Gait Analysis Laboratory

CleveLabs Laboratory Course System Version 6.0

Introduction

Walking is the most convenient way for humans to travel short distances and exercise. It is an activity that requires coordinated contraction of the skeletal muscles in our legs, balance of our entire body, and reflexes to maintain stability in light of external forces that can perturb the gait cycle. However, in spite of all these required parameters, we seem to walk almost effortlessly, without thinking about it. Walking is a natural reflex that some researchers say is controlled by central pattern generator circuitry located in the spinal cord. Normal gait cycles have regular, repeating cycles and phases. Free mobility of the joints and the ability to apply appropriate forces are key components in increasing walking efficiency. However, when neurological disorders or other clinical problems exist, the gait cycle can be interrupted and appear abnormal and the efficiency of gait can be greatly decreased.

Gait analysis is a quantitative measurement of various parameters as a person is walking. It uses electronic measurements, such as EMG, velocity, joint angles, and three dimensional tracking of the rigid segments of the body to obtain information about motion as a person walks. The study of gait can give us a better understanding of pathologies that affect it, and can be used to study the mechanisms that result in optimal walking movements to increase gait efficiency.

During this laboratory session, students will record EMG from their calf muscles as they walk. They will review the alternating patterns of EMG as they walk and process that data to determine their stride times in each leg. A clinical database of stride times of normal subjects and those with neurological disorders will be reviewed. Students will then develop algorithms to predict what subject has a particular neurological disorder based on quantitative features of their stride times.

Equipment required:

- CleveLabs Kit
- CleveLabs Course Software
- Five (5) snap electrodes
- Five (5) snap leads
- Skin Prep
- Microsoft Excel®, MATLAB®, or LabVIEW™

Background

The Gait Cycle and Phases

One gait cycle in a normal subject is defined as the time from the touching of the heel of one foot to the ground until that heel touches the ground to begin the next cycle. A stride is the equivalent of the gait cycle. Each gait cycle consists of one period of support on the left leg, one period of support on the right leg, and two periods of support on both legs. These translate into four phases in normal gait: stance, heel-off, swing, and heel-strike. Heel-strike is initial contact made with the ground by the foot. Following heel-strike is the stance phase, which includes the loading response and transfer of weight on the new stance leg while maintaining velocity and balance. The swing phase consists of the time when the body is supported by one leg, known as single support. The first half of single support is referred to as mid stance and includes the period when the center of mass passes over the supporting foot. The last half of single support is the terminal stance. In this phase, the heel of the support foot rises and the other foot makes contact with the ground. Heel-off occurs when the heel rises off the ground.

Gait Muscle Activation

Several muscles of the leg are responsible for creating the gait cycle and maintaining balance during walking. The gait cycle begins with the stance phase. At the start of this phase, the knee and hip extensors are activated so that these joints will not flex noticeably under the weight of the body. The extensor muscles of the leg provide the force that causes the body to be propelled forward. Additionally, the ankle extensors strongly contract at the end of the stance phase. As the ankle extends, the body is pushed forward.

The swing phase begins after heel-off has occurred. In the swing phase, the back leg is transferred forward. The force that causes this leg movement is mainly provided by the hip extensors. At the end of the swing phase, heel-strike occurs. At the moment of contact, the foot is pointed upward. Ankle extension causes the whole foot to touch the ground, and the stance phase begins again.

Normal Gait

By looking at quantitative aspects of each individual phase, the characteristics of an efficient gait can be determined. These characteristics are important for comparison with the gait patterns of those with pathologies that result in poor gait. Major components of walking include equilibrium, the ability to maintain balance, and the ability to initiate and maintain stepping. Many biological factors contribute to these components. The body needs to have intact bones and well functioning joints. Muscle tone must be high enough to resist gravity and low enough to allow movement. Antagonist muscles must be able to work in a coordinated fashion. Also, the senses, especially sight, are an important part of gait.

