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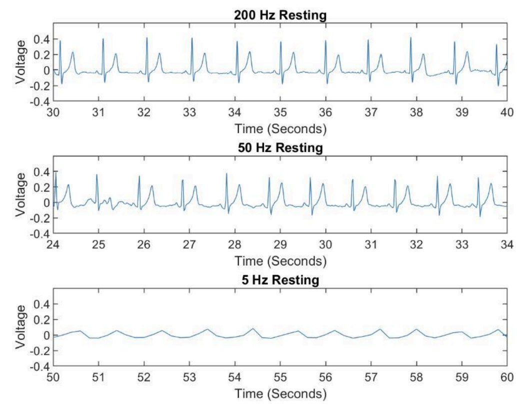
Data Acquisition with the Electrocardiogram (ECG)

Abstract:

An electrocardiogram (ECG) is a device used to measure the electrical signals of the heartbeat. It utilizes the process of chemical and electrical communication between nerve and muscle cells to measure voltages across the skin. Specifically, it takes the depolarization in cardiac muscle tissue caused by electric signals that start at the sinoatrial node in the heart. When the intracellular space near the cardiac muscle tissue depolarizes, it sends an action potential towards the positive electrode of the ECG that produces a positive signal. And as the cells depolarize the action potential will propagate away from the ECG lead and produce a negative signal. Another facet of the ECG is its sampling rate. The American Heart Association suggests a minimum sampling rate of 500 Hz (1). As we go lower, the overall signal we detect will begin to deteriorate as the machine will start to miss the intricate voltage changes of the cardiac system. In conducting our data acquisition, we used the HeartRateVariability setting in LabScribe as well as a IX-B3G ECG. We collected this data by first placing electrodes on the subjects inner wrists and outer ankles. We then took recorded data at 200 HZ, 50 Hz, and 5 Hz until we got 100 consecutive heartbeats without any distorting signal for all three sampling rates. Along with the sampling rate, physiological states of a person will also have an effect on the ECG signal. If a person is exercising, more oxygen is needed in the muscles, leading to an increase in respiration rate. The cardiac output - and in turn heart rate - of the heart will increase alongside this change in order to carry the newly oxygenated blood throughout the body. This will cause the ECG's R-R interval (the time elapsed between two successive R-waves of the WRS signal on the ECG) to decrease. Oppositely, a person resting after this exercising state - such as performing controlled breathing - will cause this R-R interval to expand. To examine this, we first had our subject perform box-breathing (a technique where an individual breathes in for four seconds, holds for four, exhales for four, and holds for four) for another 100 heartbeats of non-distorted data at 200 Hz. After, we had our subject jump jacks for 60 seconds to elevate their heart rate - then immediately hook them up to the ECG and take a 100 heartbeat sample without distortion at 200 Hz. We concluded that exercising will decrease the R-R interval, increase HR, and the ECG signal will appear to have a greater peaking magnitude. From box-breathing we concluded that the R-R interval will increase the R-R interval, decrease HR, and make a lower peak magnitude ECG signal.



Results:

After testing the effect of sampling rate on the ECG signal we found that as the sampling rate decreased, the ability of the ECG signal to pick up the small interactions of a singular heartbeat and the electrical potentials involved. As seen in Figure 1, there is a small distinction between the 200 Hz sampling rate and 50 Hz. We still saw the steps of depolarization and repolarization involved in a heartbeat with some flattening of the process in the 50 Hz sample. However, the 5 Hz sampling rate almost completely flattens the voltage potential change involved with a heartbeat. We are left with an ability to determine the R-R interval as seen in Table 1. However we do not know where the specific processes of the heartbeat are and would likely not use this rate in an experimental setting.

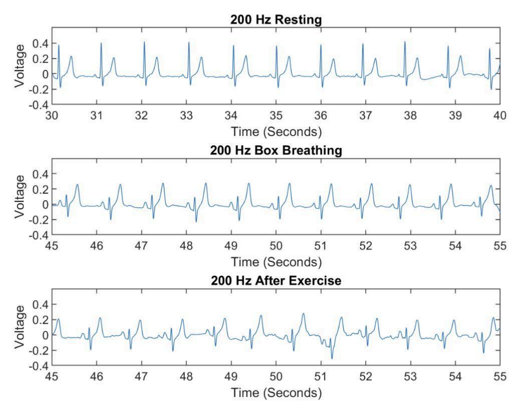


Figure 2: Voltage measured at 200 Hz during three tested physiological conditions.

