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Lab Report 1: Data Acquisition with the Electrocardiogram (ECG)

## Abstract

The purpose of this experiment was to measure Electrocardiogram (ECG) signals during various physiological states as well as at different sampling frequencies to extract and analyze heart rate variability (HRV) data, heart rate (HR) data, inter-pulse (R-R) interval data, and the effect of different sampling frequencies on the ECG signal recorded. The ECG signals were measured using disposable electrodes and an iWorx- IXB3G recorder and LabScribe software was used to analyze the time domain recording. MATLAB was then used to analyze all the data collected. The ECG signal variations were recorded across three different physiological conditions: at rest, post-exercise, and during Box Breathing.

To collect ECG data, three electrodes were placed on the body of a subject for this experimenttwo on the inner wrists (positive and negative electrodes) and one the hip bone (grounding wire). The signals were then measured by the iWorx- IXB3G recorder and LabScribe software to get at least 100 samples per physiological state and/or sampling frequency. 200 Hz, 50 Hz, and 5 Hz were the three different sampling frequencies that were recorded and analyzed while the subject was at rest. 200 Hz was the sampling frequency that was chosen to measure and record the three different physiological states. For the post-exercise ECG signal, the subject performed 30 seconds of high-intensity exercise, and then their ECG signal was recorded as they winded down from the exercise. Another ECG signal was recorded as the subject then began Box Breathing, a breathing technique involving inhaling, holding breath, exhaling, and holding breath again at 4-second intervals. At rest, the subject sat still, and guietly as their ECG signal was recorded. The subject was a 20 year old female in good health. 200 samples/sec was chosen as the sampling rate for the rest of the experiment as 50 samples/second and 5 samples per second caused aliasing of the ECG signal. During exercise, the ECG signal showed more cycles and a noticeably wider R-R interval range compared to rest, reflecting increased heart rate variability due to faster breathing. In contrast, during Box Breathing, the ECG signal displayed fewer cycles and a longer R-R interval range compared to rest, leading to decreased heart rate variability as well.



# Results

### Section 1

Three different sampling frequencies were recorded while the subject was at rest and 100 samples were collected at each frequency. 20 seconds out of the 100 seconds of data for each sampling rate was then plotted on MATLAB subplots in Figure 1. Generally, an ECG signal at rest is expected to capture the peaks of 3 consecutive waves. The P wave (a low peak) is followed by the QRS complex (the highest peak), which is then followed by the

Figure 1. ECG signal at 3 sampling frequencies while the subject is at rest

T wave (a peak lower than the QRS complex peak). At a sampling frequency of 200 Hz, there is a clear distinction between all the peaks and the signal looks clear apart from a little noise present on the signal.

At 50 Hz, the peaks are still distinct and clear, however, the amplitude of the QRS complex signal is significantly lower than the amplitude at 200 Hz. At a sampling rate of 5 Hz, the ECG signal isn't readable, the peaks that are displayed are unidentifiable, and it contains an extra cycle within the same time frame as the other two sampling frequencies. This is an effect known as aliasing which is when the input frequency is greater than half the sample frequency. The 200 Hz sampling frequency produces a better signal because it is more than twice the size of the input frequency (The ECG signal).

Table 1. R-R intervals in resting subject at different sampling rates	200 samples/sec	50 samples/sec	5 samples/sec
Filename	Nikita Resting ECG 200 Hz	Nikita Resting ECG 50 Hz	Nikita Resting ECG 5 Hz
R-R Interval Measurement (msec)	840	840	800
Sampling Time Resolution (T2-T1)	14.85-14.81	11.56-10.72	15.8-15.0

A normal resting heart rate for adults is about 60-100 beats per minute (American Heart Association, 2021) which translates to a resting R-R interval of about 0.6- 1.0 seconds. In Table 1,The R-R intervals at 200 samples/sec and 50 samples/sec are the same, however the R-R interval at 5 samples/sec is lower due to the extra cycle present in figure 1 graph 3. While all 3 R-R values fall within the expected range, the value of the 5 Hz R-R value is the least accurate due to the extra ECG cycle in figure 1 subplot 3 as well as because of aliasing.

