Electromyography II Laboratory

(Hand Dynamometer Transducer)

CleveLabs Laboratory Course System Version 6.0

Introduction

As described in the Electromyography I laboratory session, electromyography (EMG) is an electrical signal that can be recorded with electrodes placed on the surface of the skin. The electrical biopotential that can be recorded from a muscle is a function of the number of fibers that are contracting in the muscle. The more fibers contracting in parallel, the larger the electrical signals and the more force a muscle generates. Therefore, a general relationship exists between the EMG recorded from a muscle and the force that muscle is producing.

In order to better understand and quantify the relationship between force and EMG, a force transducer can be utilized to measure the amount of force that is produced by a muscle or group of muscles. For this laboratory session, we will utilize a hand dynamometer to measure force. The hand dynamometer allows measurement of the amount of grasp force a subject is exerting on it. In addition to measuring grasp force, we will also record one channel of EMG from finger flexor muscles during the experiments. This will allow us to quantify the relationship between hand grasp force and finger flexor EMG.

There are many biomechanical principles that can be explored by quantitatively evaluating force and muscle activity. For example, one can examine how force magnitude declines over time during a maximum isometric contraction to explore muscle activity changes during fatigue. In another example, reaction time can be explored and delays between the electrical activity of a muscle and the force generation phase can be measured. Measuring force and EMG has a wide range of applications in biomechanics, sports medicine, and biomedical engineering.

Equipment required:

- CleveLabs Kit
- CleveLabs Course Software
- Three (3) Snap Electrodes and Snap Leads
- Hand Dynamometer and Transducer Interface Cable
- Microsoft® Excel, MATLAB® , or LabVIEW™

Background

Force Sensing

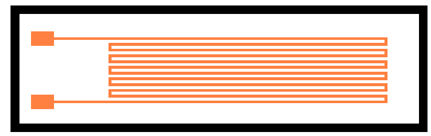

Figure 1. A strain gage may consist of a tightly wound wire.

In order to quantify the force that a muscle or group of muscles is producing, a sensor is required that can accurately measure the force exerted on it. One common method for designing and implementing force transducers are strain gages. There are various forms of strain gages, but a very common method is resistive strain gages. Resistive strain gages are composed of a conductive wire wound back and forth and bonded to a flexible insulating backing. They are wound back and forth to maximize the length of the conductor, and thereby maximizing the sensitivity, while minimizing the size of the strain gage (Fig 1). Minimizing the size of the strain gage is important, because as the size increases, the output of the gage will decreasingly approach a point strain. As the size of the sensor increases it would increasingly measure a strain averaged over an area.

Resistive strain gages operate on the principle that as the strain in a wire increases, so does its resistance. The relationship is a function of resistivity of the gage conductor, the length of the conductor, and the cross sectional area of the conductor. The formula that describes this relationship is: $R = \rho \frac{l}{A_c}$ The strain gage is bonded in such a way that the strain measured in the gage is considered equivalent to the surface strain in the part being investigated.

Application of Strain gages

There are different ways to design an electrical circuit to measure the voltage in a strain gage transducer. A very common circuit setup for a strain gauge is a Wheatstone bridge (Fig 2). The Wheatstone bridge is an electrical circuit that is used to measure a resistance. V+/- refers to the excitation voltage of the circuit. V output is the measured voltage from the circuit which is a function of the resistances. Since the Wheatstone bridge is well suited for measuring small changes in resistance, it is a useful tool for strain gages. A full bridge setup may have temperature compensation built into the circuit. This would allow the system to compensate for any changes in size or resistance due to temperature changes.

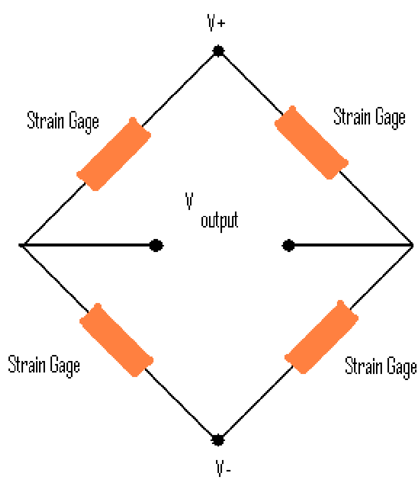

Figure 2. A typical Wheatstone bridge circuit.