Table 1: Heart Rate Variability in Resting Subject and the Effect of Sampling Rate

	Minimum R-R Interval	Maximum R-R Interval
Box Breathing	930 ms	1.04 Sec
Exercise	780 ms	895 ms

Table 2: R-R Intervals and Heart Rate Variability with Box-Breathing and Exercise

	Minimum R-R Interval	Maximum R-R Interval
Box Breathing	930 ms	1.04 Sec
Exercise	780 ms	895 ms

When analyzing the ECG signals for minimum and maximum R-R intervals (Table 2) we found the minimum and maximum R-R interval after performing a box-breathing exercise did not change much from the original expected R-R interval for our resting heart rate. We expected the box-breathing exercise to lower the R-R interval by around thirty ms on both ends as we expected the heart rate of the subject to decrease by around 5 bpm. Instead, we observed a very small change in the R-R interval between the resting heart rate and after box-breathing. After exercising we expected the heart rate of our subject to increase by fifteen to twenty bpm (Figure 2) which would decrease the R-R interval by around 330 ms on both ends. We observed a value that is in line with this hypothesis (Table 2).

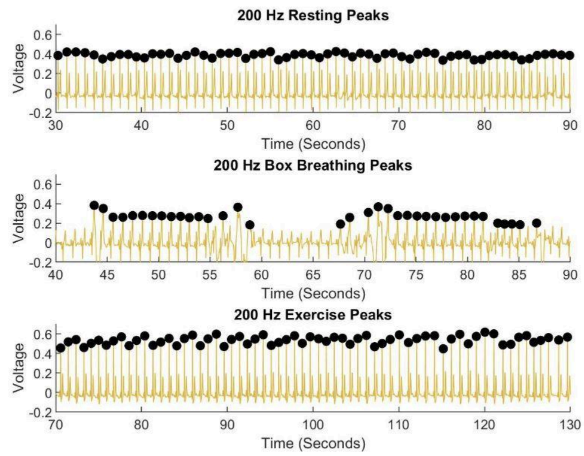


Figure 3: ECG measurements of the subject at rest, box-breathing, and immediately after exercising

Naturally, heart rate and stroke volume increase during inhalation, and decrease during exhalation. This is due to the intake of oxygen during inhalation and the excretion of carbon dioxide during exhalation. This phenomenon is apparent in Figure 3. When looking at the shapes traced by markers on top of the ECG data, we saw a small oscillation. This can be described by the stroke volume during inhalation and exhalation. The increase in stroke volume needs an increase in voltage in order to cause more cardiac muscle tissue to contract. This need is apparent and met while looking at the peaks of Figure 3. In the box-breathing exercise, there was a measurement error where the machine had a difficulty in acquiring consistent peaks of heart rate. Within the segments of labeled heartbeat peaks, we saw the oscillation phenomena briefly. This pattern is also apparent in Figure 4. Looking at the first plot of Resting Peak BPM vs. Time, we saw the consistent oscillation of bpm of our subject during their inhalation and exhalation. Further, when comparing the waveforms across each condition we observed the heart rate values would decrease in magnitude during boxed breathing, and increase in magnitude after exercising when compared to rest. Quantitatively, this observation can be supported as the ranges of each condition oscillated around 0.4 volts for rest, 0.3 for box-breathing, and 0.5 for exercise. The R-R intervals decreased when going from resting to box-breathing to exercise. The average heart rate increased slightly with box-breathing when compared to rest, and increased after exercise when compared to rest (Table 3).

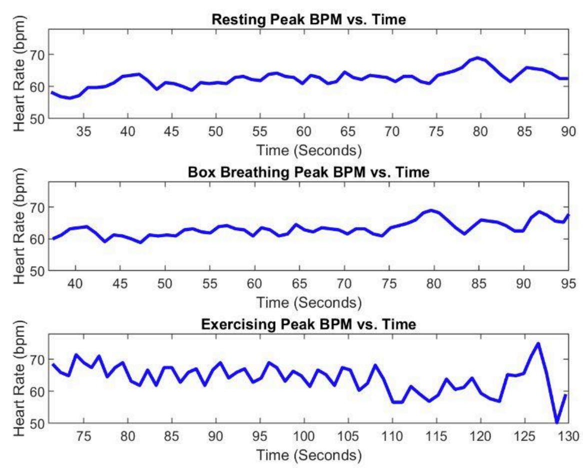


Figure 4: Heart rates over a minute showing the BPM of a subject under three different physiological conditions.

Table 3: Average R-R Intervals and Mean Heart Rate across all three tested physiological states.

	Average R-R Interval	Average Heart Rate
Resting	0.96194 ms	62.4741
Box Breathing	0.94839 ms	63.3515
Exercise	0.9377 ms	64.2862

We observed that while at rest, the majority of calculated heart rates peaked from 60 to 64 bpm with the most bell curve related shape as seen in Figure 5. While box-breathing we observed the heart rate distribution centered from 62 to 66 bpm with high peaks at these points and low peaks above the range. After exercise, the histogram in figure five flattens out to a high of 75 bpm and a low of 56 bpm with a bell curve like distribution in between. In Figure 5 we also see the width of the box-breathing exercise is the greatest in the histogram, while the resting width is the next biggest, and the exercise width being the slimist. After conducting a t-test between resting and box-breathing heart rate conditions, we found a p-value of 0.043. We further conducted a t-test of similar stature on resting and after exercise breathing and got a p-value of 0.005. Finally, we conducted an F-test on resting breathing and box-breathing and received a p-value of 0.

