

Heart Rate Detection Laboratory

(Electrocardiography Application)



Introduction

In previous laboratory sessions you have learned how to measure and record the electrocardiography (ECG) signal. Additionally, you have seen how various disease states of the heart can affect the temporal and spectral characteristics of the ECG signal. Under normal conditions, the ECG signal appears as a fairly stationary, repeating signal. A heart beat occurs approximately once a second as indicated by the characteristic peaks and valleys on the ECG recording. Therefore, computer based methods can



be used to automatically calculate heart rate based on the quantitative repeating features of the ECG signal. Heart rate is an extremely important variable in many research and biomedical signal applications. Variations in heart rate can give insight into disease and other clinical applications including the control and function of the autonomic nervous system over the body. Additionally, heart rate is an important variable to include in many other applications such as sleep studies, biofeedback, and exercise training, and inputs to medical devices such as cardiac defibrillators and pacemakers.

During this laboratory session, you will learn how computer based quantitative methods can be used to calculate heart rate from the ECG signal. You will explore the advantages and disadvantages between using particular methods to calculate heart rate. Additionally, you will see the importance of calculating heart rate variability from the ECG signal. Finally, you will examine sources of noise that occur in the ECG signal, learn how the noise affects algorithms, and propose methods for reducing that noise and artifact.

Equipment required:

- CleveLabs Kit
- Four (4) snap electrodes
- CleveLabs Course Software
- MATLAB® or LabVIEW™

Background

At first glance it would appear that the ECG is a fairly stationary and repeating signal. Therefore, typical time and frequency domain quantitative methods could be used to calculate the heart rate. However, there is actually a complex degree of variability in a normal heart rate and cardiac arrhythmias. As the human body responds to environmental conditions, it places different constraints on the cardiac output required of the heart. The heart must be able to quickly respond to rapidly changing environmental parameters. The rate at which the heart responds to those needs can be an indicator of underlying pathology concerning the autonomic nervous system or other systems of the body.

Cardiac Output

Cardiac output refers to the amount of blood that is pumped out of the left ventricle and into the aorta during a period of one minute. The average cardiac output for a resting male is approximately 5L/min. However, this value can change depending upon the needs of the body at a particular time. For example, during exercise the body needs the heart to pump more blood to the body at a faster rate. Therefore, the cardiac output increases. Cardiac output is the product of the stroke volume of the heart and the heart rate. The stroke volume refers to the amount of blood pumped out of the heart during a single beat. Therefore, the body has two mechanisms to control the cardiac output. It can increase the stroke volume or the heart rate.

The autonomic nervous system is responsible for controlling heart rate and cardiac output. Heart rate is determined by the rate of depolarization of the sinoatrial (SA) node. This rate can be influenced by a number of parameters including stimulation of autonomic nerve fibers, hormones, electrolyte concentrations, and body temperature. Heart rate is regulated by both parasympathetic and sympathetic nerve fibers. Parasympathetic fibers tend to decrease heart rate while the sympathetic fibers will increase the heart rate.

Cardiac Contraction Cycle Relation to the ECG

The voltage of the ECG signal (Fig 1) can vary depending on the location of the electrodes placed on the body. If the electrodes are located close to the heart, the recorded potentials can be as high as 5 mV. However, if the electrodes are placed further apart, such as at the wrists, a typical value is 1mV. Both of these measurements, however, are small compared to electrodes placed directly in contact with the heart muscle membrane. Here the potential can range as high as 110 mV. Typical amplitudes are around 1mV for the top of the Q wave to the bottom of the S wave, 0.1 - 0.3 mV for the P wave, and between 0.2 - 0.3 mV for the T wave.

The PQ interval (also known as the PR interval) is the amount of time from the beginning of the P complex to the QRS complex. This represents the amount of time between the beginning of atrial contraction and the beginning of ventricular contraction. The normal duration is approximately 0.16 seconds. Similarly, the QT interval is the time between ventricular

contraction and ventricular repolarization. This is measured from the beginning of the Q wave to the end of the T wave and typically lasts 0.35 seconds. The heart rate can be determined directly from the ECG. The heart rate is the inverse of the time between similar segments in the ECG recording. For example, if the time measured between two QRS complexes is 0.8 seconds, then the number of beats per second is the inverse, 1.25 beats / second. In order to obtain the heart rate per minute, you would simply multiply by 60 seconds/minute. This would yield 75 beats per minute.

