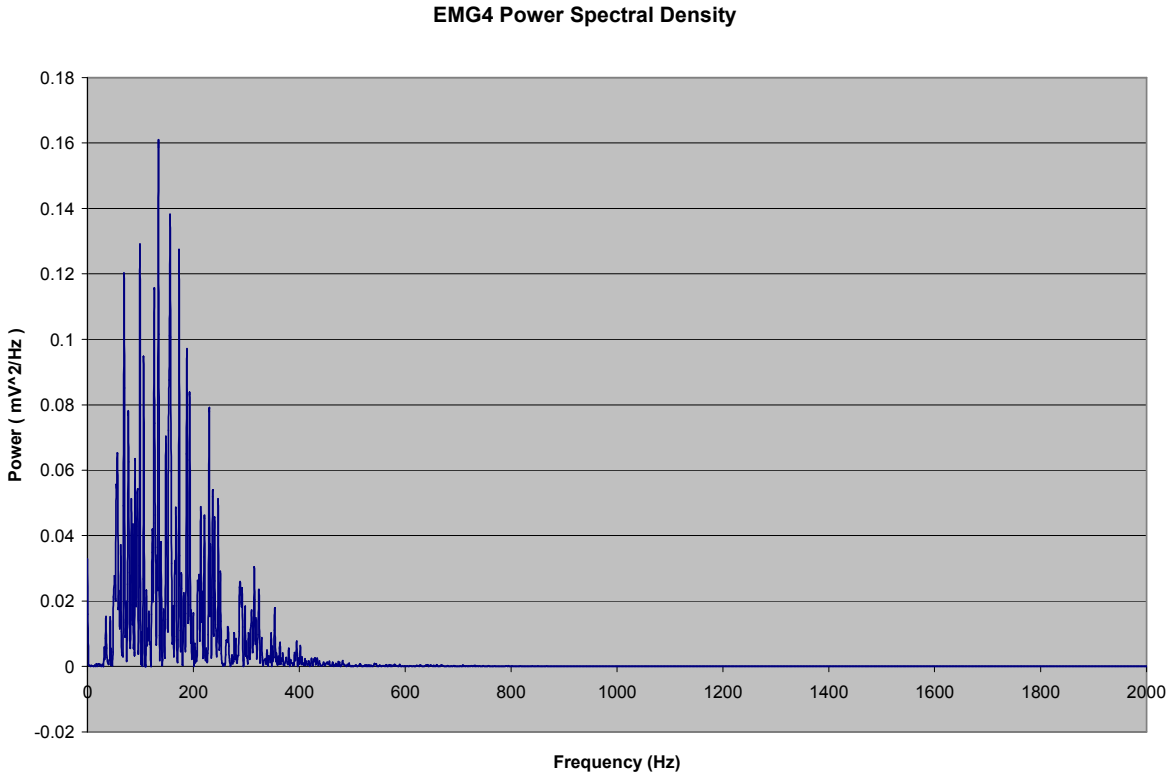


**Figure 19: EMG4 Power Spectral Density**

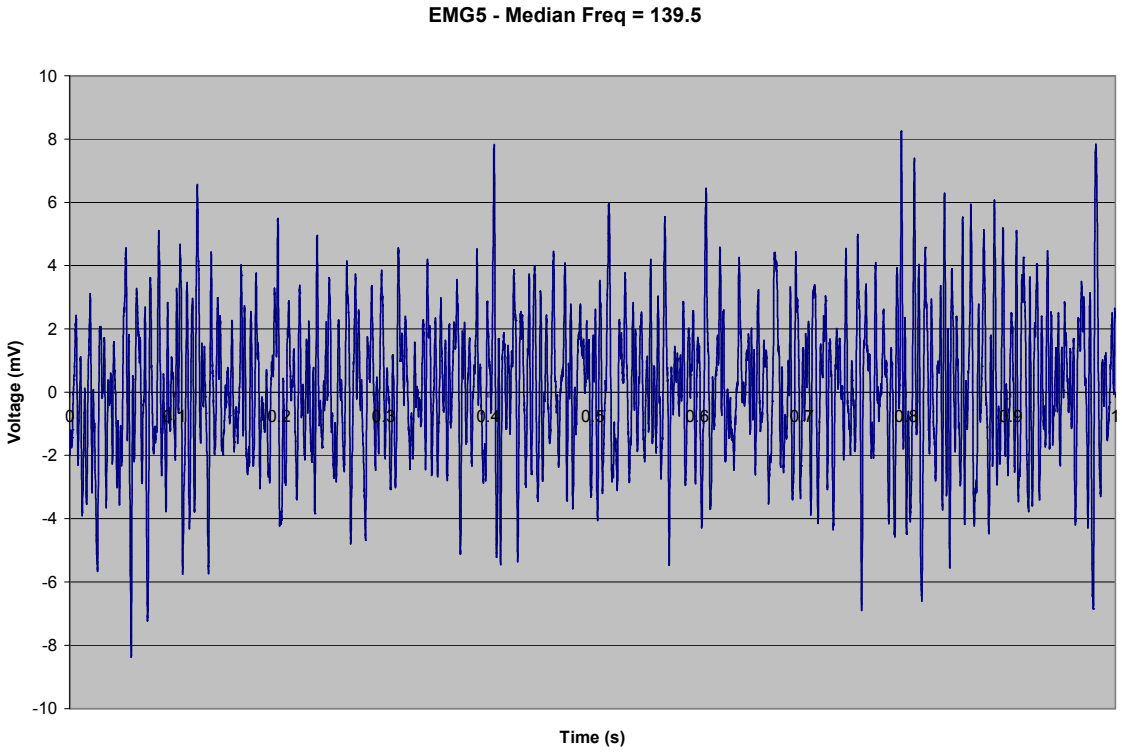


**Figure 20: EMG5 Median Frequency**

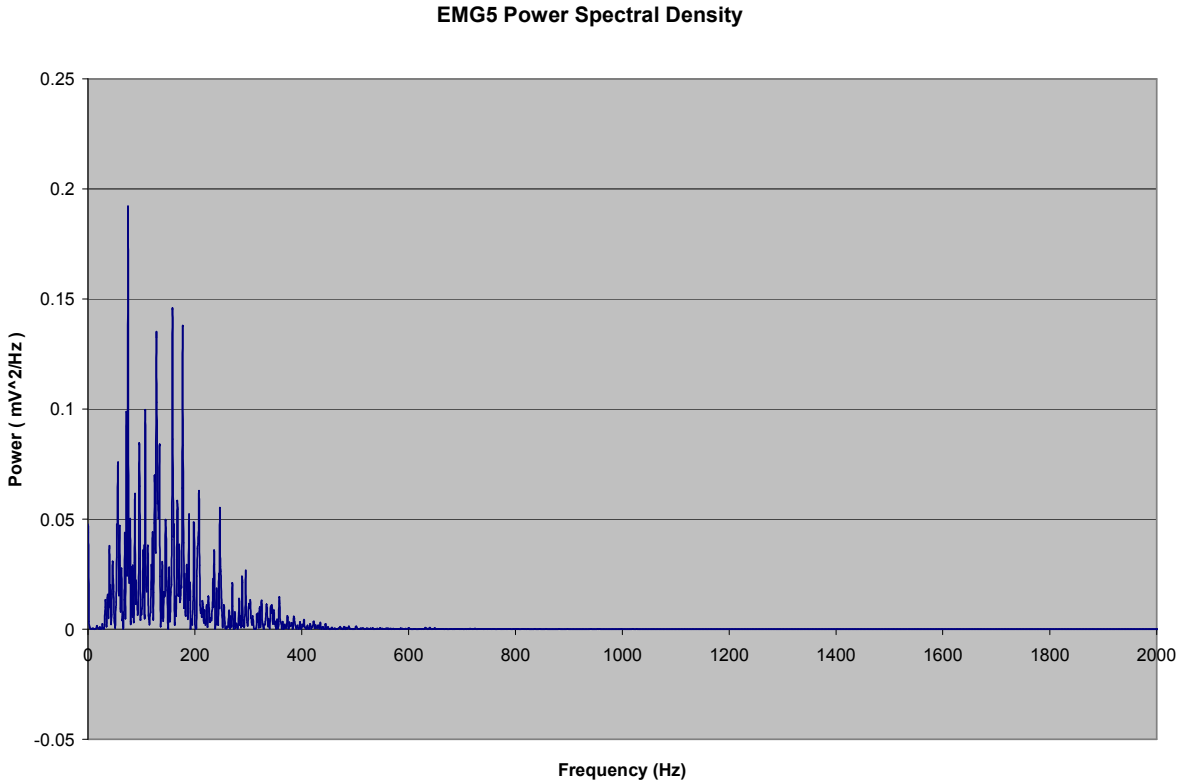


**Figure 21: EMG5 Power Spectral Density**

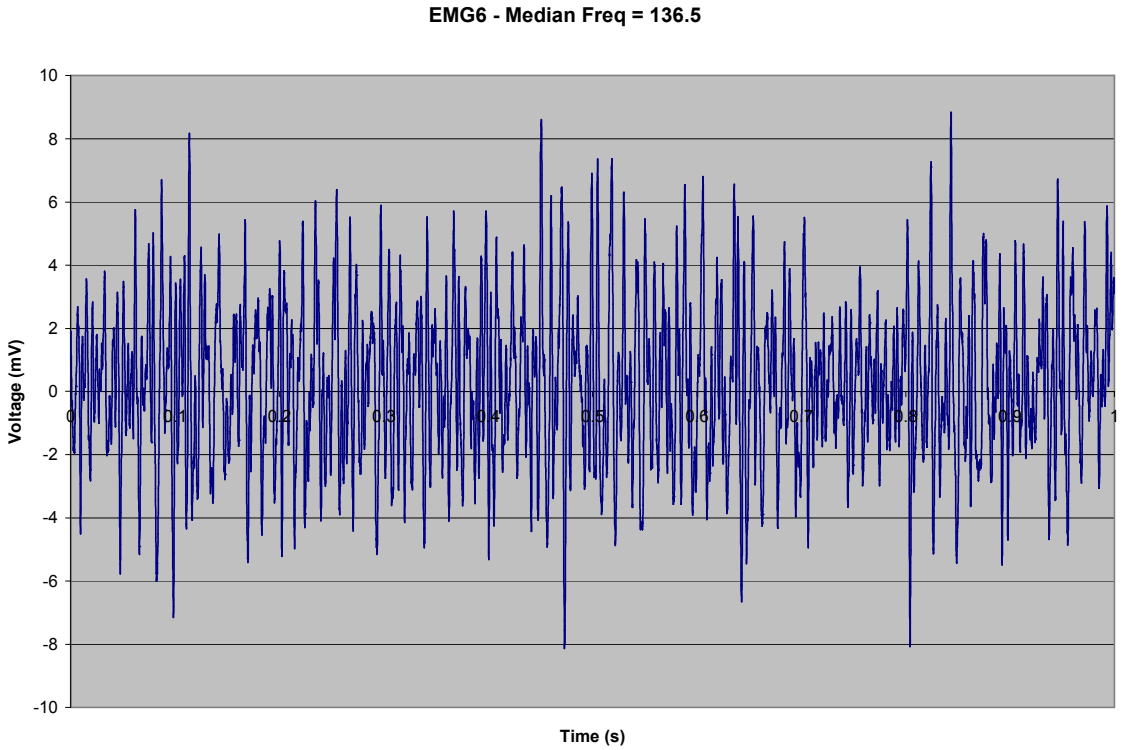


**Figure 22: EMG6 Median Frequency**

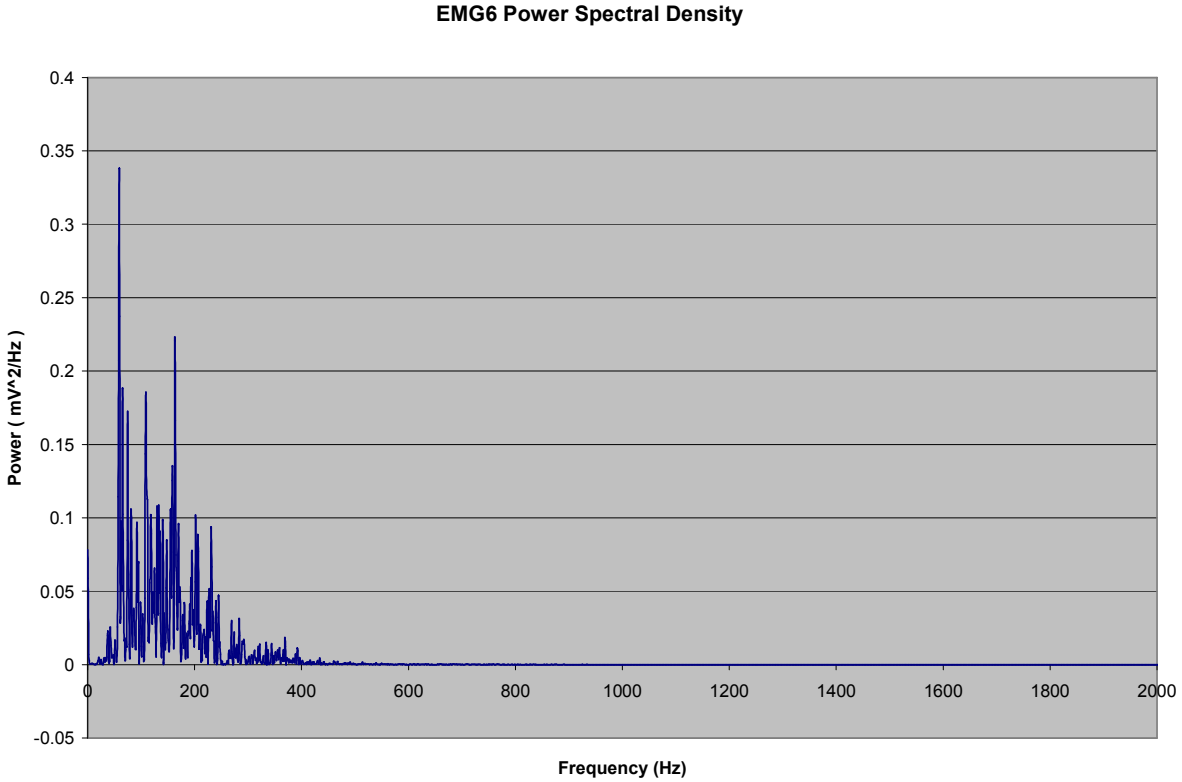


**Figure 23: EMG6 Power Spectral Density**

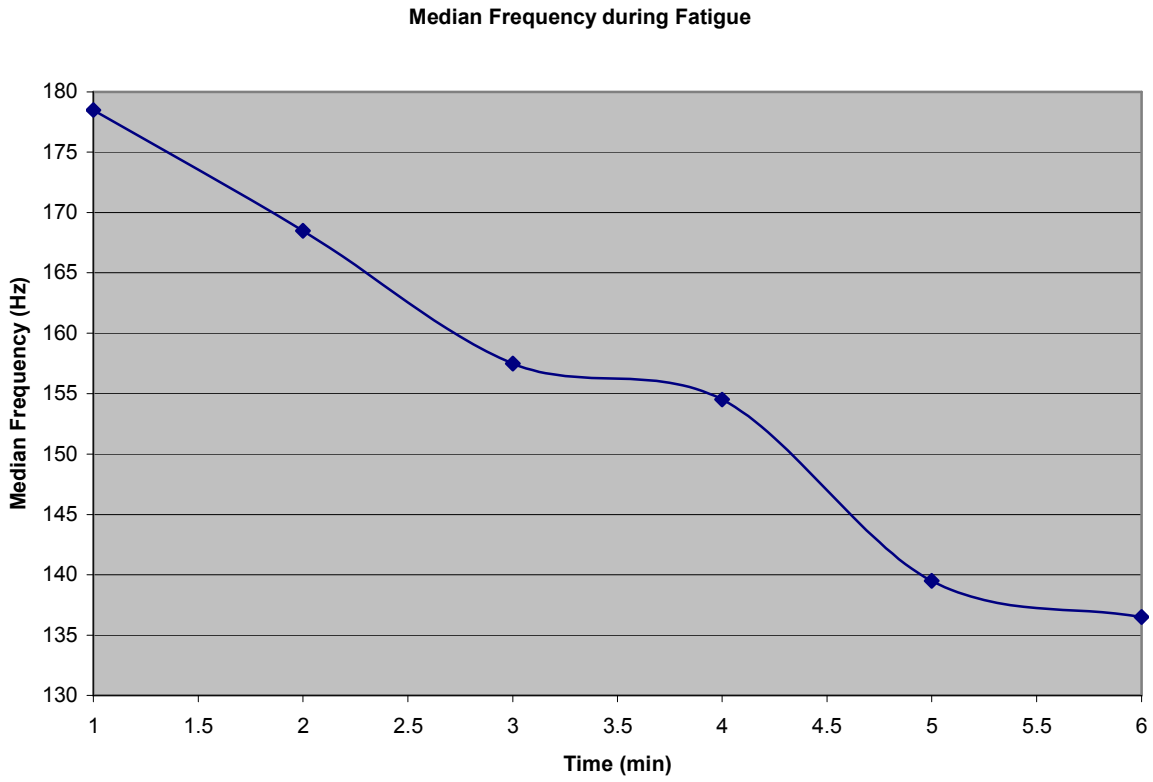


**Figure 24: Median Frequency During Fatigue**

## 6.0 ELECTROCARDIOGRAM (EKG)

The 12 Lead EKG measures biopotentials generated by the heart. It can diagnose quite a few problems with the heart including but not limited to right bundle branch block, left bundle branch block, hyperkalemia, myocardial ischemia, and myocardial infarction. Heart problems are the cause of a large portion of deaths in the United States and the EKG is a vital tool for diagnosing heart problems.

The twelve leads for the 12 Lead EKG measurement are as follows: Lead I, Lead II, Lead III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6. Each of these signals together gives a lot of information. It can successfully diagnose all of the heart conditions listed above. Driven ground is always placed on the right leg when taking measurements for the 12 Lead EKG. Lead I, II, and III are measured by place electrodes on your right arm, left arm, and left leg. The rest of the

measurements are recorded by running the negative input of the biopotential amplifier through a wire that is connected to variations of the right arm, left arm, and/or left leg. They give more detailed information of the dipole generated by cardiac contractions.

There signal recorded from the EKG measurement can be seen as a culmination of several waves. It is generally referred to as the PQRST complex. Here is a summary of the PQRST complex for the lay person. The P wave initiates the depolarization of the atrium which pushes blood into the ventricles. The QRS complex initiates of the contraction of the ventricles which to the contraction of the ventricles. This causes the heart to actually pumped blood to the lungs and body. The T wave is the repolarization of the entire heart so it can contract again. This happens over and over the entire time a human is alive.

Matthew – EKG:

The T-wave is a little large on my Lead I measurement. The T-wave is non-existent on my Lead III measurement. These do not seem like to be listed as symptoms of heart problems however. The morphology of the rest of my "12 Lead EKG" looks mostly normal. Any other slight discrepancies are most likely due to the slightly inaccurate placement of the V1-V6 leads. These leads are the most difficult to place correctly. The signals do look pretty noisy, but it seems pretty easy to observe all of the normal features one would expect to be present. The final conclusion is that I have a healthy heart and hopefully I am correct.

Shea – EKG

My Lead I and Lead II measurements look pretty good. The Lead III measurement does not have a depression after the QRS complex. It does not appear that this is a symptom of any of the heart problems we have studied. The remaining measurements for the 12 Lead EKG were slightly noisy and did not look exactly as they are supposed to. I believe this was due to the placement of the electrodes for these measurements. Overall, my EKG measurements look pretty normal.

Nathan – EKG:

Most of my lead measurements look pretty good. Several of the measurements are obscured by noise due to an undetected disconnect of power supply decoupling capacitors as noted in the introduction. Lead III is particularly overcome by noise. This error has since been fixed, but we did not have time to take more data. My Lead I, Lead II, and aVF display an elevated ST segment characteristic of low-level ischemia. However, the other leads fall within expectations for a normal morphology.