### Section 2

A sampling rate of 200 samples/sec was used to measure and record the effect of three different physiological states of the

subject on the ECG signal. During exercise, should increase in order to supply oxygen to

the body at a quicker pace which means that the number of cycles in an ECG signal must be evidently higher than at rest. This is evident in the second graph of Figure 2 as the ECG signal during exercise has 5 more cycles than at rest within the same time frame (10 seconds) which proves that the subjects heart rate increased significantly during exercise. The general heart rate range of a healthy 20 year old female post-exercise should be about 50%-85% of her maximum heart beat which is about 200 bpm producing a range of about 100-170 bpm(American Heart Association, 2021).



This translates to an R-R interval of about Figure 2. ECG signal of three different physiological states 0.6 - 0.35 seconds. This is also partially reflected in Table 2. The minimum R-R interval is about 150 milliseconds lower than the range it should be in, further confirming the effect pf exercise on

heart rate, however the maximum R-R interval is much higher than the range (by 590 ms) Box Breathing is a technique used to slow the heart rate down to a range a little lower than the resting heart rate This is visible in figure 2 as the Box Breathing ECG signal has one less cycle than the resting ECG signal and 6 cycles less than the Post-Exercise ECG signal within the

Table 2. Minimum and Maximum R-R intervals during Box Breathing and Exercise	Average R-R Interval (seconds)	Average Heart Rate (BPM)
Resting	0.814	74.3
Exercise	0.722	83.2
Box Breathing	0.826	73.2

same time frame. This is also reflected in table 2 because the minimum R-R interval is 150 milliseconds less than at rest and the maximum R-R interval is only 50 milliseconds

higher than at rest.

### Section 3



The peak heights are expected to be fairly spaced apart at rest, closer together in the beginning of the Post-Exercise ECG signal while gradually increasing towards the end, and further spaced apart than at rest during Box Breathing. Figure 3 matched these expected shapes. In the first subplot of figure 3, the peak heights form a sinusoidal shape due to the subjects regular

Figure 3. Peak marked graphs of ECG signal at Rest, Post-Exercise, and Box Breathing breathing pattern, and the distance between each peak seem to be amost equally and fairly spaced apart as expected for resting heart rate. The Exercise subplot have more sinusoid cycles and the peaks are evidently closer together than it was at rest due to the quicker breathing pace. The last subplot seems to have the least amount sinusoid cycles and the peaks are further spaced apart in comparison to the resting ECG signal. These results match the

expected results. From section 1 and 2, the heart range values for a resting heart rate is 70-100 BPM, Exercise heart rate is 100-170 BPM, and Box Breathing heart rate is in a range that should be a little less than at rest. This is reflected in Figure 4 apart from a few irregularities. At rest, the heart rate fluctuates according to the breathing pattern of the subject and it falls within a range of 60-95 BPM. During exercise the heart rate range was in between 50-140 BPM. The heart rate fluctuates faster due to the physical stress that the subject was under causing the heart rate variability to also increase. In the last subplot of Figure 4, the heart rate range falls



between 55-90 BPMand the HRV is the lowest out of the three graphs because of the slower breathing effect of Box Breathing.Table 3 reflects the average R-R intervals and average heart rates of the three different physiological states from Figures 3 and 4 The difference between the values in table 3 reflect what was expected. The average R-R interval post-exercise was 0.092 seconds slower than at rest and the heart rate was 8.9 beats faster than at rest accurately representing the fact that the

Figure 4. BPM vs time subplots

subject was under some sort of physiological stress. During Box Breathing, the average R-R interval was 0.012 seconds longer than at rest and the heart rate was 1.1 beat slower than at rest, further proving that Box Breathing slows down breathing and heart rate.

Table 3. Average R-R interval and Heart rate at different physiological states	Minimum R-R Interval (msec)	Maximum R-R Interval (msec)
Exercise	290	1190
Box Breathing	690	890

### Section 4

The heart rate values for each physiological state were distributed over a histogram in Figure 5.