EMG Use for Gait Analysis

EMG is a useful parameter to quantify when examining the gait cycle. For example, the EMG of a normal subject could be collected as they walk around a room. After processing the EMG, one could then examine the timing patterns of the firing of different muscles that produce the gait cycle. The same experiment could then be repeated with individuals who have neurological disorders that affect their gait. By examining the differences in the timing patterns of the EMG signals among normal and affected groups, a clinician may be able to determine which muscle is causing the deficiency in the gait cycle and come up with strategies to compensate for it.

Clinical Disorders and Gait

There are several neurological disorders that can have an impact on the gait cycle. Some of these include Huntington's disease, Parkinson's disease, and Amyotrophic Lateral Sclerosis. **Several examples of all the abnormal gait stride times described below are included with the laboratory course software. You will explore these in this laboratory session. These data files were obtained from the Physionet website at www.physionet.org.** A description of each of these disorders is given below:

Huntington's disease

Huntington's is a genetic, degenerative, neuropsychiatry disorder. Degeneration of nerve cells causes uncontrolled movements, loss of intellectual faculties, and emotional disturbance. In patients with Huntington's disease, there is often a "prancing" and wide gait. The gait of someone with Huntington's is often mistaken for that of a person who has too much to drink.

Parkinson's disease

Parkinson's is a progressive disease of the central nervous system. Symptoms of the disease include a decrease in spontaneous movement, postural instability, rigidity, bradykinesia, tremor, and gait difficulty. In patients with Parkinson's, there is a tendency to lean backward or forward when walking. Often, these patients walk with a stooped, head-down stance, take short steps, and use little or no arm swing. It is common for someone with Parkinson's to have trouble initiating walking and to freeze in mid-stride.

Amyotrophic Lateral Sclerosis

Amyotrophic lateral sclerosis (ALS) is commonly known as Lou Gehrig's disease. It is a progressive and fatal neurological disease. ALS results form the degeneration of nerve cells that control voluntary movement in the spinal cord and brain. Loss of motor neurons causes the muscles to weaken and eventually can cause paralysis. A common symptom of ALS is weakness in the ankle and foot. This weakness affects the gait. This results in patients dragging their leg or being unable to pick up their foot when walking.

In order to compensate for this, patients often excessively raise their hip or knee. This behavior can cause accidental falls.

Experimental Methods

Experimental Setup

This laboratory will record EMG in the subject's calf muscles. You should watch the setup movie included with the software prior to beginning the experimental setup.

1. Your BioRadio should be programmed to the "LabGait" configuration.

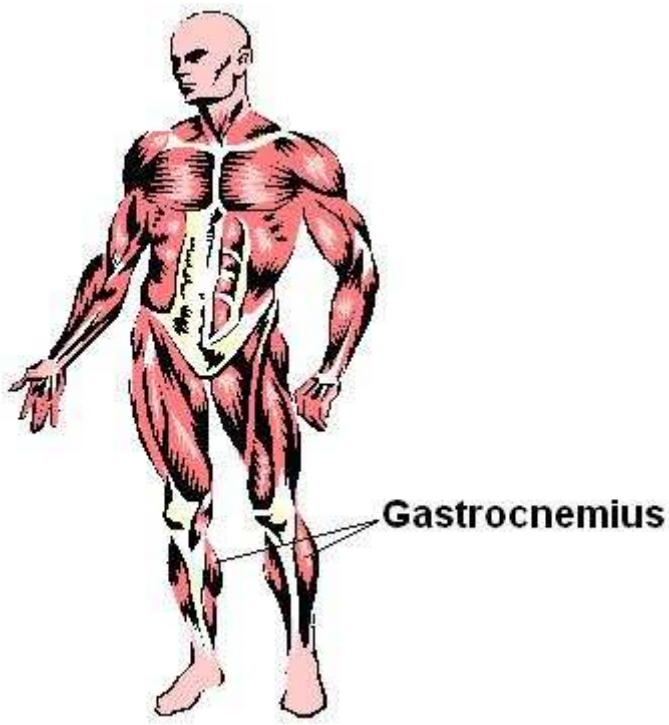

Figure 1. Gastrocnemius (or calf) muscles of the leg.