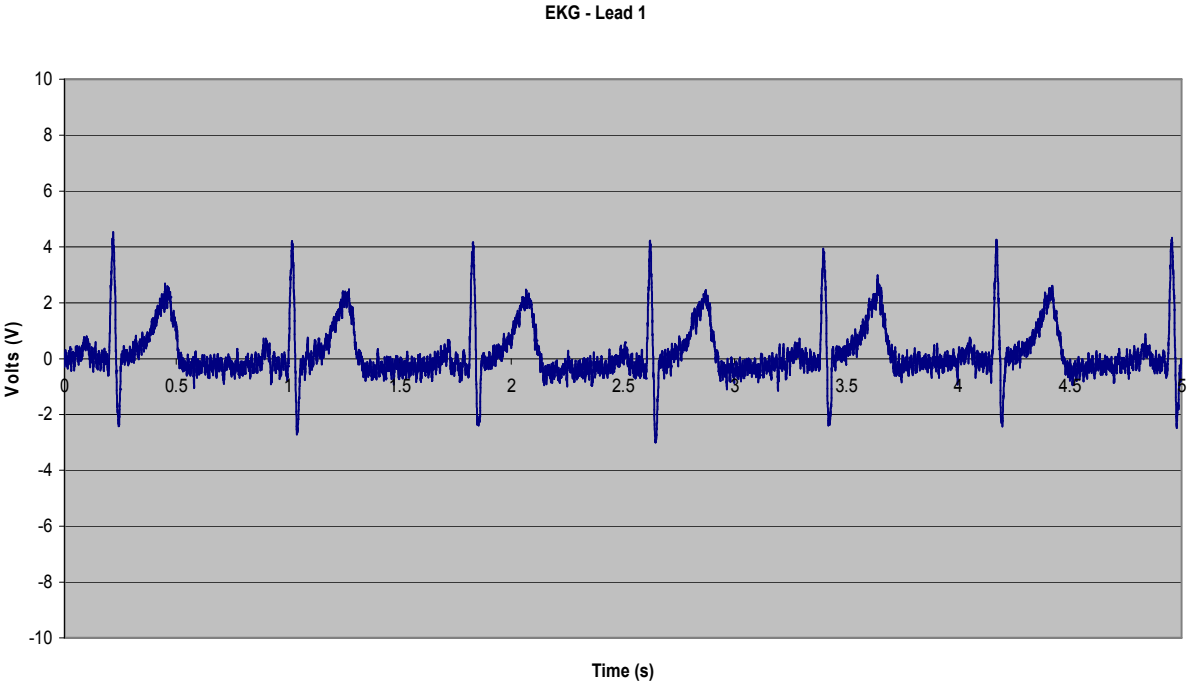


**Figure 25: Matt - EKG Lead I**

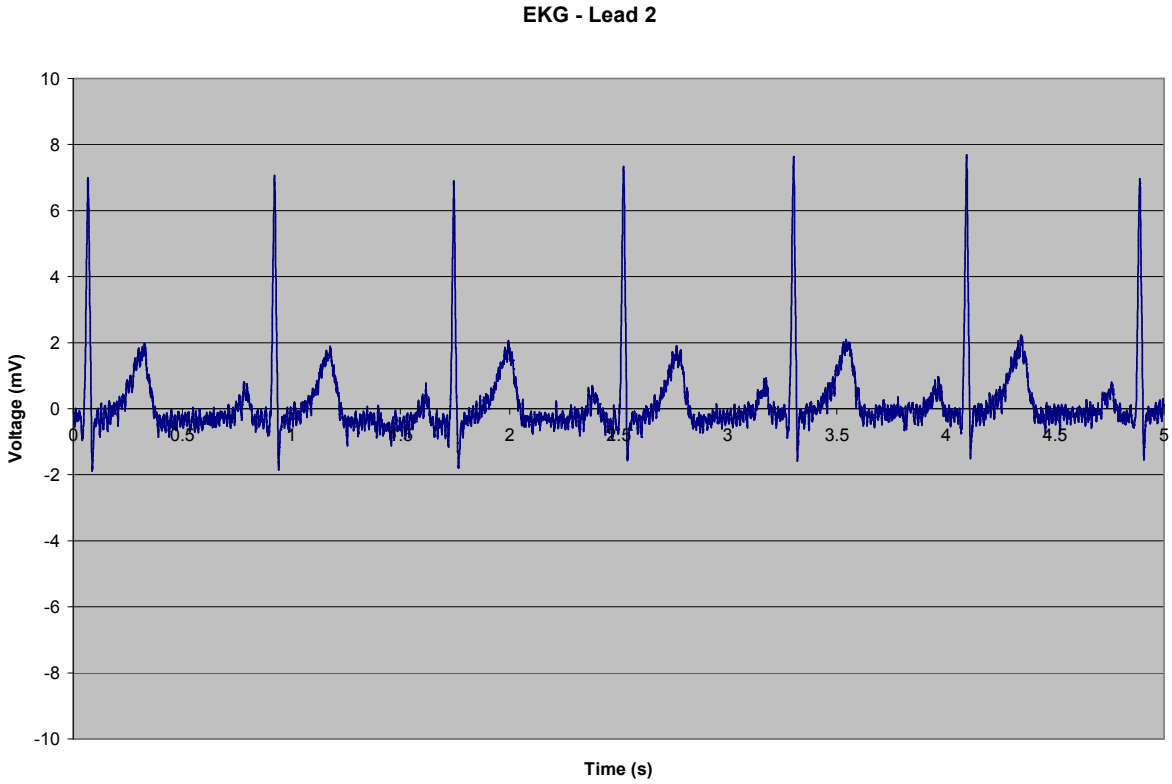


**Figure 26: Matt - EKG Lead II**

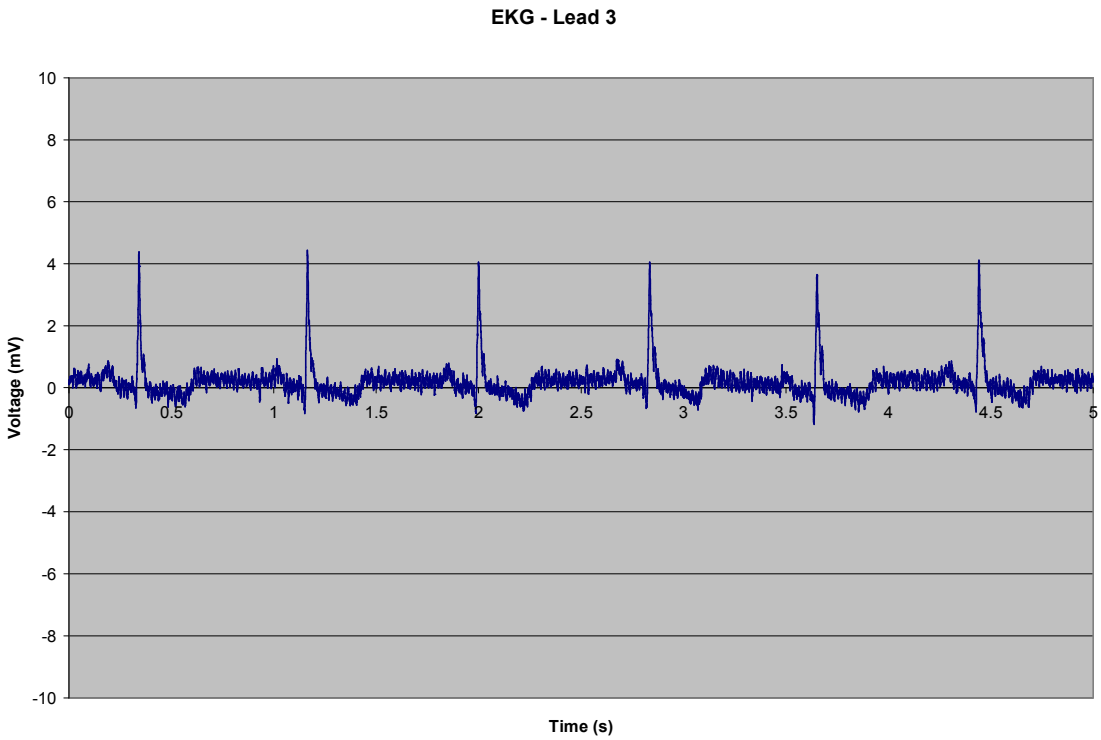


**Figure 27: Matt - EKG Lead III**

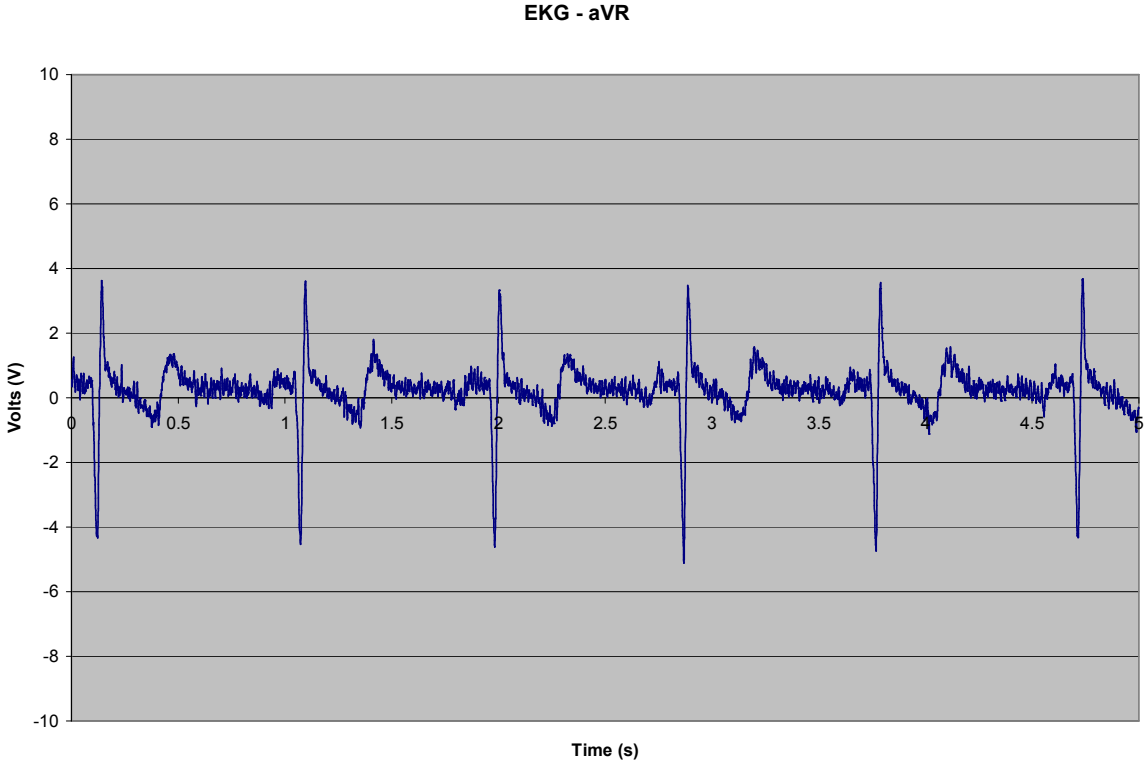


**Figure 28: Matt - EKG aVR**

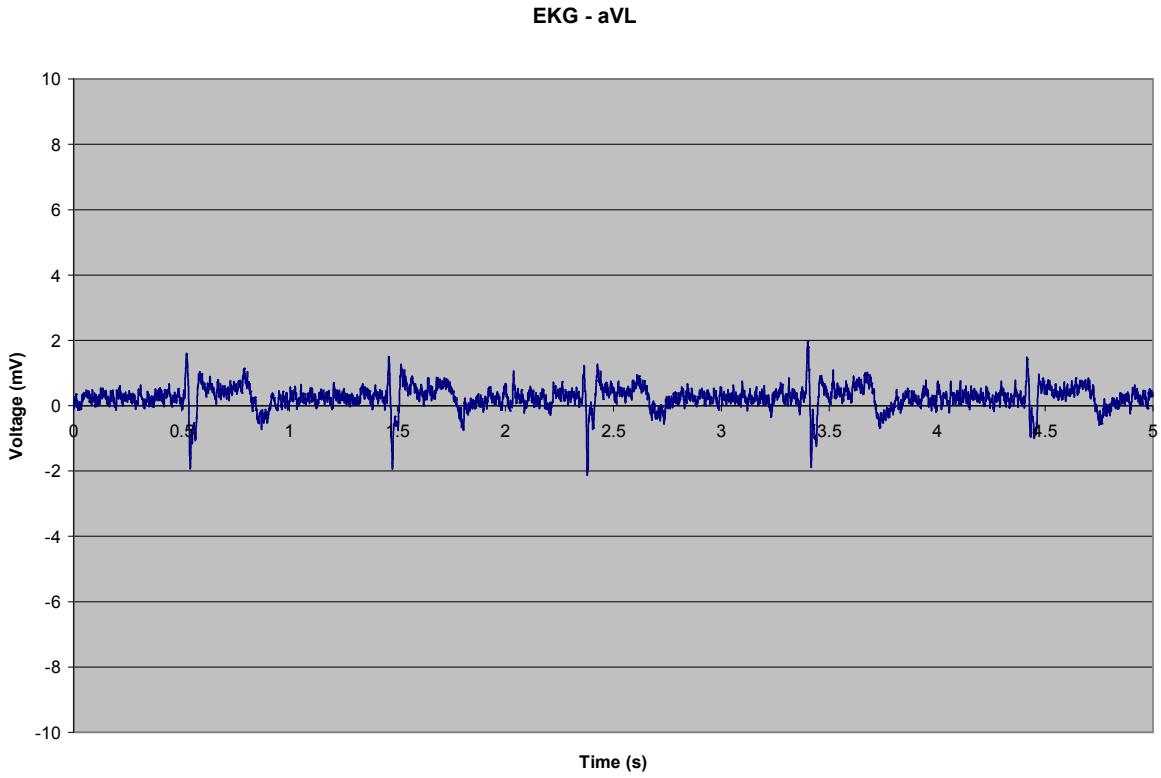


**Figure 29: Matt - EKG aVL**

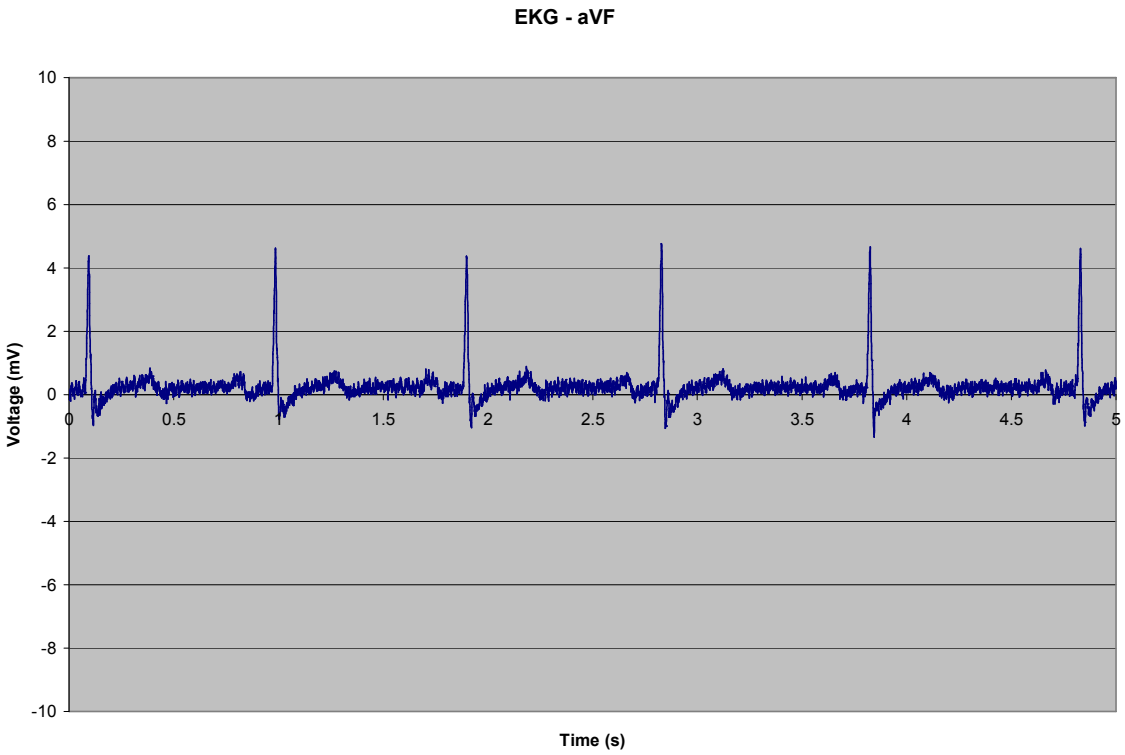


**Figure 30: Matt - EKG aVF**

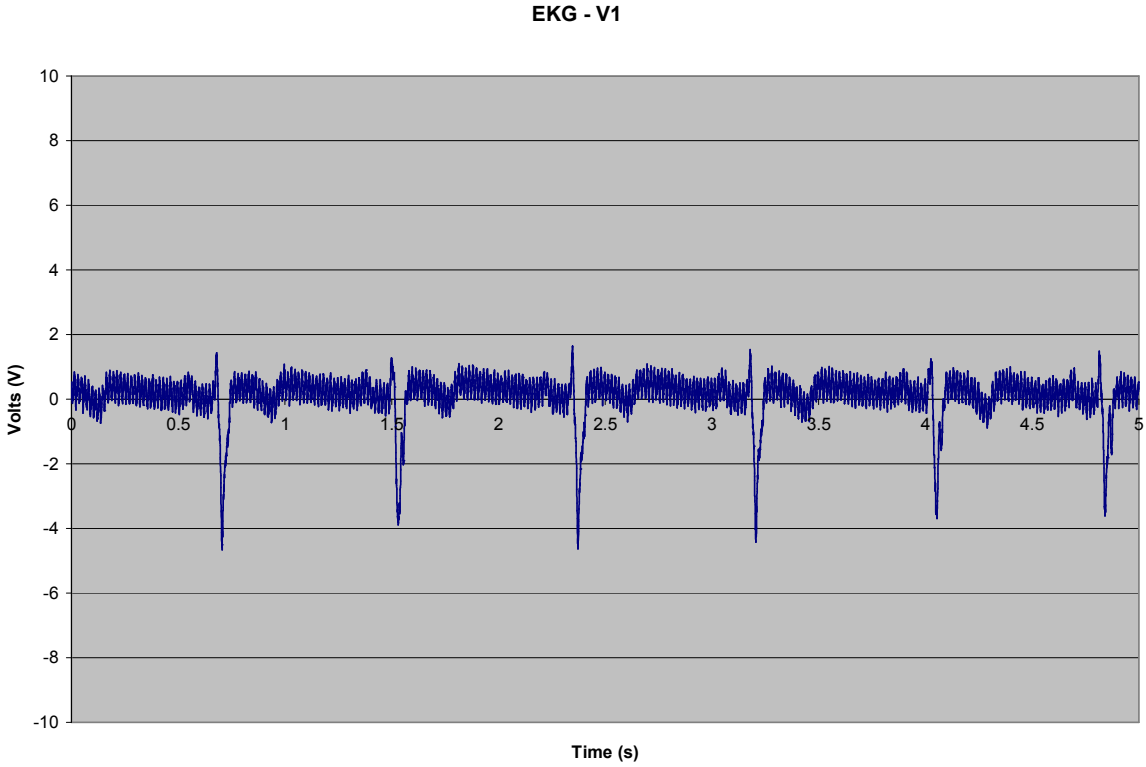


**Figure 31: Matt - EKG V1**

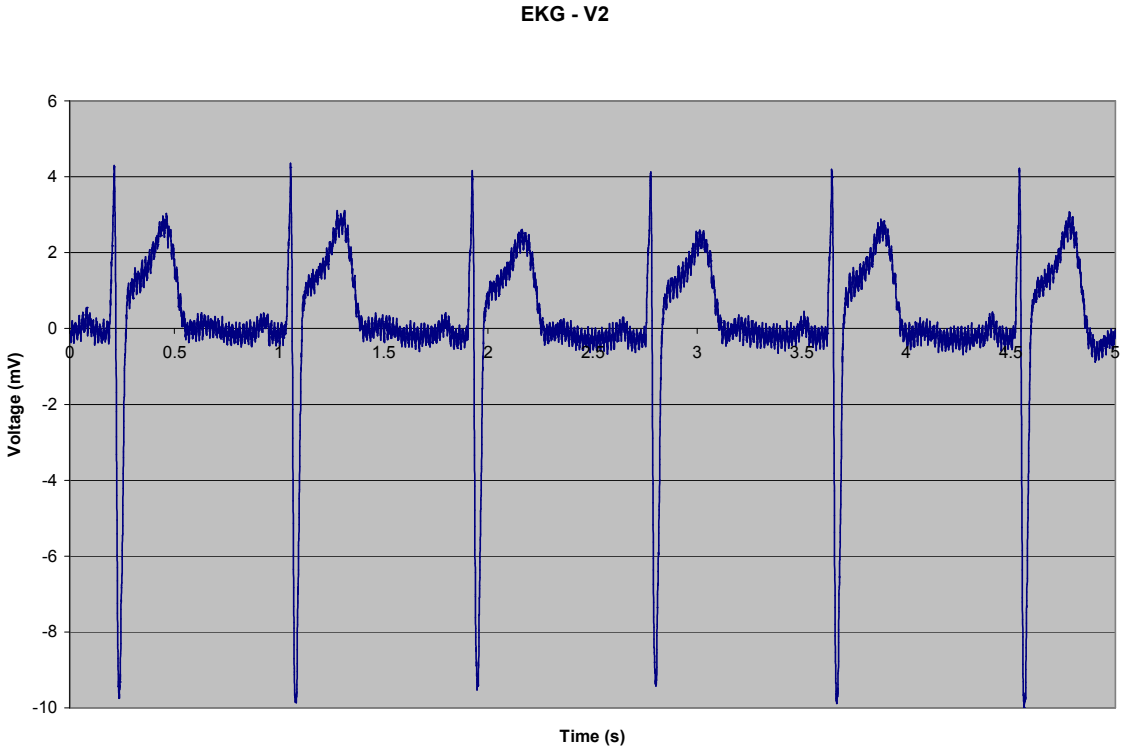


**Figure 32: Matt - EKG V2**

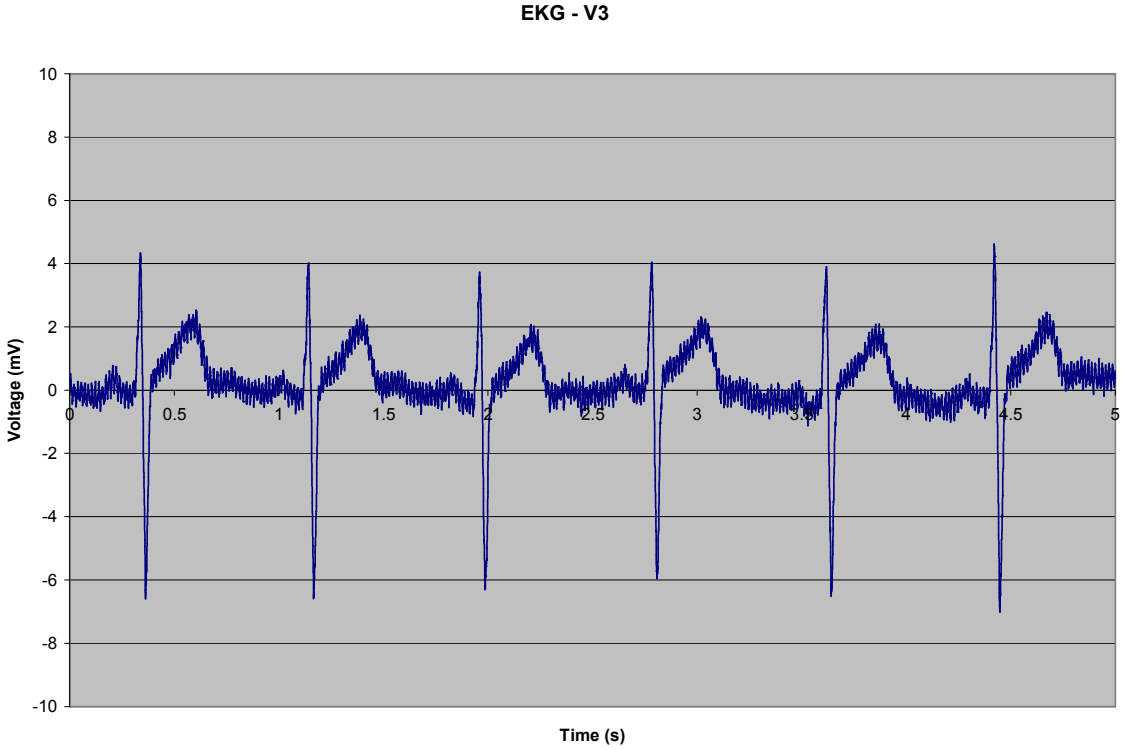