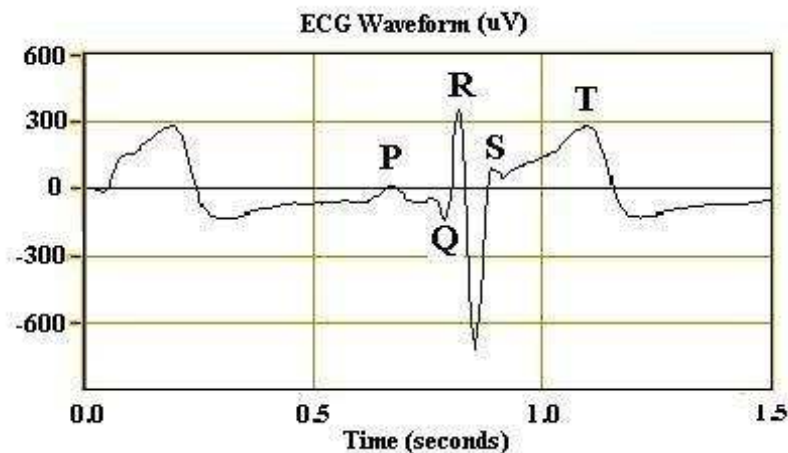


Figure 1: Typical ECG with P, QRS, and T complexes marked.

While Figure 1 illustrates an ECG recording from a normal heart, recordings from cardiac arrhythmias may appear very different. For example, if a conduction block is present in the heart, the time between particular intervals may appear stretched. Additionally, some arrhythmias may appear to have completely different shapes than Fig 1. You can examine a database of abnormal ECG signals in the laboratory session ECG II. Due to the wide variety of possible ECG recordings, it becomes challenging to develop a method of heart rate detection that can be applied to all individuals.

Heart Rate Variability

Heart rate variability is currently a popular topic in biomedical research. Once heart rate can be calculated from the ECG signal, heart rate variability can be calculated as the variance of heart rate about its mean. By examining quantitative features of heart rate variability, researchers are learning that they can predict particular diseases and abnormal function of the autonomic nervous system (ANS). In normal subjects, heart rate fluctuates to compensate for certain external constraints that are placed on the body. The body has many sensors that act as inputs to the autonomic nervous system. Based on these inputs the ANS adjusts the heart rate to compensate for the current needs. Consider the “fight or flight” reaction of the body to an external disturbance. If you were resting in a chair and then suddenly attacked by a bear your body would have to quickly prepare itself to fight or run from the predator. The ANS responds to the external disturbance and increases heart rate and cardiac output. More subtle events also

call for a change in the cardiac output control by the ANS. In some subjects, the ANS does not properly modulate heart rate and hence the heart rate variability is reduced. Abnormal heart rate variability tends to exhibit a flat spectral pattern whereas normal variation has a broadband with peaks that correspond to respiration, baroreceptor control and other physiological parameters. The parameter of heart rate variability is currently being researched for its effectiveness in predicting diseases such as sleep apnea and Parkinson's disease.

Pace Makers

In some pathological conditions the nervous system has such poor control over heart rate that an external cardiac pacemaker must be implanted into a person. This pacemaker automatically paces the heart to avoid life threatening conditions that may occur if the heart is not beating properly. A cardiac pacemaker creates pulses of electrical stimulation that are delivered to the heart via electrodes placed on the cardiac surface or implanted in the cardiac tissue. A typical pacemaker consists of a power supply, a timing circuit, an output circuit, leads that travel from the pacemaker circuitry to the heart, and electrodes. There are two types of cardiac pacemakers including asynchronous and synchronous pacemakers. Asynchronous pacemakers stimulate the heart at a constant rate irrespective of the current heart rate or any other physiological feedback. Synchronous pacemakers deliver electrical stimulation pulses to the heart based on feedback. For example, some cardiac arrhythmias only occur at certain times. Therefore, the heart only has to be stimulated at those times. Additionally, delivering stimulation at the inappropriate time in the cardiac cycle such as during the repolarization period can cause a spontaneous ventricular contraction, ventricular tachycardia, or fibrillation. Some pacemakers measure the ECG signal in addition to pacing the heart. These systems have smart algorithms embedded that then detect the QRS complex of the ECG, calculate heart rate, and stimulate the heart at the appropriate time in the cardiac cycle.