The Histogram for Box Breathing is distributed over a mean value(Instantaneous heart rate) that lavs lower than the mean value in the resting heart rate histogram. The histograms for rest and Box breathing also have a more narrow distribution in comparison to the Post Exercise histogram. The only thing that is unexpected is that the Box Breathing histogram seems to have a larger HRV than at rest and this maty be due to irregularities during data collection but if the outliers were neglected, the Box Breathing histogram would have a lower HRV than at rest. The exercise histogram has a much

Figure 5. Histogram of Heart rates at different physiological states wider distribution than at rest and the mean value lays at a much higher value than at rest, indicating that the heart rate variability aslo increased during exercise. The null hypothesis states that the mean heart rate during rest, exercise, and box breathing are equal, while the alternative hypothesis suggests they are not equal. A significance level ( $\alpha$ ) of 0.05 was chosen for a two-sided t-test. Comparing resting heart rate with box breathing yielded a p-value of 0.358, failing to reject the null hypothesis. However, comparing resting heart rate with post-exercise data resulted in a p-value of 6.08e-08, rejecting

the null hypothesis. A variance test between box breathing and resting heart rate produced a p-value of 0.742, also failing to reject the null hypothesis.

#### Discussion

The features of the ECG signal that needed to be captured for this experiment were the R-R intervals, the R-R peaks and the shape that the peaks form, and the accurate amplitudes for the P wave, QRS complex, and the T wave. 200 samples per second is the minimum effective sampling rate that should be used to accurately capture the ECG signals for this experiment because it effectively recorded all of the features that were needed to be captured. At 50 samples per second, most of these features were captured except for an accurate amplitude which was needed to compare the shapes of the R-R peaks in section 2 and this would have affected the analysis of how different breathing rates affect the ECG signal as a sinusoid shape may not have formed properly during data graphing and analysis. At a sampling rate of 5 samples per second, almost none of the features were captured.

When the two sided t-test was performed on the resting heart rate and the Box breathing heart rate data sets, the p-value was significantly higher than the chosen significance level which indicates that the two data sets and distributions have a lot of overlap and that the mean values are close to eachother. This further confirms that Box Breathing does slightly alter the heart rate due to an altered breathing pattern. However, when the test was performed on the exercise heart rate and resting heart rate data sets, the p-value was significantly lower than the chosen significance level as stated in section 4. This indicates that the two data sets barely overlap and the mean heart rate during exercise and rest are evidently very far apart from eachother, therefore rejecting the null hypothesis. Finally, when an F-test was performed on the data sets of box breathing and resting heart rate, the p-value was, again, much higher than the significance value. This could be because the distribution of the box breathing heart rate was wider than at rest as seen in Figure 5 which is a little odd as the heart rate variability during box breathing should have decreased as seen in Figures 2 and 4. This can be explained by the fact that a short data set with fewer irregularities were used for figures 2 and 4 where as a larger data set with many irregulairties including the movements made by the subject was used causing the distribution to be a little bit more spread out.

During Box Breathing, the subject's physiological state changed from when they were at rest. Their breathing slowed down causing their heat rate to also slow down resulting in a reduced heart rate variability as displayed in Figures 3 and 4. There are many methods used to track heart rate. The manual method involves checking a subjects pulse by placing two fingers on pulse points on the body, counting the number of pulses within a time frame of 30 seconds and doubling the count by 2 to calculate a rough estimate of the number of beats per minute, however, none of the statistical analyses made in this report could be made using this method. Another method that could be used could be by photoplethysmography. This method uses infrared light to see the expansion of your arteries as your heart pumps blood through them (Cleveland Clinic, 2022). The difference in blood absorption is converted to a pulse signal. The EKG method is still the best method to measure heart rate as the other methods only calculate pulse rate and not the actual heart rate accurately enough.

### Sources

American Heart Association. (2021, March 9). *Know Your Target Heart Rates for Exercise, Losing Weight and Health*. American Heart Association. https://www.heart.org/en/healthy-living/fitness/fitness-basics/target-heart-rates

Cleveland Clinic. (2022, July 5). *Heart Rate Monitors: How They Work and Accuracy*. Cleveland Clinic. https://my.clevelandclinic.org/health/diagnostics/23429-heart-rate-monitor

GAIA statement: I did use a form of generative AI during the completion of this assignment. If I did, I understand that I must also turn in a completed copy of the course's GAIA Disclosure Worksheet for this assignment.