The hand dynamometer that we will be using in these lab experiments utilizes total strain energy input into bending beams to determine the force input. This energy method is advantageous because the force can be accurately calculated no matter where the force is applied along the beam. It is calculated from the energy put into the beam rather than force and moment equations. The hand dynamometer has a bending beam setup with strain gauges along the compressive and the tensile surfaces of the beam. From the strain at these points, the strain energy input may be calculated and related to the bending force applied to the beam using Castigliano's Theorem. Castigliano's Theorem is based on the conservation of the strain energy that is put into a material in order to deform it. The first partial derivative of total strain energy with respect to an external load is equal to the displacement at the point of application of the load. In the same direction, the relationship between this energy of deformation, the geometry of the beams being deformed, and the strain at the points where strain gages are attached gives enough information to calculate the force being applied to the beam.

Delays in Muscle Contraction and Reaction Time

During the EMG I laboratory session we were measuring isometric contractions as you held different weights. During this lab session however, we will begin to explore how the electrical muscles excitation compares with the force generation of a muscle. The generation of force by a muscle can be separated into two events including the excitation and contraction phases. When you record an EMG signal, you are recording the excitation phase of the process. The electrical excitation opens actin sites in the muscle fiber which allows myosin heads to insert and the contraction to begin. Therefore, there is an electromechanical delay that occurs between the excitation phase and the contraction phase of the muscle action. The time of the electromechanical delay can vary based on the speed at which the muscle is recruited into a task. In this experiment, you will be recording both force and EMG. Therefore, you will be able to measure the delay between the two events.

Muscle Fatigue

Muscles can begin to fatigue after prolonged periods of use. The energy supply cannot meet the energy demands of the muscle. In this case, the force output of the muscle will decrease until the muscle is rested for a short time. Chemical measurements have shown that the ATP in a muscle is not significantly reduced during fatigue. Therefore, the actual reason the fatigue occurs may lie somewhere in the coupling between the membrane depolarization and myofilament activation.

When a muscle fatigues, the quantitative characteristics of the EMG signal may begin to change. Therefore, it may be possible to detect when a muscle is fatiguing by monitoring the electrical muscle activity. Typically, as a muscle begins to fatigue, fewer motor units will be firing which will decrease the frequency of the EMG signal.

Muscle force can also be affected by other parameters. The amount of force a muscle can produce is impacted by the velocity at which the muscle is contracting and by the length of the muscle. Therefore, position and velocity have a non-linear effect on the ability of a muscle to generate force.

Experimental Methods

Experimental Setup

During this laboratory session you will record grasp force with the hand dynamometer and EMG data from those muscles generating the force with a setup similar to that of the Electromyography I laboratory. There are three particular experiments that will help you to thoroughly investigate the relationship between EMG signal and the force output. The first experiment will help you explore the relationship of muscle contraction events as related to force and EMG. The second experiment is designed to investigate muscle exertion fatigue over time. The third experiment will investigate some of the aspects of right/left hand dominance. You should be sure to watch the experimental setup movie included with the CleveLabs software before beginning the initial setup in the experiment.

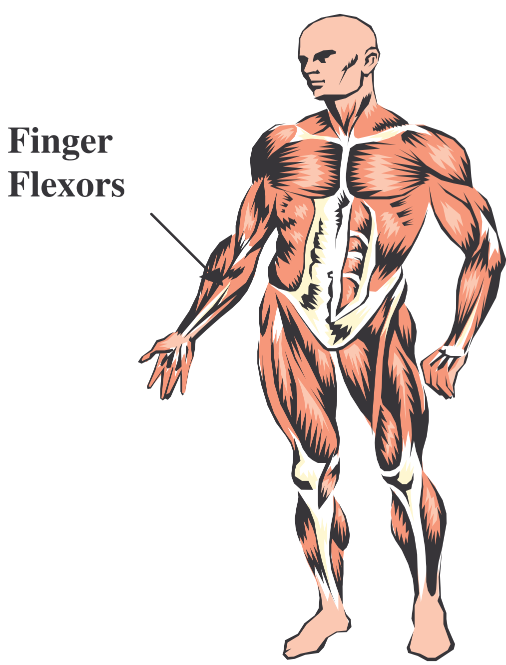

Figure 3: Locations of the finger flexors.