New types of cardiac pacemakers are evolving to better simulate ANS control over heart rate variation and cardiac output of an individual with intact physiological control. Several types of physiological sensors have been employed as the inputs to control heart rate stimulation rate and magnitude. These variables have included right-ventricle blood temperature, ECG stimulation to T wave interval, ECG R-wave area, blood pH, rate of change of right ventricular pressure, respiration rate, and body vibrations. By including a wide range of sensors that the ANS typically has available, artificial systems may be able to better regulate heart rate.

Methods for Calculating Heart Rate

Heart rate has shown to be an important variable to measure in medical research applications as well as in artificial systems to control cardiac function. Therefore, quantitative methods need to be used to calculate heart rate and heart rate variability. There are many methods and sensors that can be used to calculate heart rate. One method is to utilize quantitative features from an ECG recording. Both time domain and spectral techniques can be employed to calculate heart rate from the ECG signal. There are tradeoffs to using each type of method. Time domain

methods are computationally simple to implement, however, they can lack the ability to discriminate some features of the ECG signal. While frequency based methods such as a Fast Fourier Transform (FFT) and power spectral density estimation can be more computationally intensive, they can offer improvements to time domain methods.

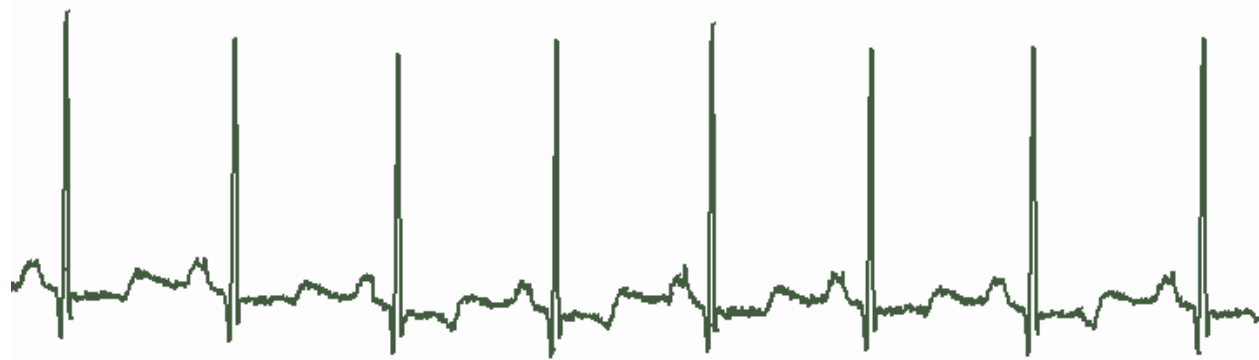


Figure 2. A normal ECG signal.

Through visual observation of a normal ECG signal you could simply count the number of QRS complexes that occur over a given period of time (Fig 2). You would then divide the number of complexes that were found by the amount of time to yield heart rate. This is a simple method of using a temporal feature of the ECG to calculate heart rate. For the purposes of this laboratory session we will utilize threshold detection on the QRS complex to calculate heart rate. Therefore, to implement this in a computer based method we need to define what a QRS complex is. There are several QRS complex variables that need to be defined by a user to implement this type of algorithm. These include the amplitude threshold, how long the amplitude should stay above the threshold, and how much past data should be included in the calculation.