**Figure 33: Matt - EKG V3**

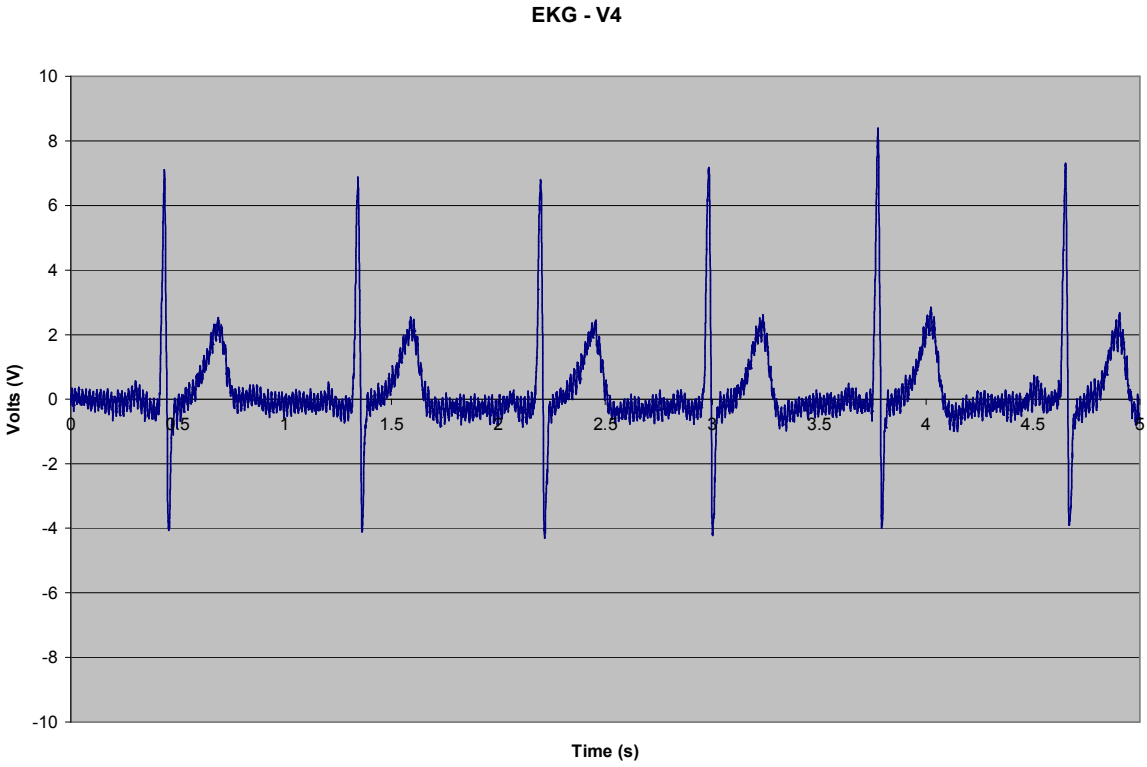


**Figure 34: Matt - EKG V4**

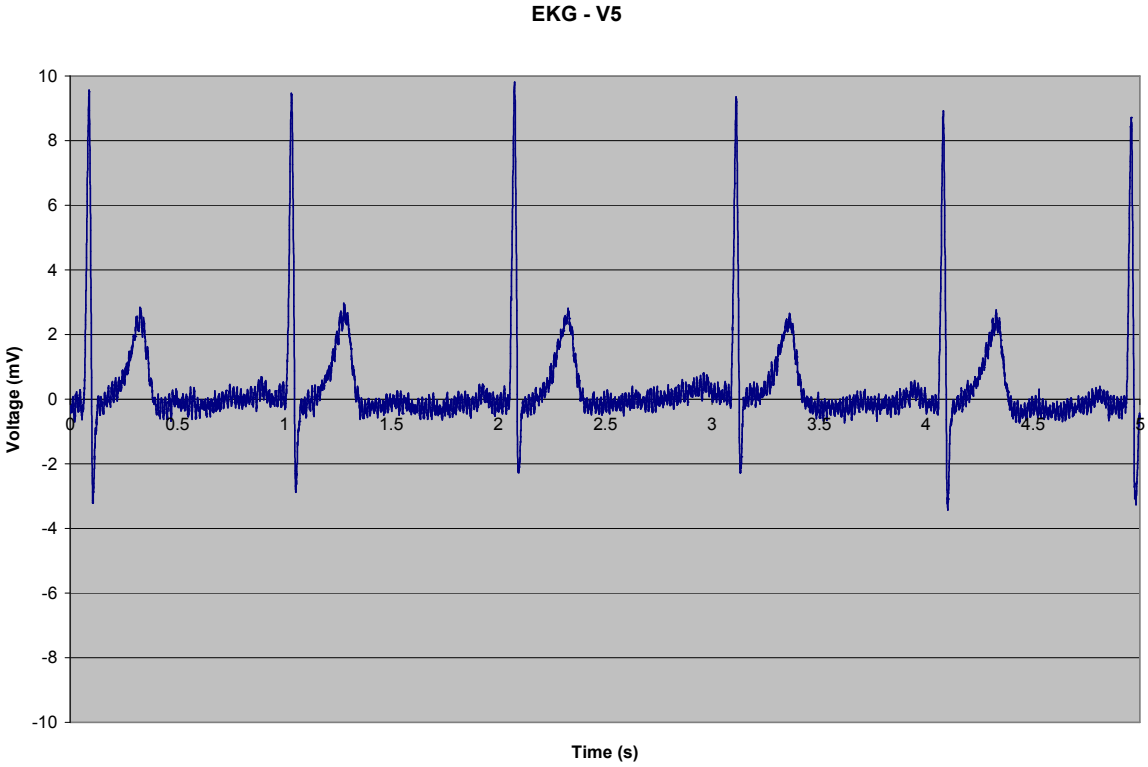


**Figure 35: Matt - EKG V5**

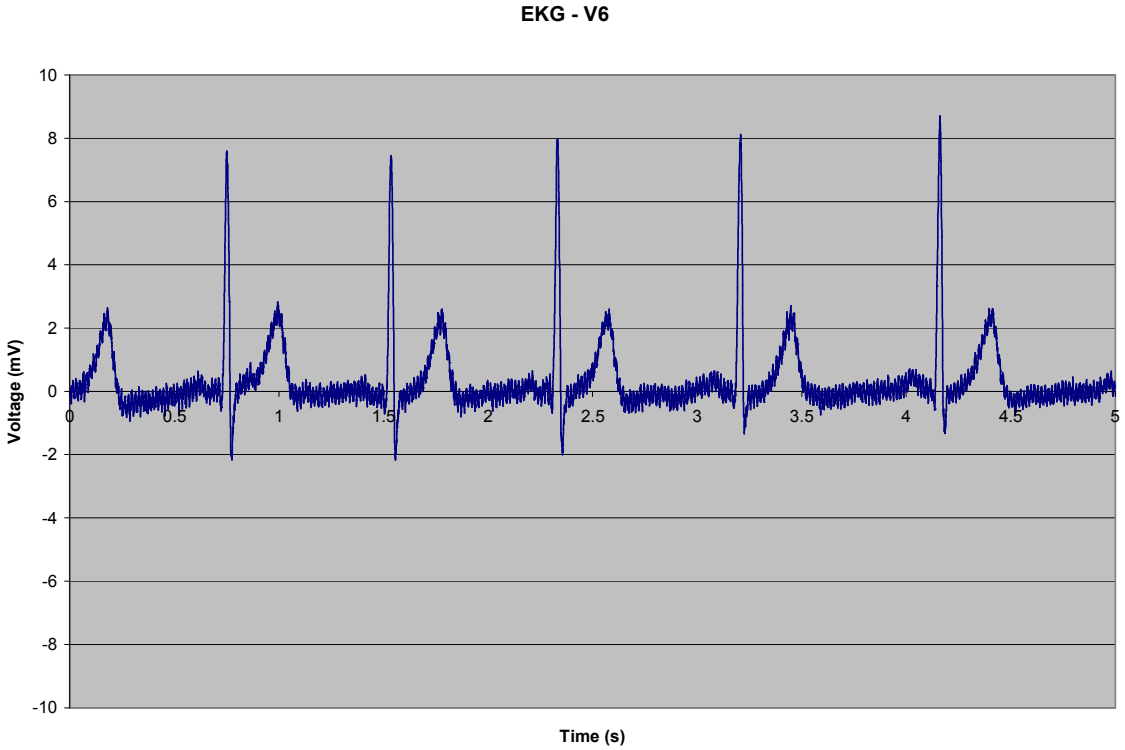


**Figure 36: Matt - EKG V6**

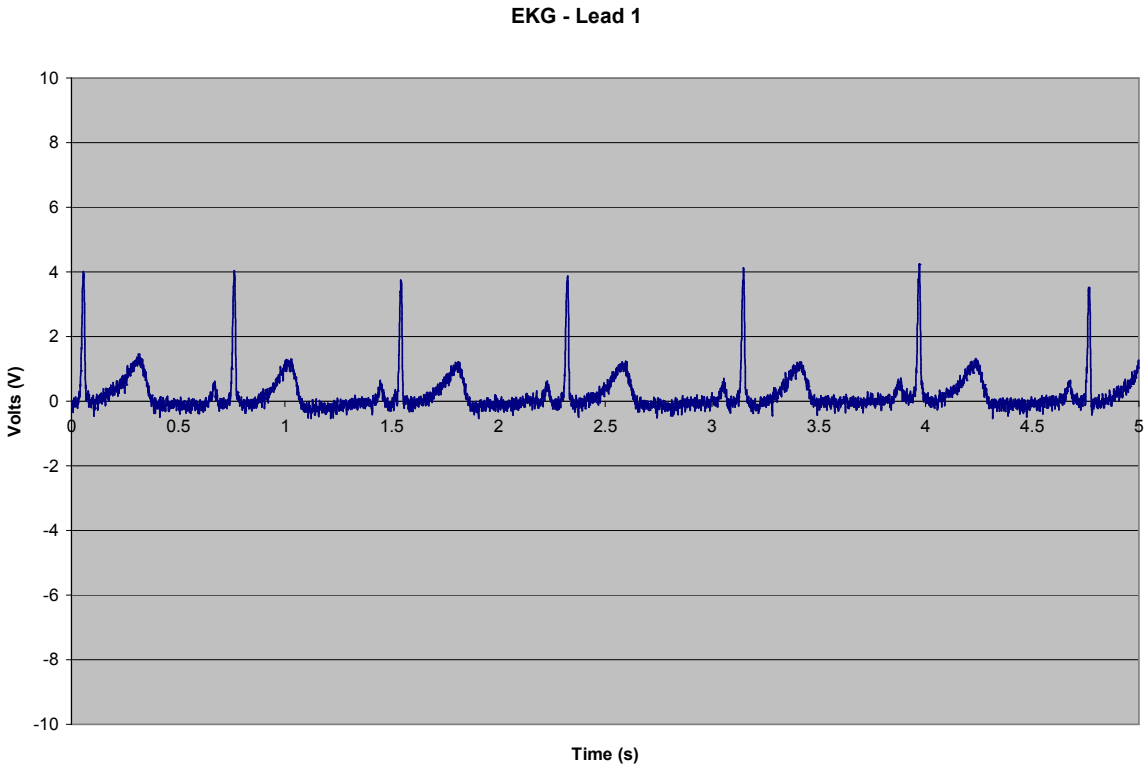


**Figure 37: Shea - EKG Lead I**

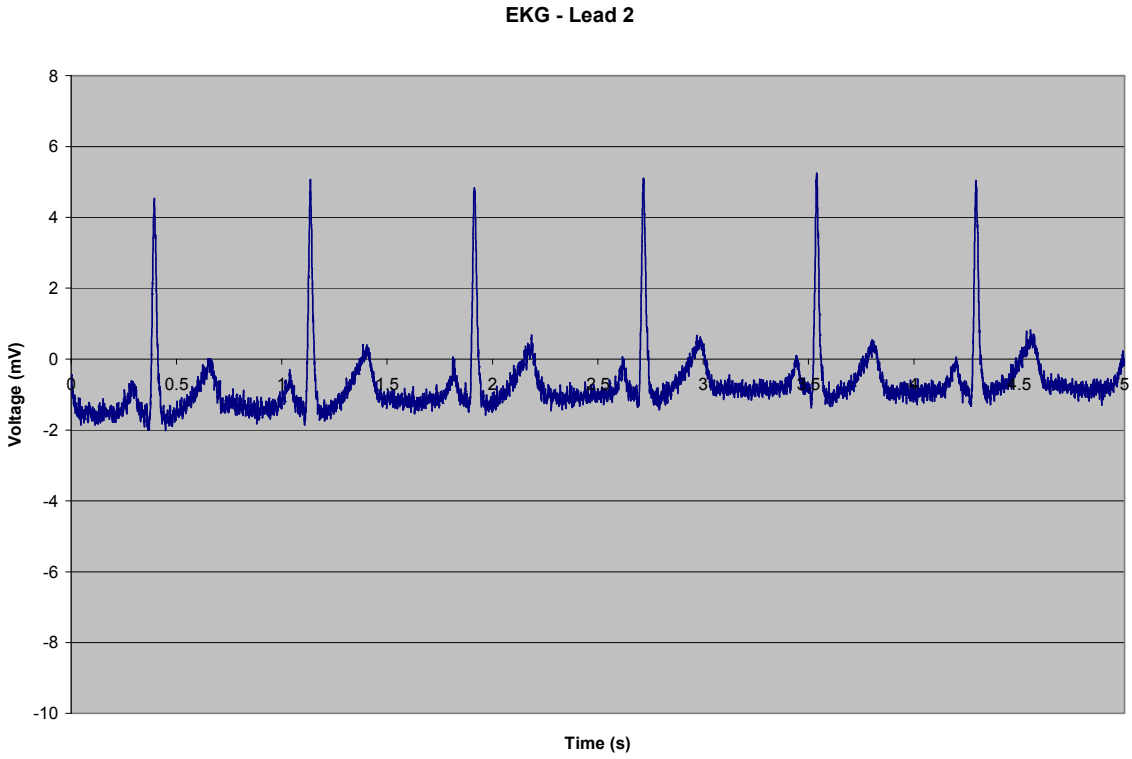


**Figure 38: Shea - EKG Lead II**

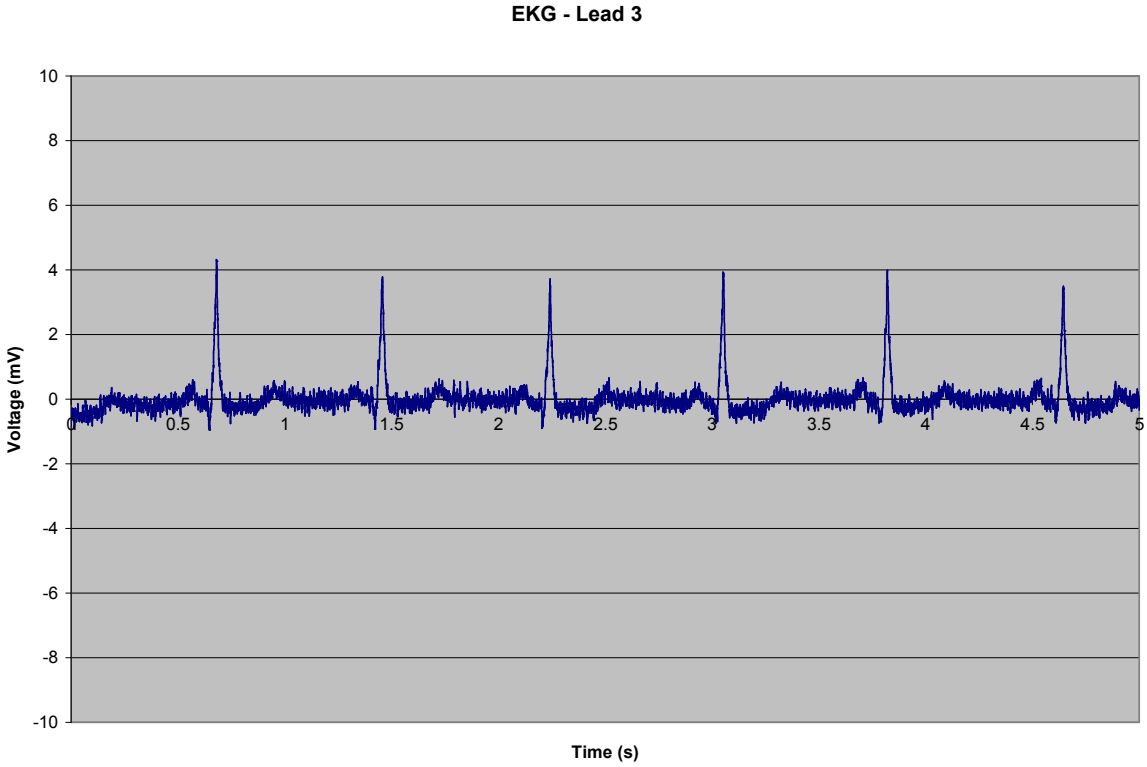


**Figure 39: Shea - EKG Lead III**

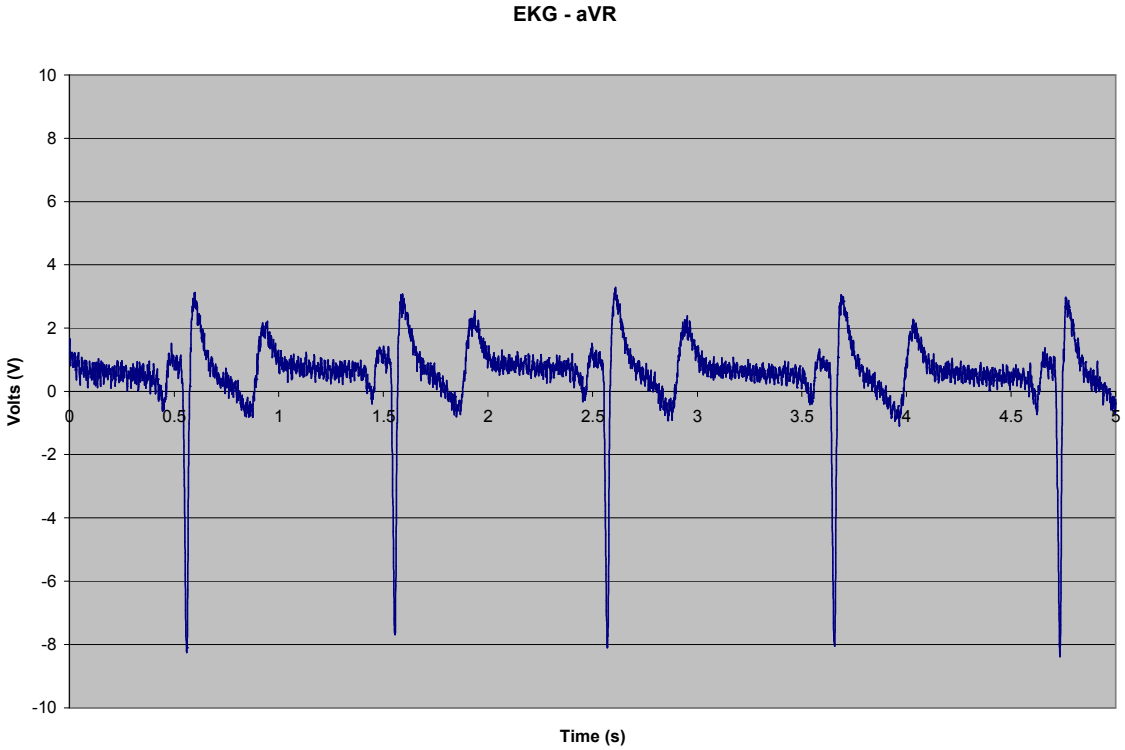


**Figure 40: Shea - EKG aVR**

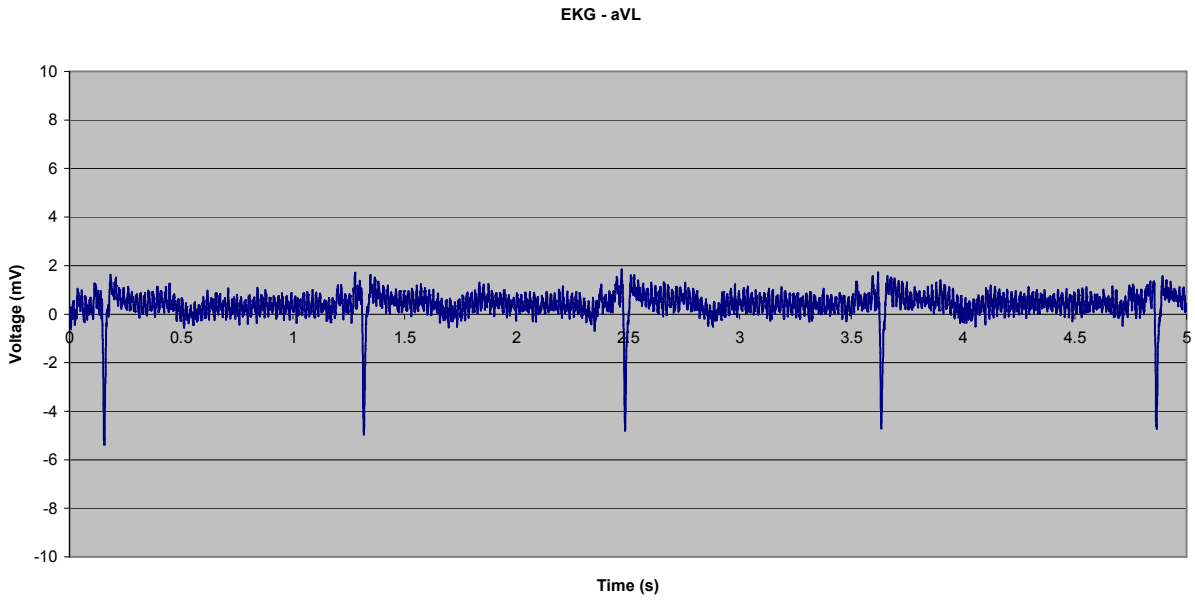


**Figure 41: Shea - EKG aVL**

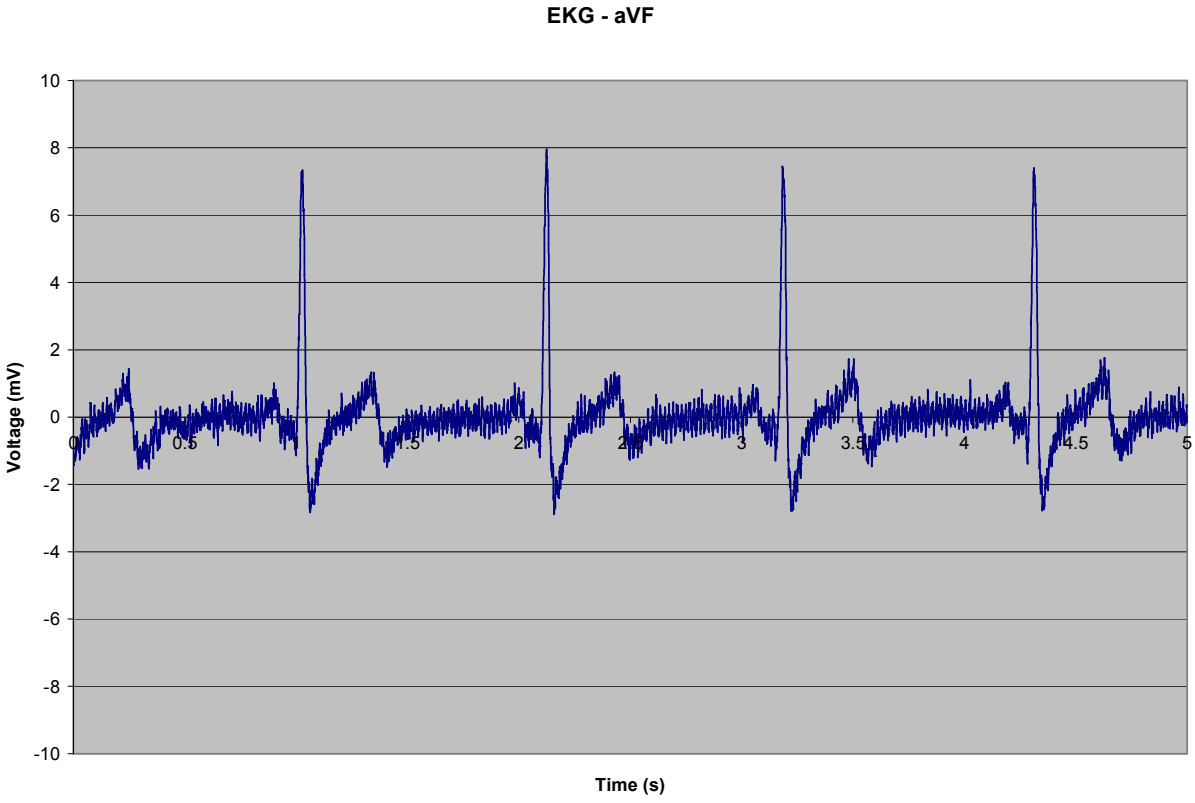