2. For this laboratory you will need to use five 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 two electrodes about one inch apart over the surface of the left calf (Fig 1), attach two electrodes about one inch apart over the surface of the right calf, and attach one electrode to the bony part of one of the knees to use as the ground electrode.

3. After the electrodes have been placed on the subject, connect one snap lead to each electrode. Then, connect those snap leads to the harness inputs channels 1, 2, and the ground using the picture below as a reference (Fig 2).

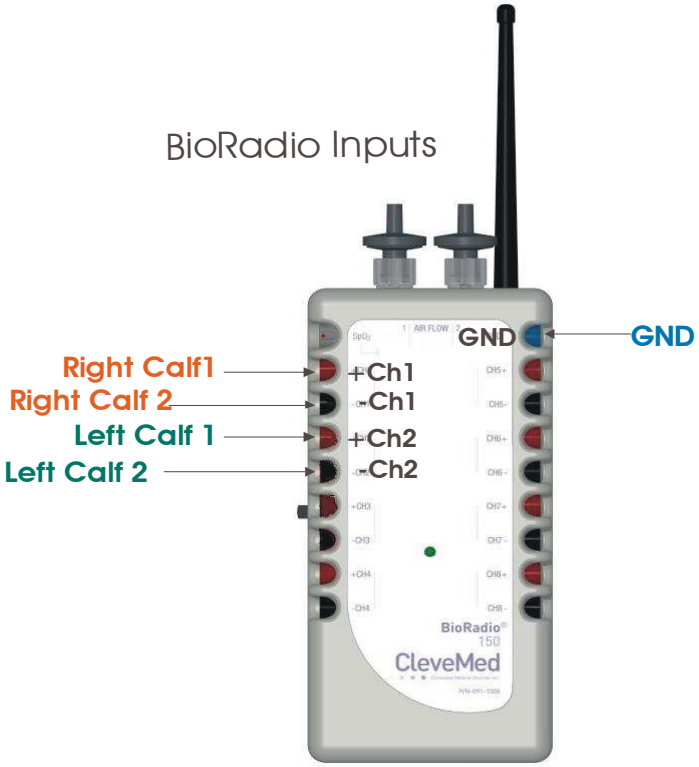

Figure 2: BioRadio Leg EMG Setup

Procedure and Data Collection

1. Run the CleveLabs Course software. Select the "Gait Analysis" laboratory and click on the "Begin Lab" button.

2. Turn the BioRadio ON.

3. Set the data collection interval to be 100ms and click on the green "Start" button.

4. Click on the "Process EMG" tab and then on the "Time Domain" tab to start the EMG data scrolling on the screen. Set the filter type to band pass, the high pass setting to 20 Hz to help remove motion artifact, the low pass setting to 400 Hz, and the order to 4. Turn on the filter.

5. Watch the EMG signals on the screen as the subject walks around the room. You should see an alternating pattern of EMG signals increasing and decreasing in both legs as the subject walks. Capture a screen shot of these alternating patterns for your report.

6. Save five data files that are each approximately 30 seconds long with the subject walking at a normal speed. Name the data files "walknormal1", "walknormal2", …

7. Save five data files that are each approximately 30 seconds long with the subject walking at a fast speed. Name the data files "walkfast1", "walkfast2", …

8. Save five data files that are each approximately 30 seconds long with the subject walking at a slow speed. Name the data files "walkslow1", "walkslow2", …

9. Now click on the tab labeled "Stride Analysis". There will be a drop down menu on this screen which contains a list of all data files that you saved during this laboratory session. Select the data file named "walknormal1", and then click on "Analyze Stride". The raw EMG data will appear in the plots for each leg.

10. Now you will process that data to obtain stride time from the EMG signals. There are several variables available for you to complete that processing. The EMG signals are processed in the following manner. First, we rectify the EMG signals. Then we complete a sliding window integral of the EMG signal to smooth it. You can select the window size that you want to use to see the effect on the EMG signal. Try several values of the sliding window size and see the effects on the processed EMG signal in the bottom plot. Each time you change the window size you must click on "Analyze Stride" to update the plots.