In addition to temporal methods, you may also use frequency based methods to detect heart rate. For example, if you calculate an FFT over an ECG signal, you should obtain a peak in the power spectrum at the average heart rate. If the average heart rate of the subject was occurring at 60 beats per minute, you would expect to see a peak around 1 Hz. However, a disadvantage to this method is that you cannot examine how the heart rate was changing over the entire time of the recording. In other words, this method does not provide a quantitative measure of heart rate variability. Utilizing joint time-frequency analysis methods will allow a user to visually inspect how the heart rate is changing over time in response to other variables.

Finally, artifacts and noise can have a large impact on the ability of an algorithm to calculate heart rate. For example, motion artifacts can often have a larger amplitude than the actual QRS complex of an ECG recording. If one is using simple threshold detection to calculate heart rate the algorithm may confuse motion artifact for a QRS complex and yield an inaccurate reading. Therefore, algorithms should also include methods for filtering artifacts and noise.

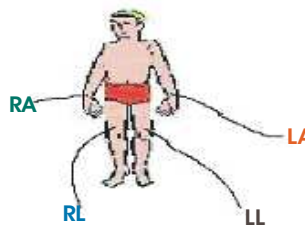
Experimental Methods

Experimental Setup

This laboratory will use three channels to record a standard three lead ECG. You should watch the setup movie included with the software prior to setting up the experiment.

1. Your BioRadio should be programmed to the existing “LabHRDetect” configuration.

Subject Recording Sites



BioRadio Inputs

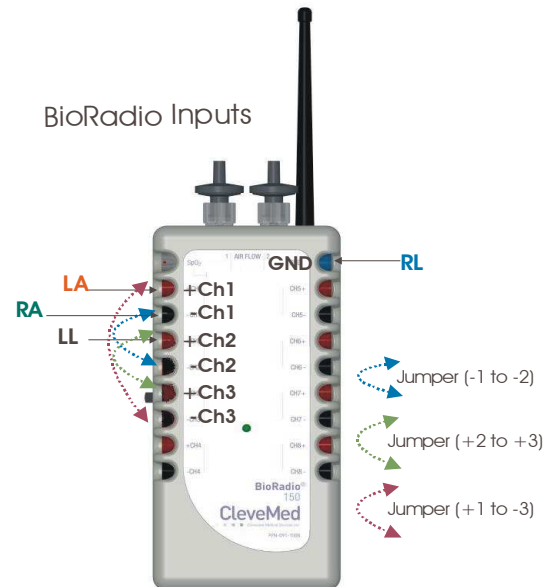


Figure 3: Setup for Lab ECG.

2. For this laboratory you will need to use four snap electrodes from the BioRadio Lab Kit. Remember that the electrode needs to have good contact with the skin in order to get a high quality recording. The surface of the skin should be cleaned with alcohol prior to electrode attachment. For the best recordings, it is best to mildly abrade the surface with pumice or equivalent to minimize contact resistance by removing the outer dry skin layer. Attach one electrode on the palmar side of the right wrist, one on the palmar side of the left wrist, one on the left leg, and one on the right leg. **NOTE: The electrodes on the arms can be placed at the wrists and the electrodes on the legs can be placed near the ankles.**
3. After the electrodes have been placed on the subject, connect one snap lead to each of the four electrodes. Then, connect those snap leads and jumpers to input channels 1, 2, 3, and the ground using the picture above as a reference (Fig 3).