**Figure 42: Shea - EKG aVF**

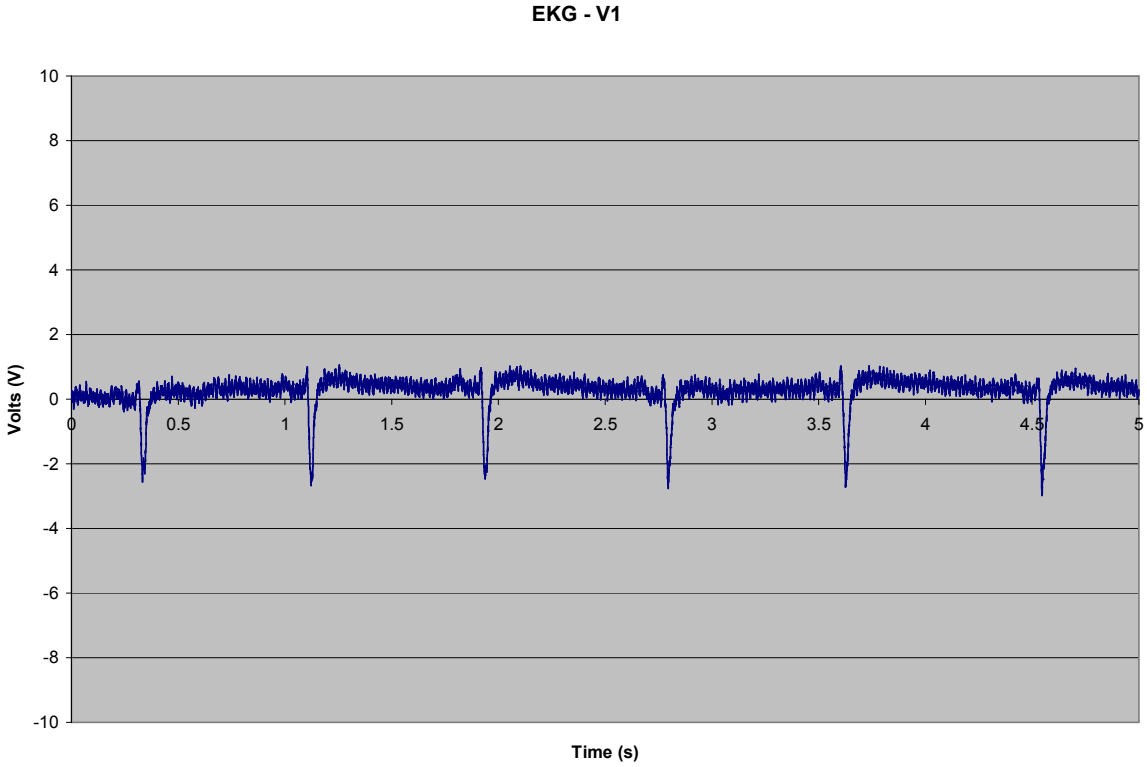


**Figure 43: Shea - EKG V1**

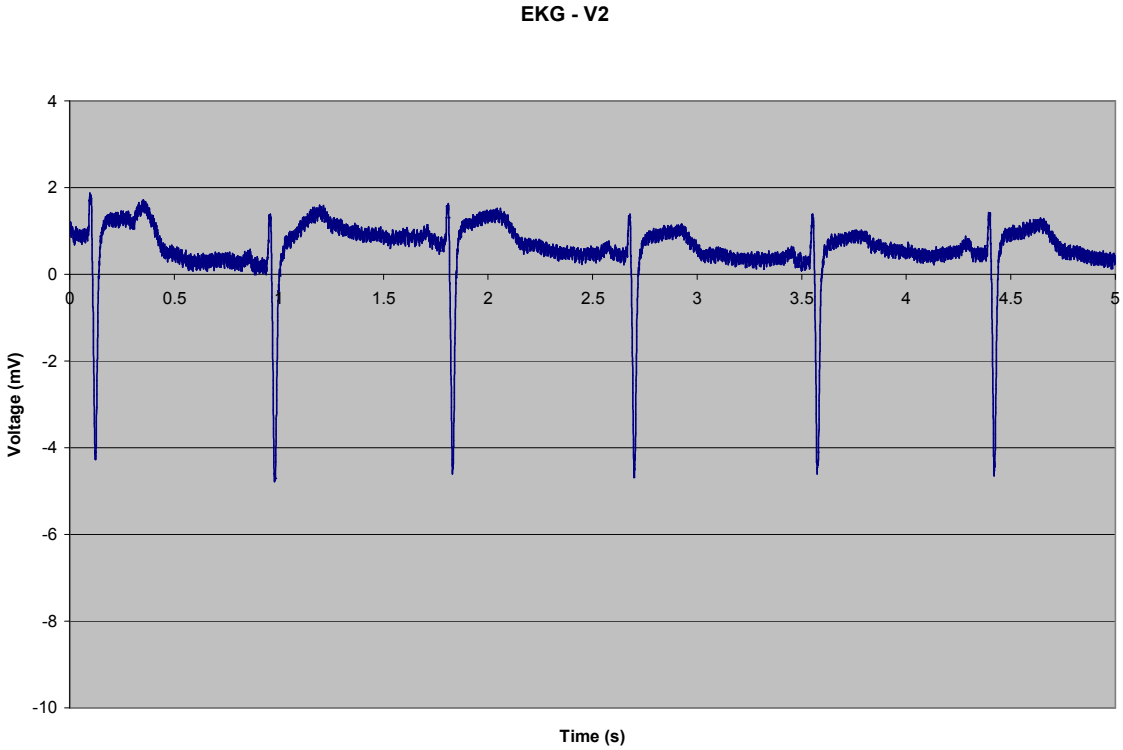


**Figure 44: Shea - EKG V2**

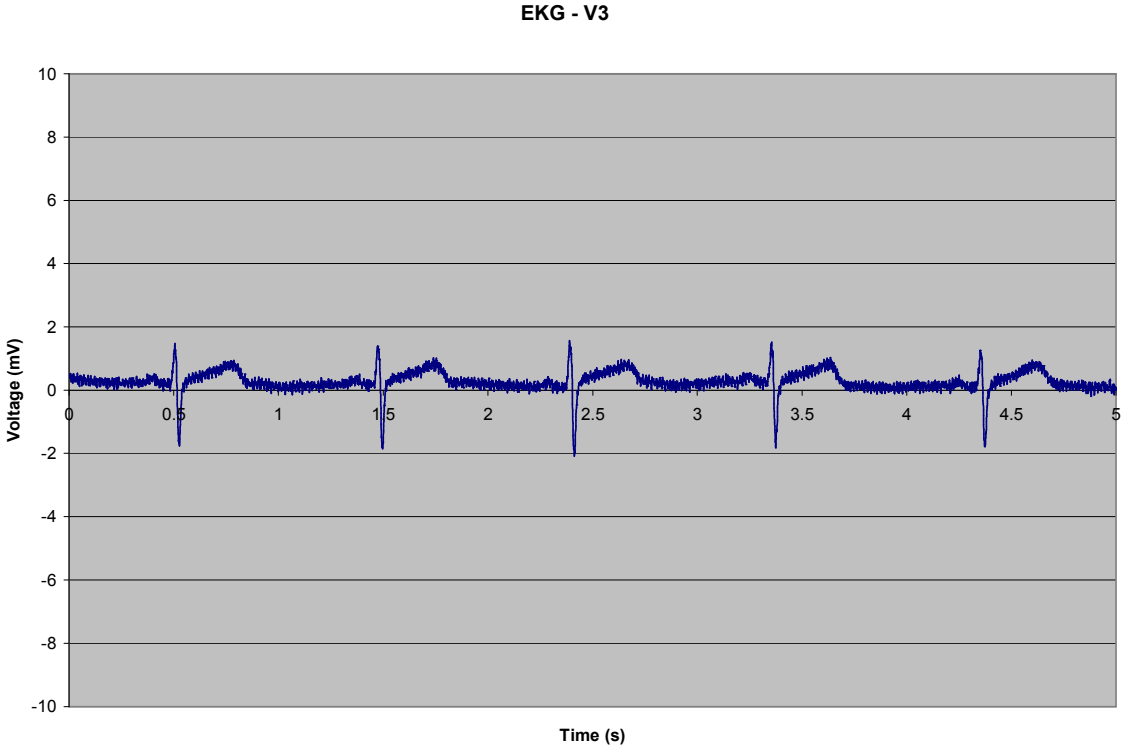


**Figure 45: Shea - EKG V3**

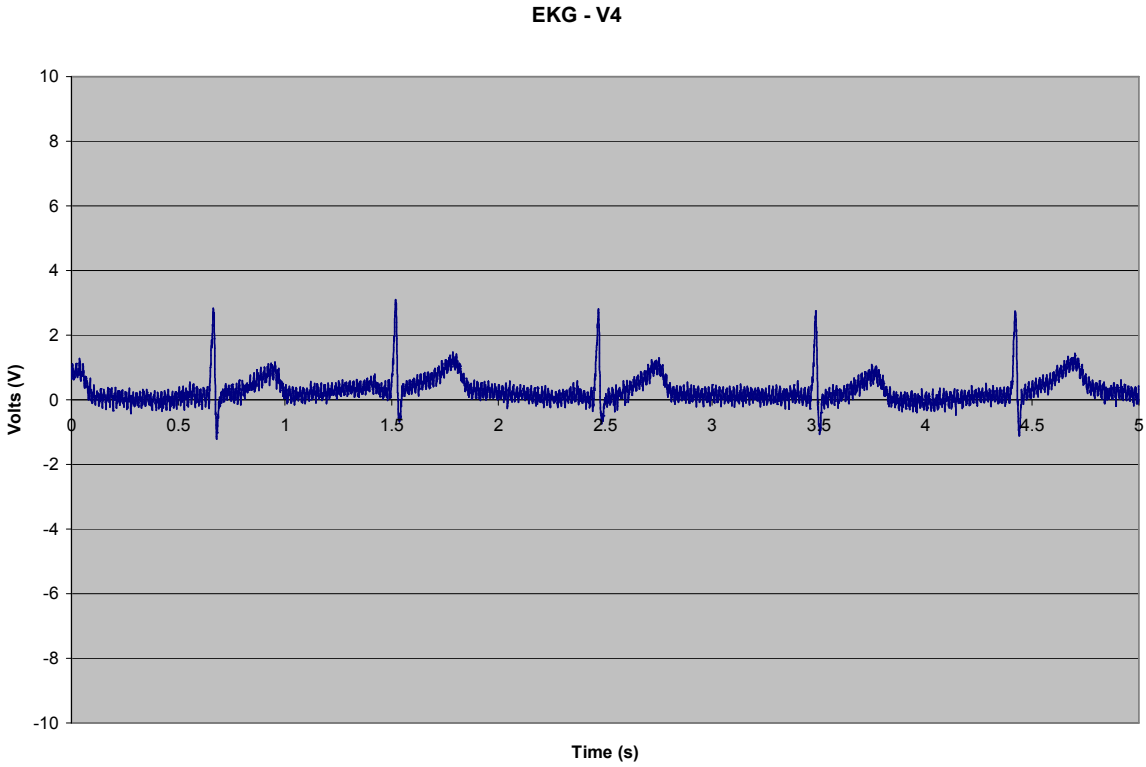


**Figure 46: Shea - EKG V4**

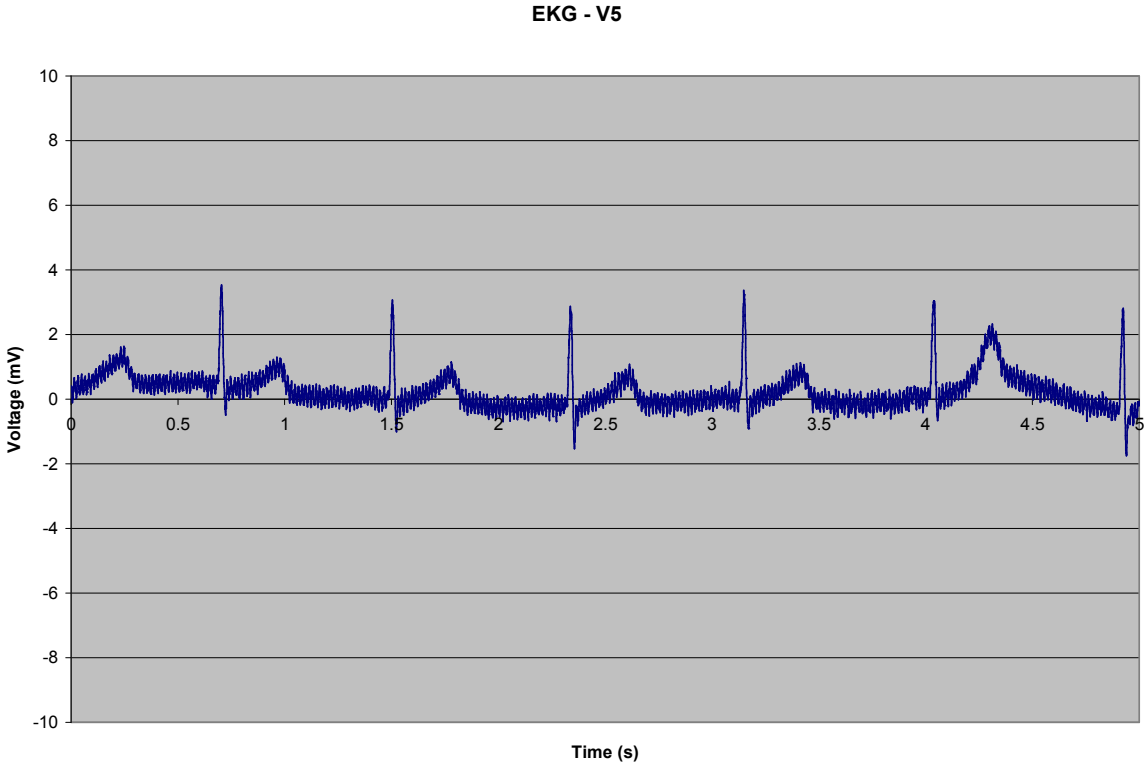


**Figure 47: Shea - EKG V5**

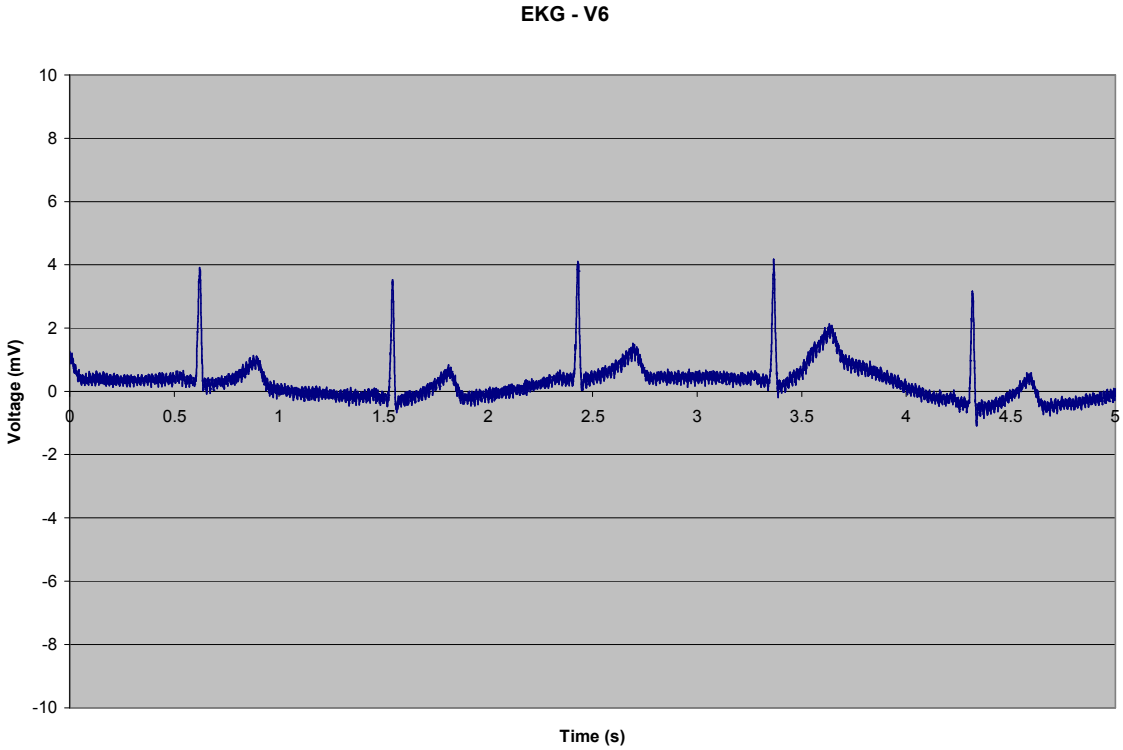


**Figure 48: Shea - EKG V6**

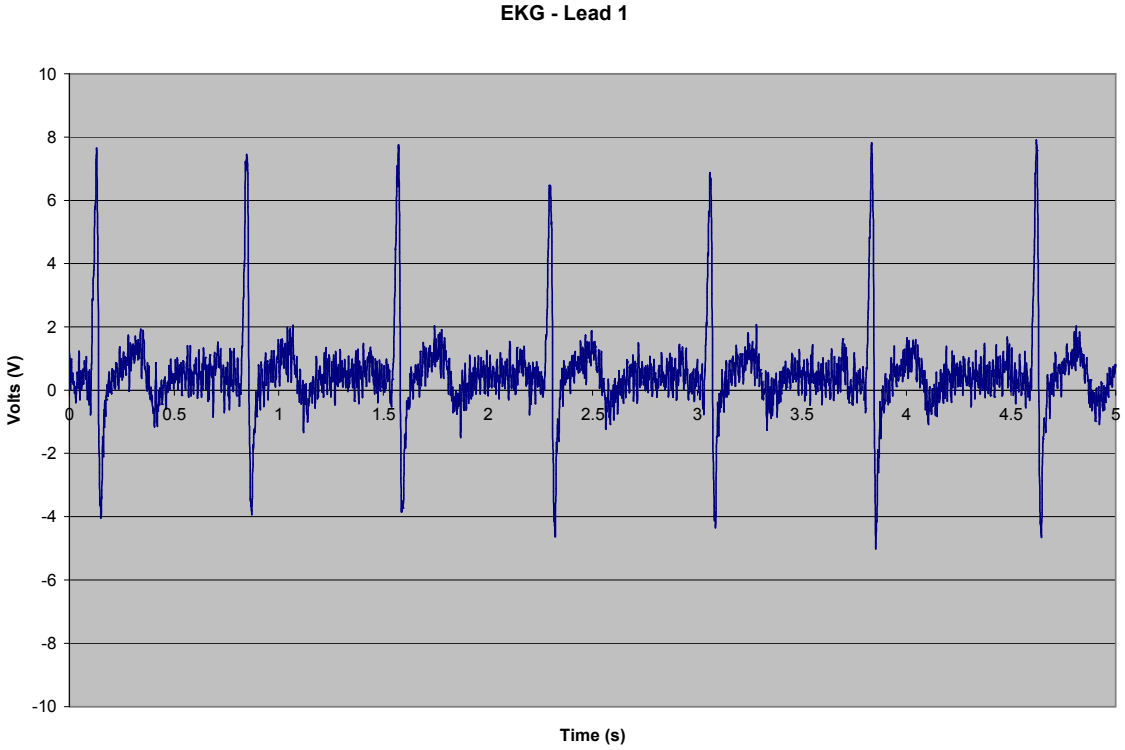


**Figure 49: Nathan - EKG Lead I**

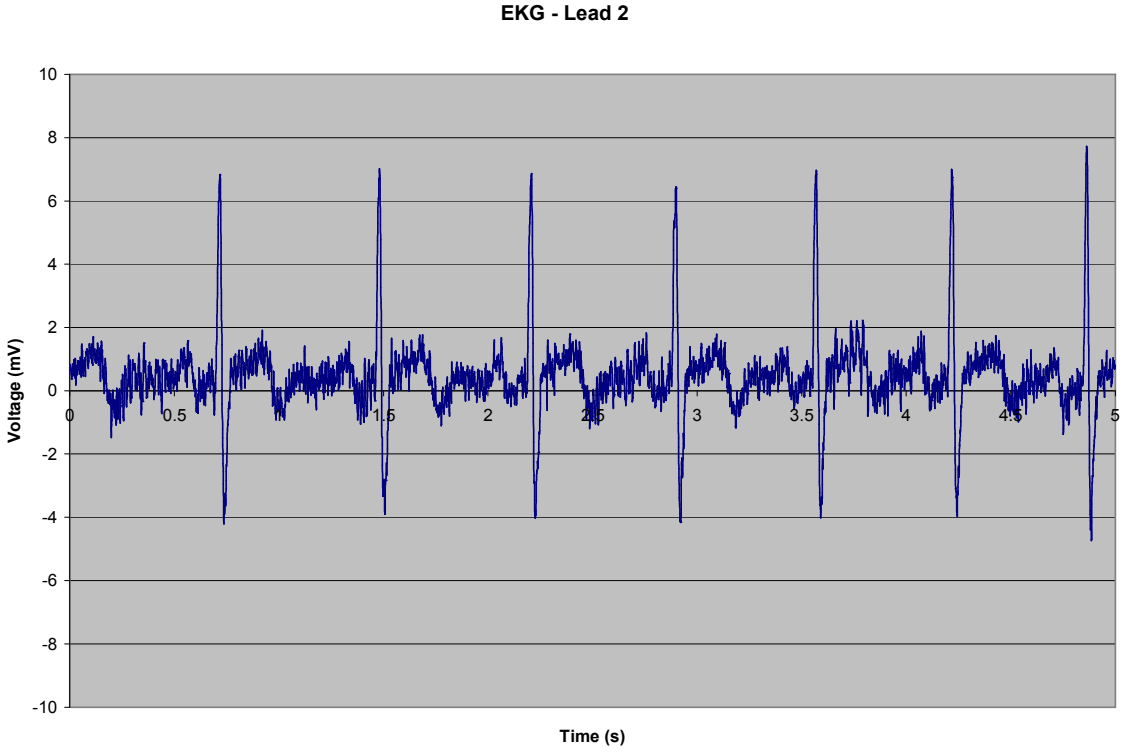


**Figure 50: Nathan - EKG Lead II**

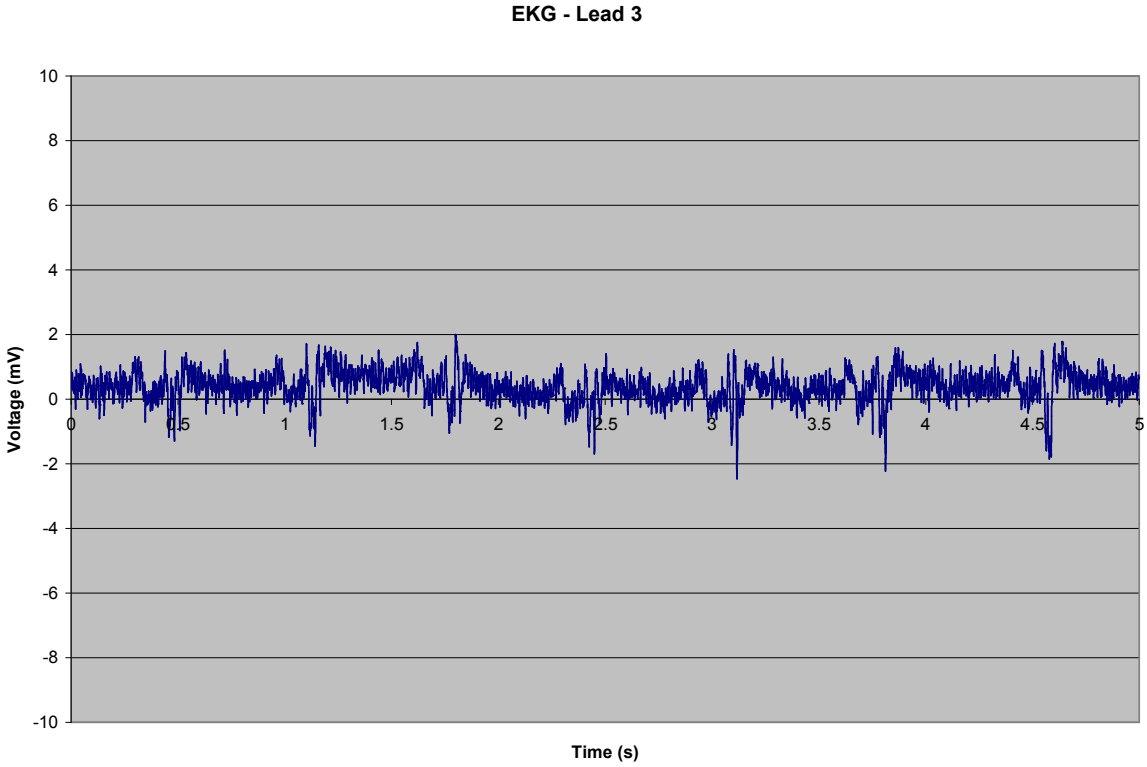