1. For this laboratory you will need to use three snap electrodes from the CleveLabs 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 above the finger flexor muscles and attach one electrode to the bony part of the elbow to use as the ground electrode.

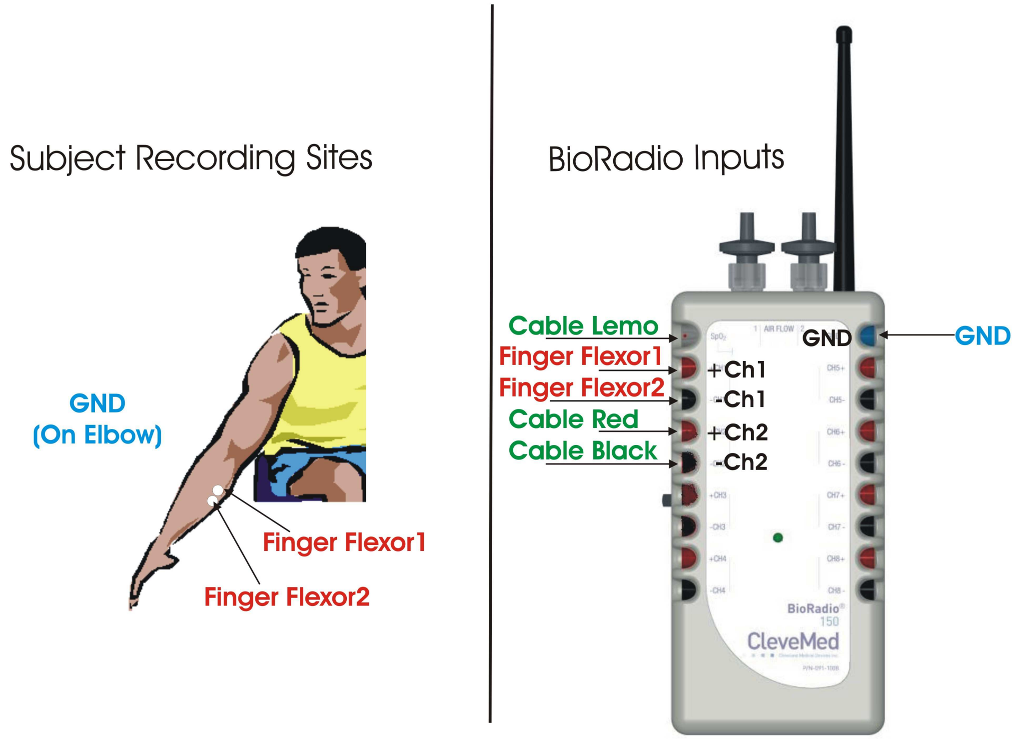

Figure 4: EMG Setup

2. After the electrodes have been placed on the subject, connect one snap lead to each electrode. Then, connect those snap leads to input channel 1 and the ground using the picture above as a reference (Fig 4).

3. Connect the transducer interface cable to input channel 2 and the pulse oximeter input on the BioRadio 150. The pulse oximeter input provides power to the transducer.

4. Connect the hand dynamometer to the transducer interface cable.

Procedure and Data Collection

1. Run the CleveLabs Course software. Log in and select the "Electromyography II" laboratory session under the Advanced Physiology subheading and click on the "Begin Lab" button.

2. Turn the BioRadio ON.

3. Click on the EMG data Tab and then on the green "Start" button. One channel of EMG and one channel of hand grasp force should begin scrolling across the screen. Your BioRadio should be programmed to the "LabEMGII" configuration.

4. First you will record isometric EMG from your finger flexors as you record grasp force. An isometric contraction is one in which the arm does not move during the contraction. More specifically, the length of the muscle does not change during the contraction. Click on the "BioRadio Data" tab. Examine the EMG signal and the force as you squeeze the force transducer.