Procedure and Data Collection

1. Run the CleveLabs Course software. Log in and select the “Heart Rate Detection” laboratory session under the Clinical Applications subheading and click on the “Begin Lab” button.
2. Turn the BioRadio unit ON.
3. Click on the ECG data Tab and then on the green “Start” button. Three channels of ECG should begin scrolling across the screen.
4. The first part of the lab will record normal resting ECG with the subject sitting up. It is important that the subject is relaxed and still during this procedure in order to prevent EMG artifacts from contaminating the ECG signal. Record about 30 seconds of data to a file named “HRrest”. Also, report a screen shot of this to your report. While you are recording this data file, record the subject’s pulse at their wrist and note it for later.
5. Next, begin saving another data file with the subject still at rest. Call this data file “HRchange”. After about 15 seconds instruct the subject to stand up and begin jogging in place. The subject should jog quickly in place for about 20 seconds. Then instruct the subject to sit down again and continue to record data for another 15 seconds. Record the subject’s heart rate at their wrist before and after the jogging and note it for later.
6. With the subject sitting and relaxed again, click on the Spectral Analysis tab and examine the ECG signal in the frequency domain. Depending on your surroundings, it is likely that there is some 60Hz noise in the signal. Note where the peak frequency of the signal occurs. Report this plot.
7. Setup filter parameters that will remove the 60Hz noise from the signal and report the filtered spectral analysis to verify this.
8. Now click on the Processing and Application Tab.
9. This application is a simple heart rate detector. The detector works based on simple threshold detection. There are three parameters you must define in order for the heart rate detector to work: channel, amplitude threshold, and time threshold. Channel refers to the channel that you wish to use to detect heart rate from. You should select the channel with the cleanest looking signal and largest QRS complex. This is the channel that will be shown in the ECG plot on the processing and application page when it is turned on. Next, setup the filtering parameters for that channel that will remove the 60Hz noise similar to what was done earlier. Set the time threshold, which refers to the minimum time that the signal must go above your defined amplitude threshold in order for it to be considered a peak. Finally, define your amplitude threshold. You should be able to pick a threshold that will work by watching the QRS complex peak on the scrolling plot.

10. Turn on the Simple Heart Rate detector. It will take approximately 15 data collection intervals before a valid heart rate is returned. Report this plot.
11. This simple heart rate detector calculates the peaks over the past 15 data collection interval sessions. Therefore, the data collection interval that you choose has an effect on resolution of the heart rate detector. Try running the detector at a data collection interval of 100ms and then again at 500ms. Note the minimum differences between calculated heart rate for each interval.
12. Now request the subject to jog around the room, or perform some sort of physical activity for a few minutes to increase heart rate. Then have them sit down again and save 10 seconds of the ECG while the subject is relaxed. Name the data file “HRexercise”. Report this plot. Make sure you are recording the wrist pulse as well and noting it.
13. Finally, we are going to examine the effects of motion artifact on the simple threshold detection for heart rate calculation. With the subject still sitting and the heart rate detector running, instruct the subject to make wild arm movements. Report a screen capture to your report. Save this data to a file called “ECGarms”. This file should contain a few seconds of normal ECG followed by motion artifact from the arms and then a few seconds of normal ECG again.

Data Analysis

1. Using the post processing toolbox open the file named “HRrest”. Complete an FFT and JTFA over the data file. Report a screen capture of each type of analysis to file.
2. Repeat step 1 for “HRchange” and “HRexercise”.
3. Write your own program in MATLAB or LabVIEW to compute the average heart rate of the data files “HRrest” and “HRexercise”.
4. Using MATLAB or LabVIEW create your own algorithm for detecting heart rate that is capable of compensating for motion artifact. You should use the saved data file called “ECGarms” to create this algorithm.

Discussion Questions

1. What is the heart rate of the subject laying down at rest before exercise? What is the heart rate of the subject after exercise? Why does the heart rate change during exercise?
2. Explain the location of the peaks in the FFT from the HRrest and HReXercise data files. What do the peaks represent and why do they shift between files?
3. What information does a JTFA reveal about heart rate that an FFT analysis may not be able to illustrate? Was this illustrated in the JTFA of your HRChange data file?
4. How accurate was the heart rate detector algorithm compared to the pulse that you measured at the subject's wrist?
5. The algorithm that is used in this laboratory is simple threshold detection. What are the problems with using this method and what may be a better method to use?
6. Explain how the resolution of the simple heart rate detector is affected by the data collection interval selected.
7. Examine the plots that were made when the arms were moving and when the subject was flexing their chest muscles. Explain why these plots look the way they do.
8. What could the JTFA be used for in heart rate detection? What advantages may it have over the threshold detection methods that you employed in the session?
9. Suggest how you would attempt to remove the artifact from the plots with the subject's arms moving. Explain any problems you might encounter in your proposed method.
10. What purpose does a pacemaker serve? Describe the difference between synchronous and asynchronous pacemakers.

References

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