**Figure 51: Nathan - EKG Lead III**

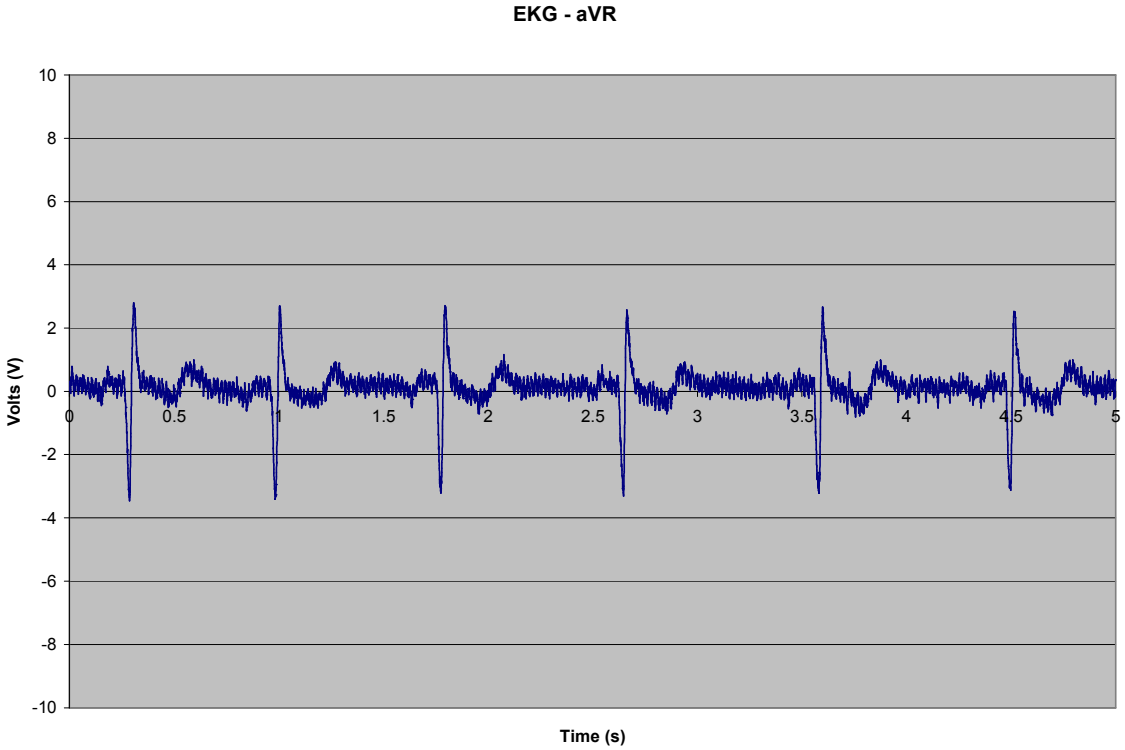


**Figure 52: Nathan - EKG aVR**

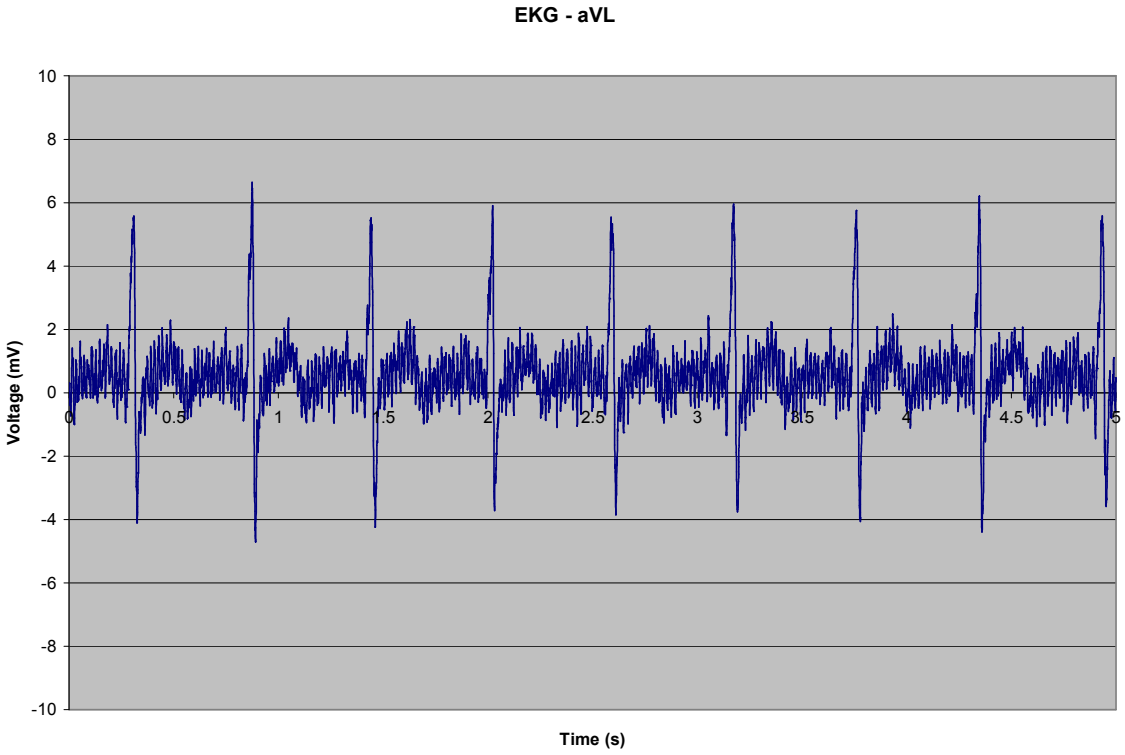


**Figure 53: Nathan - EKG aVL**

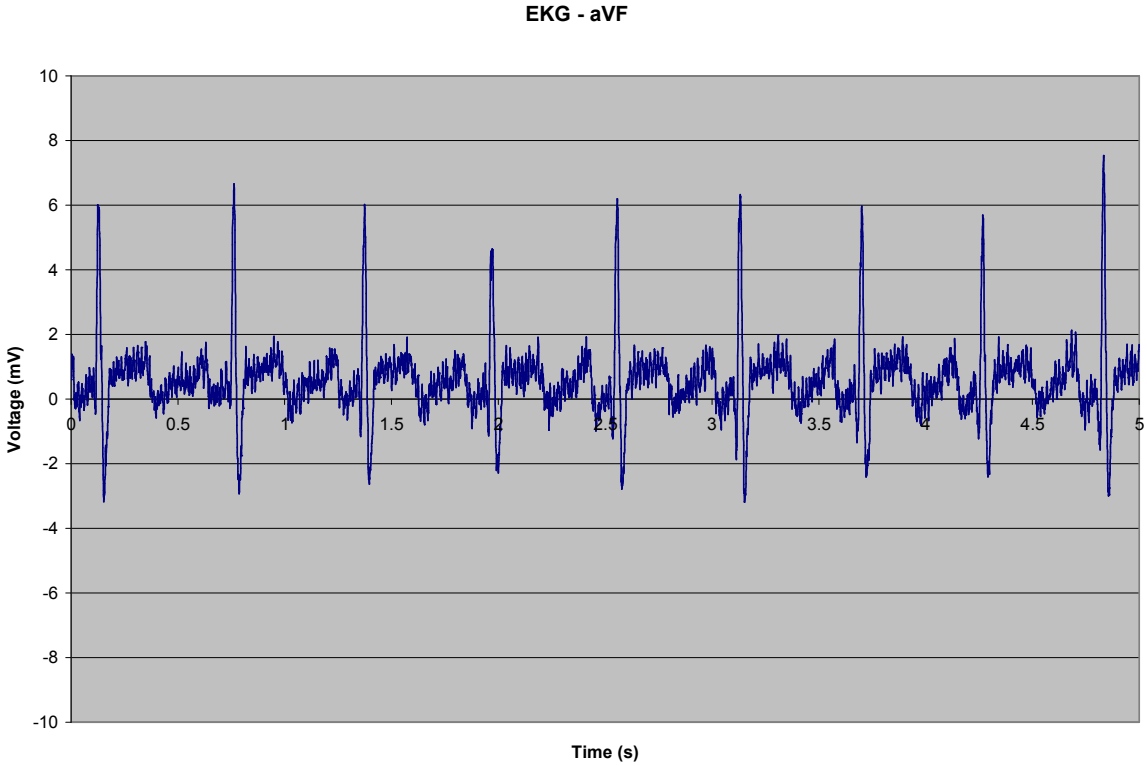


**Figure 54: Nathan - EKG aVF**

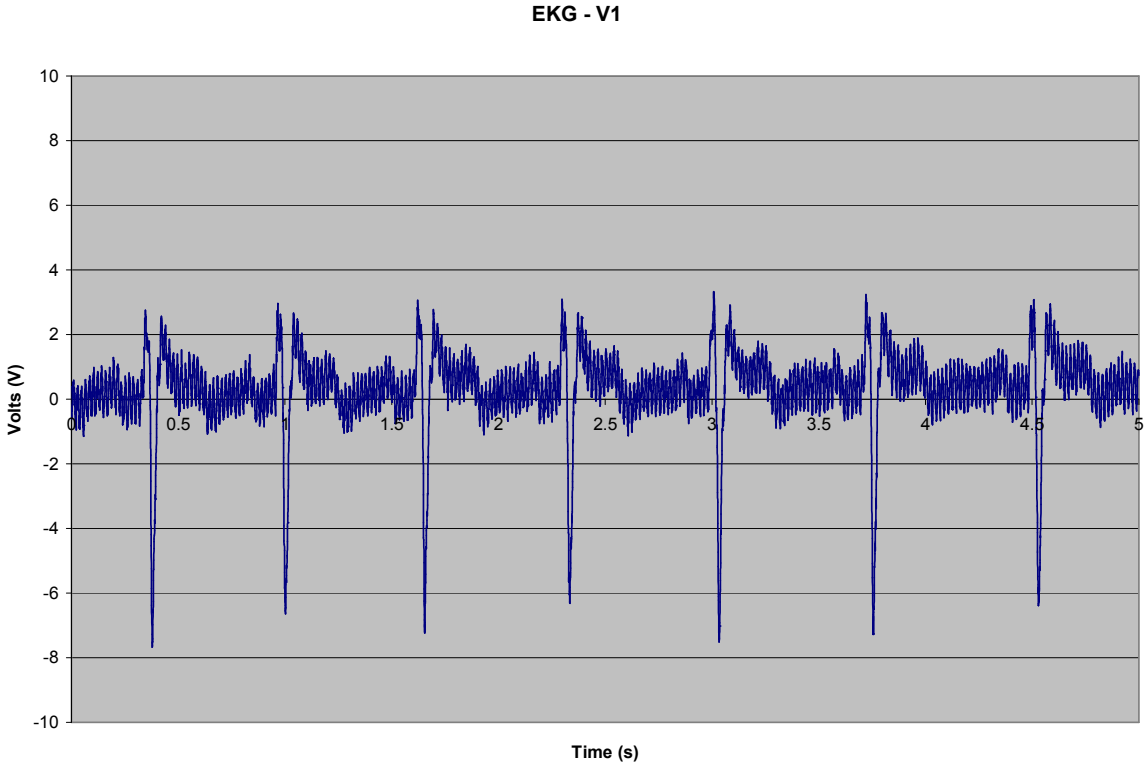


**Figure 55: Nathan - EKG V1**

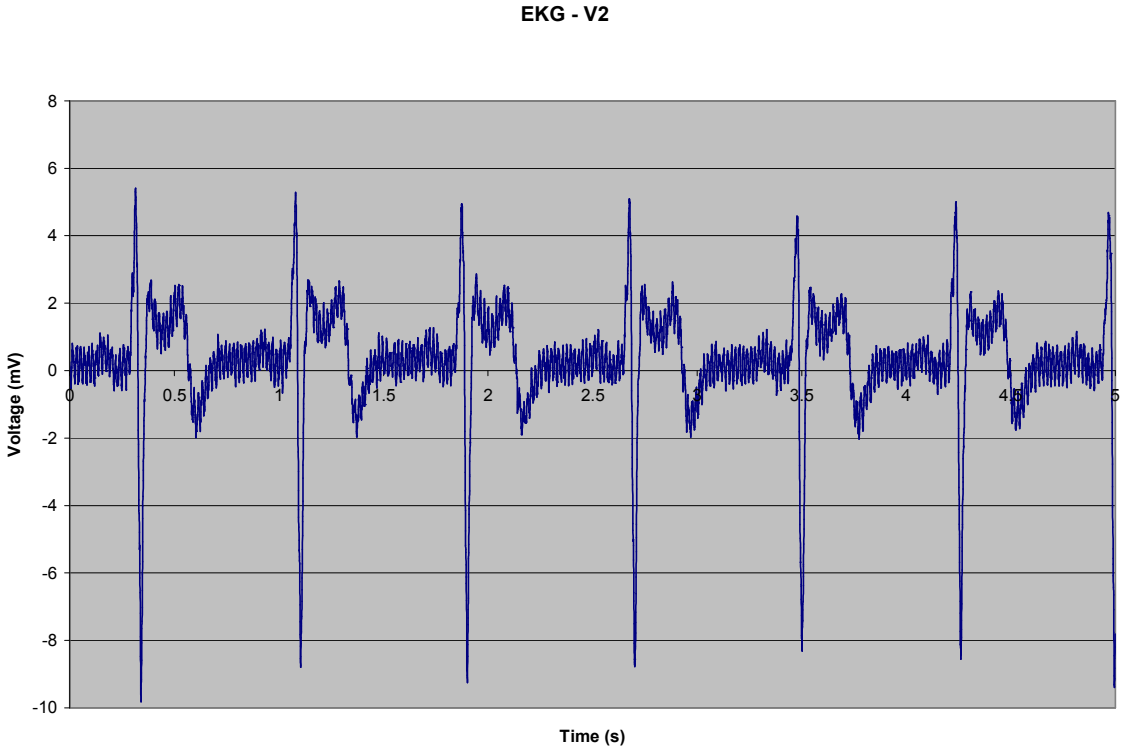


**Figure 56: Nathan - EKG V2**

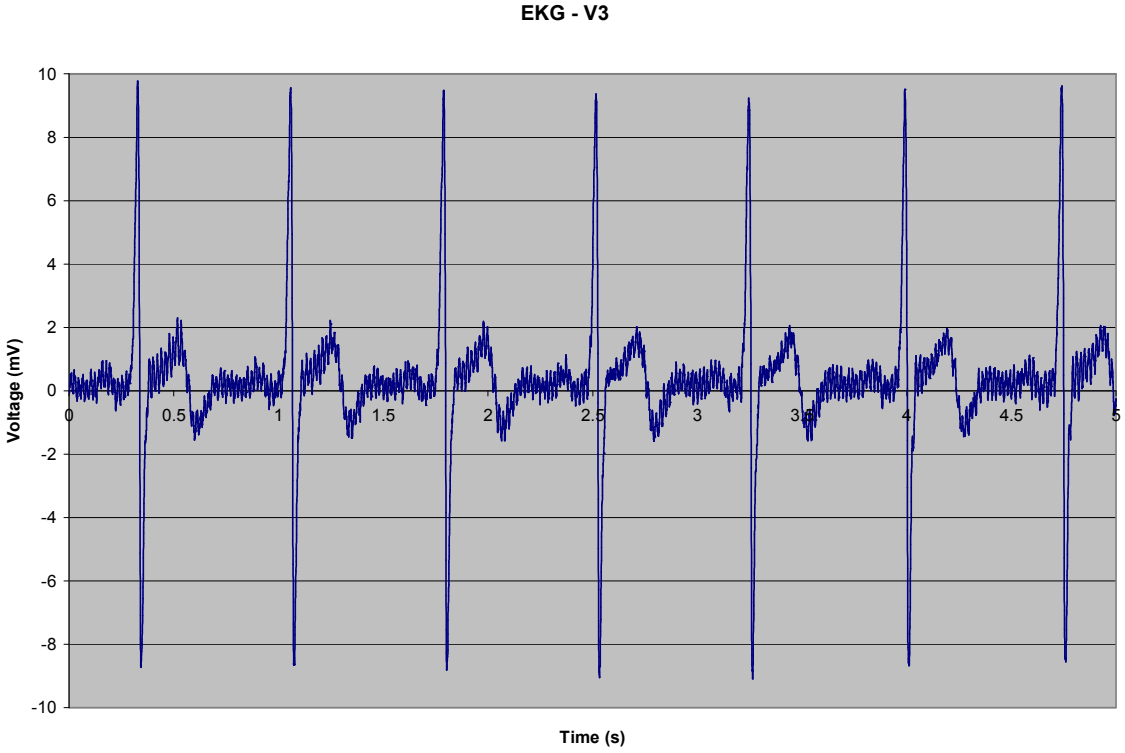


**Figure 57: Nathan - EKG V3**

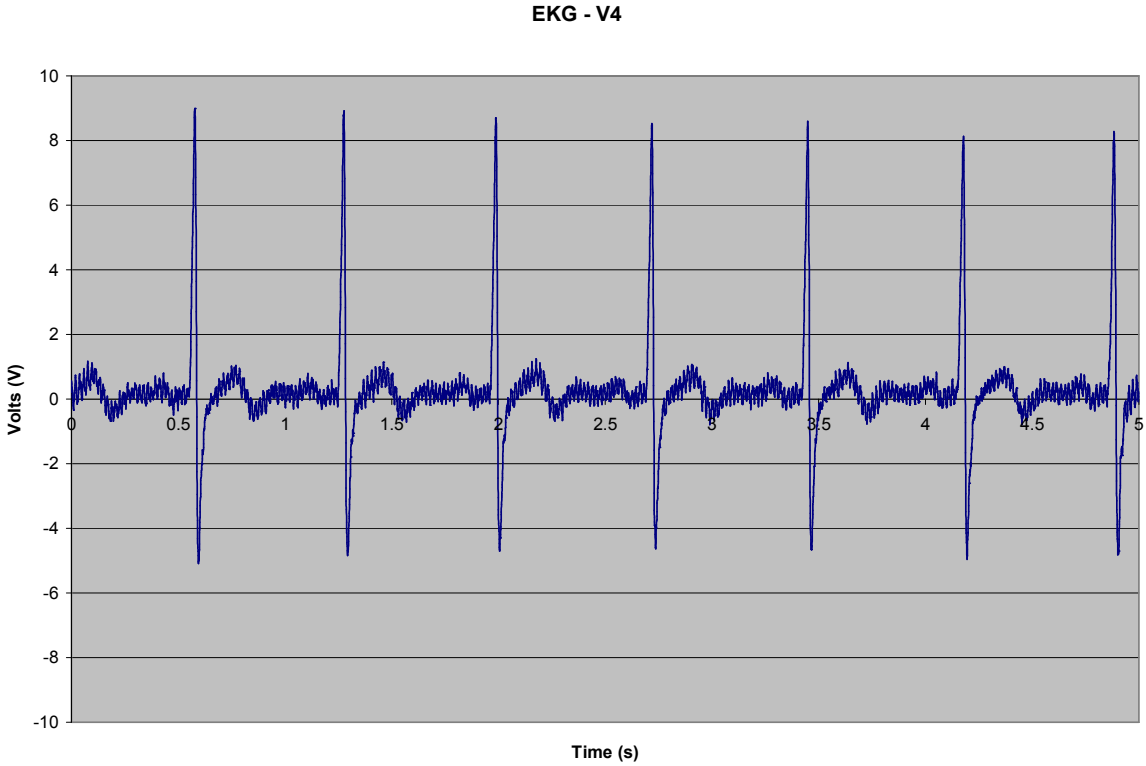


**Figure 58: Nathan - EKG V4**

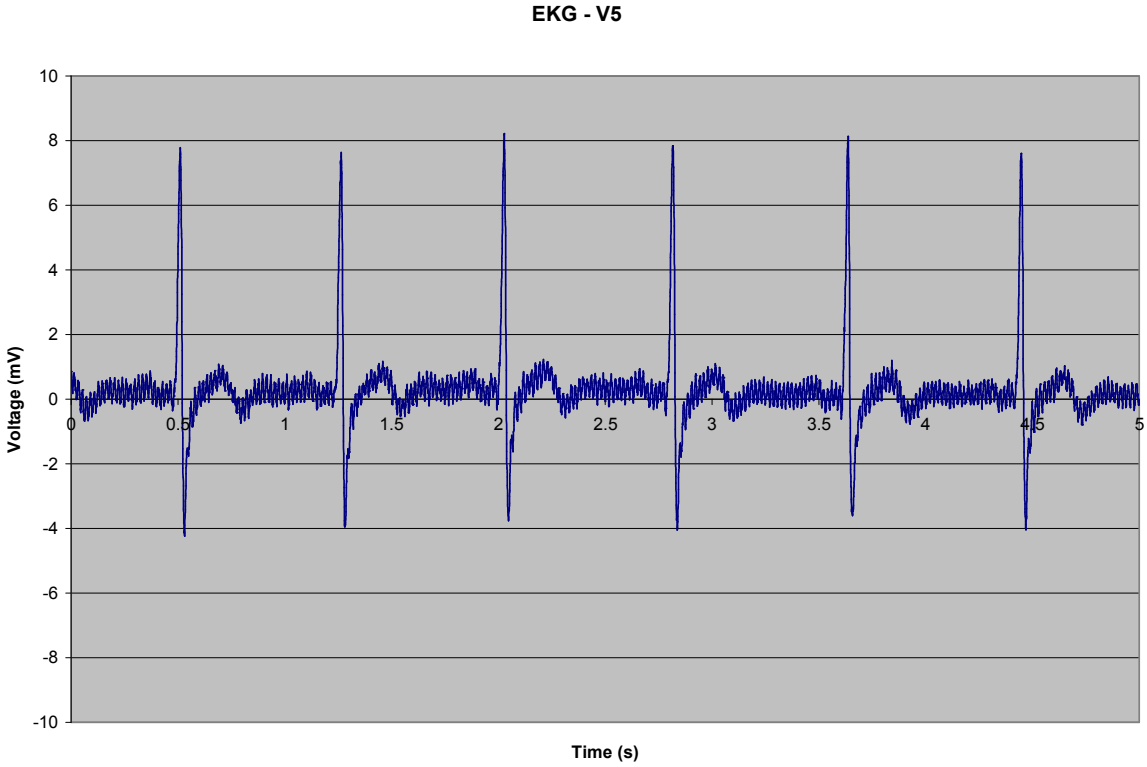