Chat GPT Script: what is heart rate variability ChatGPT

#### ChatGPT

Heart rate variability (HRV) refers to the variation in the time intervals between consecutive heartbeats, often measured in milliseconds. It is a physiological phenomenon that reflects the adaptability and responsiveness of the autonomic nervous system (ANS), which regulates involuntary bodily functions such as heart rate, respiration, and digestion.

HRV is influenced by the dynamic interplay between the sympathetic nervous system (responsible for the "fight or flight" response) and the parasympathetic nervous system (responsible for the "rest and digest" response). Higher HRV indicates greater flexibility and adaptability of the ANS, allowing the body to respond effectively to internal and external stressors. Conversely, reduced HRV is associated with decreased autonomic regulation and may be indicative of physiological or psychological dysregulation.

HRV analysis has become increasingly utilized in various fields, including medicine, sports science, and psychology, as it provides valuable insights into cardiovascular health, stress levels, emotional regulation, and overall well-being. Techniques for measuring HRV range from simple pulse checks to more sophisticated methods such as electrocardiography (ECG) and photoplethysmography (PPG).

HRV analysis involves assessing different parameters, including:

Time Domain Measures: These include statistical parameters calculated from the intervals between heartbeats, such as the standard deviation of NN intervals (SDNN) and the root mean square of successive differences (RMSSD). Frequency Domain Measures: These involve analyzing the power spectrum of HRV signals to assess the distribution of variability across different frequency bands, such as low frequency (LF), high frequency (HF), and very low frequency (VLF) components. Nonlinear Measures: These capture the complex dynamics of HRV signals using nonlinear mathematical techniques, such as fractal analysis and entropy measures. HRV analysis can provide valuable information about an individual's physiological resilience, stress levels, and overall health status. It is used in various clinical applications, including risk stratification for cardiovascular diseases, assessment of autonomic function in neurological disorders, and monitoring of stress levels in occupational settings. Additionally, HRV biofeedback techniques have been developed to help individuals improve their stress management skills and enhance their overall well-being.

# You should heart rate variability increase after xercise ChatGPT

### ChatGPT

Yes, typically, heart rate variability (HRV) increases after exercise. During exercise, the sympathetic nervous system is activated to increase heart rate and cardiac output to meet the increased demand for oxygen and nutrients by the muscles. This leads to a decrease in HRV as the sympathetic activity dominates over parasympathetic activity.

However, after exercise, as the body returns to a resting state, HRV tends to increase. This is because the parasympathetic nervous system becomes more dominant, leading to a decrease in heart rate and an increase in the variability of the time intervals between heartbeats. This shift towards increased parasympathetic activity and higher HRV is often referred to as the "parasympathetic rebound" or "parasympathetic activation" phase after exercise.

The magnitude and duration of the increase in HRV after exercise can vary depending on factors such as the intensity and duration of the exercise, individual fitness level, and recovery status. Generally, longer duration and moderate-intensity exercise sessions tend to elicit a more pronounced increase in HRV post-exercise compared to shorter and high-intensity sessions. Additionally, regular exercise training over time can lead to improvements in baseline HRV, reflecting enhanced autonomic nervous system balance and cardiovascular health.

You does this sentence make sense: The heart rate values for each physiological state was distributed over a histogram ChatGPT

ChatGPT

The sentence is almost correct but needs a minor adjustment for grammatical accuracy. Here's

the revised version:

"The heart rate values for each physiological state were distributed over a histogram."

The change made is from "was" to "were" to agree with the plural subject "heart rate values."



You

make this more concise:

During exercise, the ECG signal had more ECG cycles than at rest, the R-R interval range was significantly larger than at rest, and the heart rate variability had increased from rest as a result of the exercise and faster rate of breathing. However, during Box Breathing, there were fewer ECG cycles in the ECG signal than at rest, The R-R interval range decreased from at rest, and the HRV also reduced from the resting HRV.

### ChatGPT

ChatGPT

During exercise, the ECG signal exhibited more cycles and a significantly larger R-R interval

range compared to rest, indicating increased heart rate variability due to exercise-induced faster

breathing. Conversely, during Box Breathing, the ECG signal showed fewer cycles and a reduced

R-R interval range compared to rest, resulting in decreased heart rate variability compared to

resting levels.