11. Once you are happy with the window size, you will use the processed EMG signal in the bottom plot to calculate stride time. First, you must select the leg that you want to use (right or left). Next, you should select the amplitude threshold and the time threshold that you want to use to define that EMG activity occurred. The amplitude threshold refers to the amplitude level that the signal must cross in order for it to be considered a cycle of EMG activity. The time threshold refers to the amount of time the signal must stay above the amplitude threshold for it to be considered a cycle of EMG activity. Then click on "Analyze Stride".

12. The number of strides found will be calculated as well as a column that lists the times it took for each stride. Once you are happy with the calculation, you should click on "Write Stride File" and save it with an appropriate name. This will save the column of stride times to a file that you will need later. You should complete this analysis for each leg. Also, you should complete this analysis for all 15 data files that you saved. Save a few screen shots of this EMG processing for your report.

13. Next, click on the tab labeled "Sample Data". This section contains a clinical database of stride times that were collected from various subjects. Click on the "Plot" button to

review sample stride times from a control subject, a subject with ALS, a subject with Huntington's disease, and a subject with Parkinson's disease. You can toggle the number of the subject to review different subjects. Next to each subject number is the mean and variance of the stride time for the subject. Examine several of the subjects and notice trends in subject groups.

14. Next, click the "Clustering" tab on the screen. The purpose of this section is to illustrate in three dimensional space how subjects can be classified according to their disease, simply by examining quantitative characteristics of their stride time. Four groups are represented in the plot. Normal subjects, ALS subjects, HD subjects, and PD subjects. You can turn a particular subject group on or off by clicking on the green LED button under the view data label.

15. You can rotate the plot by left clicking on the mouse. Holding the mouse button down and moving the mouse around.

16. You can plot one of several parameters from the drop down list for each axis. Once you have selected the specific variable that you want to plot for each axis, click on "Plot Parameters" to update the plot. You can also select to auto scale the plot, or manually set the maximum and minimum ranges. The quantitative variables that you have to select for each axis include the mean, standard deviation, stationarity, and coefficient of variation.

    a. Mean – the mean of the stride times for a particular subject
    b. Standard deviation – the standard deviation of the stride times for a particular subject
    c. Stationarity – a measure of how local averages change with time
    d. Coefficient of variation – variability normalized to the mean value

17. First, turn on only the normal subjects and the HD subjects. Set the x-axis to the mean, the y-axis to stdev, and the z-axis to the coef var. Then click on plot parameters. Rotate the plot around and notice how the data sets group into the three dimensional space. The normal subjects are in one cluster and the HD subjects are located in another larger cluster. This illustrates that these variables may be used to predict what subject has HD and who is normal.

18. Try many different combinations of subject groups and variables. Notice what groups can be separated into different clusters by what variables. What groups are not distinguishable? You should create several screen shots of the plots that you create to illustrate these points in your report.

Data Analysis

1. Use your stride time files and compute the average stride time for each file. Then compute the average stride time for each data collection speed: fast, normal, and slow.

2. Using MATLAB or LabVIEW open your saved data files and try to use different processing techniques to calculate stride time from the EMG data. Try to improve the results that you obtained using the course software algorithm.

Discussion Questions

1. Why is it important to apply a high pass filter to the EMG signals in this walking example?

2. How well did the stride time algorithm work in this example? What changes could be made to the algorithm to improve performance?

3. How well did the stride times that you calculated correlate to the expected speeds that you were walking? If they did not correlate well, how might you improve the algorithm?

4. What clinical groups of subjects could be easily distinguishable in clusters from other groups and using what variables?

5. What other variables could you calculate from stride time that may be useful to cluster subjects into different groups? Are there other variables that you may want to quantify during walking other than stride time that could be useful?

6. What is the effect of increasing the number of dimensions on a clustering example? Would it be useful to have more dimensions available for clustering?

7. Explain how a clustering algorithm could be used to separate different clinical groups and also to predict if a person has a particular clinical disorder.

8. The clustering algorithm that you are using in the software program creates a visual display of the clustered data. Explain how you would quantitatively develop an algorithm with numbers to predict who has what disease using the variables and clustering method.

References

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