**Figure 59: Nathan - EKG V5**

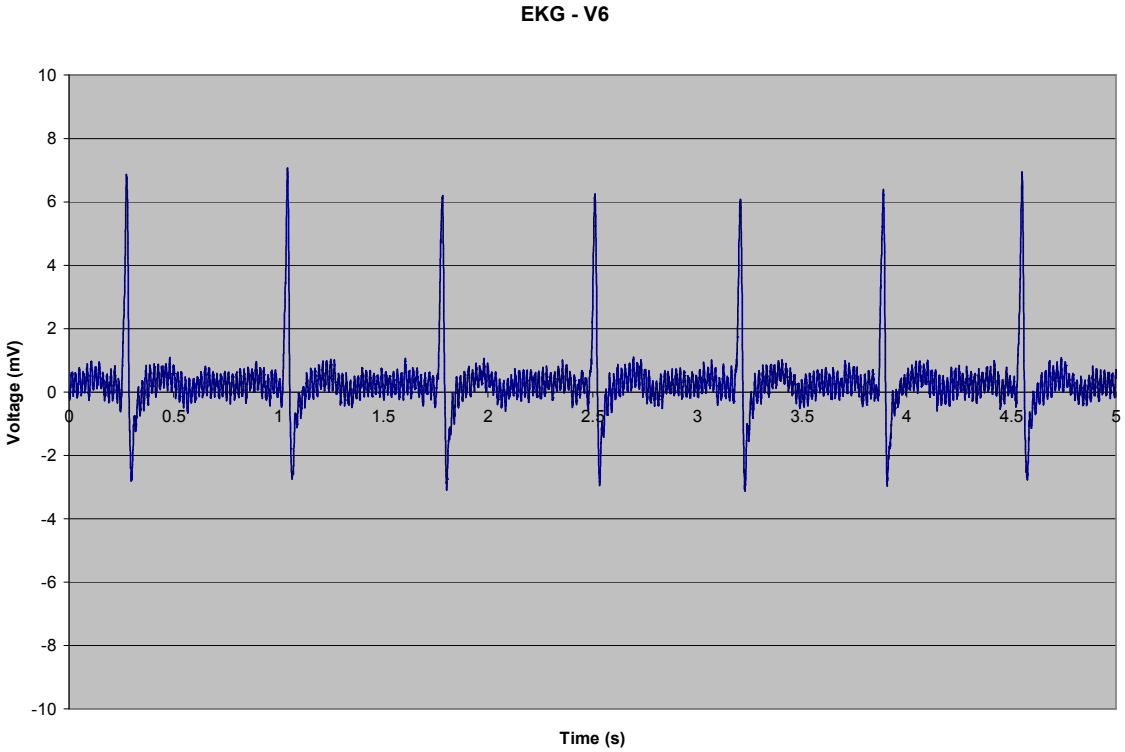


**Figure 60: Nathan - EKG V6**

## 7.0 CONCLUSION

This lab turned out to be a very time consuming lab. We spent a large amount of time taking each measurement and verify with text and colleagues that these measurements were in fact taken correctly. Also, we found quickly that the amount of electrodes provided was quite insufficient so we had to purchase more. Some things that could be done to improve future labs could include: better documentation of the required measurements and any specific requirements, how to actually take these measurements (or at least reference to some relevant accurate information), sufficient lab equipment (the lab should have enough electrodes provided, also things like alligator clips are quite essential to take measurements and they were not provided), the faraday cage was also not ready to be used and there was only time enough for one group to use it two hours before the lab closed on the day before the project was due. All in all it was a good learning experience for everyone involved, and hopefully the concepts we learned will be useful for our future endeavors.

## 8.0 REFERENCES


[1] J. Clark Jr., M. Neuman, W. Olson, R. Peura, F. Primiano Jr., M. Siedband, et al., *Medical Instrumentation Application and Design*. New Jersey: John Wiley & Sons, Inc., 1998.

[2] "Op Amps for Everyone," http://focus.ti.com/lit/an/slod006b/slod006b.pdf Accessed February 23, 2006.

[3] "Op Amp Applications Handbook," http://www.analog.com/library/analogDialogue/archives/39-05/op_amp_applications_handbook.html Accessed February 23, 2006

## A.1 INDIVIDUAL CONTRIBUTIONS

Because teamwork was required at each step of this lab, we all worked in lab on Monday, Wednesday, and Friday for around 3 hours in order to complete the project. We all worked together to take each one of the required measurements and put together the lab report. No group member did any work on their own.