5. You may need to zero the force transducer. Set the hand dynamometer flat on its side on the table, and then click on the "Zero Force Sensor" button. That will zero the force transducer.

6. Now click on the "Force vs EMG" tab. First disable the plot, then click on "Clear Plot". This will erase everything on the plot. This will plot average force over the bin integrated EMG signal on the same plot. The data is processed over bins that are the sizes of your data collection interval. Make sure that your data collection interval is set to 100ms. Now, with the subject ready to begin grasping the hand dynamometer, enable the plot. Instruct the subject to quickly squeeze the sensor as hard as they can, hold it for three seconds, and release it. Then disable the plot. Repeat three trials of this and save each of the screen shots for later. During the trials be sure to watch the data points as the plots are created. Notice how the slope of the plot is different for the grasp and release portions of the trial. Save one of these trials to a data file named "GraspForce".

7. Change the data collection interval to 500ms and repeat step 6.

8. We will now examine the effects of fatigue on the EMG signal. Click on the "fatigue" tab. Set the data collection interval to 1000ms. Begin saving data to a file named "fatigue".

9. Instruct the subject to squeeze the grasp force sensor as hard as they can for 2 minutes. If the subject is uncomfortable, you may limit the time they are squeezing the sensor. Examine what happens to the force amplitude, the bin integrated EMG value, and the peak frequency over the trial time. Create a screen shot at the end of the trial.

10. Finally, we are going to examine the effect of hand dominance on grasp force. You will need three subjects for this exercise. Go back to the "BioRadio Data" tab. Each subject will squeeze the hand dynamometer as hard as they can three times with each hand. Note the maximum force that is generated for each trial. Each subject should complete three trials with their left hand and three trials with their right hand. For each subject, you should note which hand is their dominate hand. You do not need to record EMG for these trials.

Data Analysis

1. First, examine the relationship between force and EMG that was obtained with your screen captures of the force versus EMG plots.

2. Using MATLAB, LabVIEW, or Excel open your saved data file named "Force" and plot processed bin integrated EMG versus force and fit different curves to the data. (Note: to improve your data fit, you should apply a 30Hz high pass filter to the EMG data before processing it.) Find the type of curve which best fits the data. For example, first try a straight line, and then try a second order polynomial, next try an exponential fit… Find what type of curve best fits the data.

3. Next try processing the EMG using different methods and repeat step 2. For example, process the EMG using a sliding window average or a root mean square value instead of bin integration.

4. Next, examine the fatigue data using the Post Processing Toolbox. Open the data file named "fatigue". Click on the JTFA tab. Select the channel "EMG" and complete a JFTA. You should be able to see a decrease in the frequency of the EMG signal over time due to fatigue.

5. Finally, examine the hand dominance data. You should have 6 hand grasp values for each of three subjects. Calculate the average maximum hand grasp value for each hand of each subject.

Discussion Questions

1. What is a common method used for the design of a force transducer and how does it work?

2. Why is a Wheatstone bridge commonly used in strain gage applications?

3. Derive the circuit equation for calculating Voutput in the Wheatstone bridge circuit if V and all the resistances are known. See the values below.

4. During the experiments where you viewed processed EMG versus average force in real-time, there should have been a flatter slope during the increase of force and a steeper slope during the decrease of force. This should have been noticeable when the data collection interval was set to 100ms. Explain what causes the change in slope i.e. what causes the electrical potential to change before force?

5. What is the typical delay time between initiation of the electrical EMG signal and the actual generation of force?

6. How well were you able to fit curves to the force versus EMG relationships? Were the relationships linear? Did different EMG processing techniques produce different shaped curves?

7. What factors may influence the force EMG relationship?

8. As a muscle fatigues, what happens to the force, EMG amplitude, and EMG frequency as this fatigue increases?

9. Did the dominant hand of a subject always produce the largest average maximum grasp force? Explain why or why not.

10. Why is it useful to measure force and EMG at the same time?

References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Kandel ER, Schwartz JH, Jessel, TM. Essentials of Neuroscience and Behavior. Appleton and Lange, Norwalk, Connecticut, 1998

3. Rhoades and Phlanzer. Human Physiology, Third Edition. Saunders College Publishing, Forth Worth, 1996.