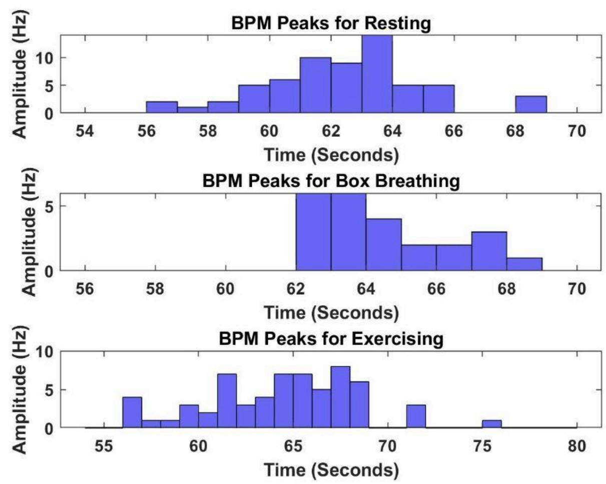


Figure 5: Histograms reporting the results of the frequency of heartbeats under rest, box-breathing, and exercise conditions

Results:

After conducting tests on three different sampling rates, we found that we needed at least 50 Hz to see a clear picture of all stages of the heartbeat. We figure we need at least fifty as we need to be able to distinguish the peaks of the ECG from any other parts of the heartbeat that may also have a peak. As seen in Figure 1 the peaks of the heartbeat at 5 Hz are singular and almost triangular. Further, the heartbeats seen at 50 Hz and 200 Hz showcase all parts of the heartbeat and we can see the second, ventricular muscle repolarization, peak that may get confused with the first peak at 5 Hz. The difference between the first depolarization peak that we need to measure and the false second peak that occurs is 0.44 seconds or 440 ms. This could cause our R-R calculations to be significantly inaccurate. Therefore, it is imperative that we use at least 50 Hz with our equipment when measuring average heart beat and R-R intervals. According to the results of our two-sided t-test we performed in order to compare instantaneous heart rates between resting and box breathing, we can conclude that the heart rate of the box-breathing exercise is significantly different from an at rest heart rate. Thus, we can conclude that box-breathing has an effect on an at rest heart rate. This is supported by Figure 3 where we see a decrease in the voltage potential the sinoatrial node puts on the heart and skin from a subject being at rest compared to when they are box-breathing.The results of our two-sided t-test we performed in order to compare instantaneous heart rates between resting and exercising concludes that heart rate after exercise is significantly different from an at rest heart rate. Thus, we can conclude that exercise has an effect on an at rest heart rate. This is supported by Figure 3 again where we see a significant increase in the voltage potential the sinoatrial node puts on the heart and skin from a subject being at rest compared to after they exercise. The F-test we performed on the variability between an at rest heart rate and a box-breathing heart rate resulted in a p-value of 1. This most likely means that our data was faulted at a point that disturbed the results of the test as we expected the variability of this test to be significantly different as the exercise performed would slow down the rate of breathing significantly, which would cause the heart rate to fluctuate accordingly. Based on the results we concluded, however, a p-value of 1 means that we can not reject the null and can not conclude that the variability of the heart rate while box-breathing is significantly different than that while at rest. The subject's physiological state was most likely changed during boxed breathing. As seen in Figure 3, besides the slight movement artifacts, we see an overall decrease in the amount of voltage produced, reasoning this to the calmness of the subject that resulted in a decrease in need of oxygen to the muscles. Apart from an ECG, we could have used a pulse oximeter. These clip onto the finger and use an optical detection method to track the pulse rate and blood oxygen levels. These devices light of varying wavelengths towards the body and track the amount of light reflected using a photodiode or transistor (2). Other than that, we could have used a stethoscope to count the beats per minute of the heart. Although it would be inaccurate compared to the previously discussed methods it is readily available and easy to use.

References:

1) Pizzuti, G.P. (1985, July). Digital sampling rate and ECG analysis. Retrieved February 8, 2024, from https://www.sciencedirect.com/science/article/abs/pii/0141542585900275

2) ROHM Semiconductor. (n.d.). What is a pulse sensor? Retrieved February 8, 2024, from https://www.rohm.com/electronics-basics/sensor/ pulse-sensor#:~:text=is%20explained%20below.-,Reflection%2DType%20Pulse%20Sensor%20