You

make it sound less AI generated

ChatGPT

ChatGPT During exercise, the ECG signal showed more cycles and a noticeably wider R-R interval range

compared to rest, reflecting increased heart rate variability due to faster breathing. In contrast,

during Box Breathing, the ECG signal displayed fewer cycles and a reduced R-R interval range

compared to rest, leading to decreased heart rate variability compared to resting levels.

You different methods to track heart rate ChatGPT

### ChatGPT

There are several methods to track heart rate, ranging from basic to more advanced techniques.

Some of the most common methods include:

Manual Pulse Check: This involves manually measuring the pulse by placing fingers on pulse points such as the wrist (radial artery), neck (carotid artery), or temple (temporal artery) and counting the number of heartbeats felt within a certain time period, usually 15 or 30 seconds, and then multiplying to calculate beats per minute (bpm).

Heart Rate Monitors: These devices typically consist of a chest strap or wristband that contains sensors to detect heart rate. Chest strap monitors use electrodes to measure electrical signals from the heart, while wristband monitors use optical sensors to measure blood flow through the skin. Some heart rate monitors also include additional features such as activity tracking and GPS.

Smartphone Apps: There are numerous smartphone apps available that utilize the phone's built-in camera and flash to measure heart rate optically by analyzing changes in blood flow under the skin. These apps typically require users to place their fingertip over the camera lens and flash for a few seconds while the app captures and analyzes the data.

Wearable Fitness Trackers: Many wearable fitness trackers, such as smartwatches and fitness bands, include built-in heart rate sensors that continuously monitor heart rate throughout the day. These devices use optical sensors to measure blood flow through the skin and provide real-time heart rate data during exercise and rest.

ECG/EKG Devices: Electrocardiogram (ECG or EKG) devices are medical-grade instruments used to measure the electrical activity of the heart. These devices typically require electrodes to be attached to the chest, arms, or legs, and provide highly accurate measurements of heart rate and rhythm. While ECG devices are more commonly used in clinical settings, there are also portable consumer-grade ECG monitors available for personal use.

Chest Strap Heart Rate Monitors: These devices consist of a chest strap equipped with electrodes that detect electrical signals from the heart. The data is transmitted wirelessly to a compatible device, such as a smartphone or fitness watch, for real-time heart rate monitoring during exercise.

Blood Pressure Monitors: Some blood pressure monitors also have the capability to measure heart rate. These devices typically use a cuff placed around the upper arm or wrist, and the heart rate is automatically measured during the blood pressure reading process.

These are just a few examples of the methods available for tracking heart rate, each with its

own advantages and limitations depending on factors such as accuracy, convenience, and

intended use.



You make this more concise:

The null hypothesis for the heart rate data collected for a subject at rest versus during exercise or during box breathing is that the mean that they are both distributed over is equal to eachother where as the alternative hypothesis for this is that the data sets aren't equal to each other. The significance level ( $\alpha$ ) was chosen to be 0.05 before a two sided t-test was performed. When the resting heart rate data set was used with the box breathing data set, the p-value was found to be 0.358 and so, the null hypothesis could not be rejected. However, when a two sided t-test was performed for the resting heart data and post-exercise data, the p-value was found to be 6.08e-08 and so, the null hypothesis is rejected in this case. A variance test was then performed on the data for the Box Breathing heart rate and resting heart rate and gave a p-value of 0.742 and so, the null hypothesis annot be rejected.

### ChatGPT

### ChatGPT

The null hypothesis states that the mean heart rate during rest, exercise, and box breathing are equal, while the alternative hypothesis suggests they are not equal. A significance level (a) of 0.05 was chosen for a two-sided t-test. Comparing resting heart rate with box breathing yielded a p-value of 0.358, failing to reject the null hypothesis. However, comparing resting heart rate with post-exercise data resulted in a p-value of 6.08e-08, rejecting the null hypothesis. A variance test between box breathing and resting heart rate produced a p-value of 0.742, also failing to reject the null hypothesis.