# Electromyography I Laboratory

Introduction

Walking, running, manipulating tools, and performing any kind of motor activity all rely on the coordination of various muscles in the body. Humans are capable of grading the amount of force generated by each of our muscles. This is useful for controlling a wide range of movements that involve both large amounts of force and the agility required for precise movements. For example, a weight lifter performing squats needs to generate high muscle forces in their legs while ballet dancer uses many of the same muscles for the agility to control graceful, sweeping movements that seem to defy gravity. Fine control and precision of the hand muscles also allows the surgeon to perform delicate heart surgery and the pianist to play music.
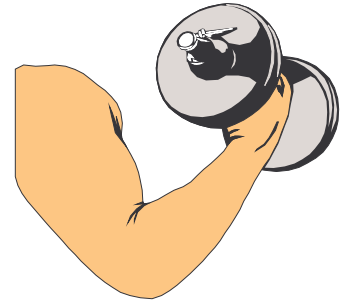
There are three major types of muscles in the body including cardiac, smooth, and skeletal muscle. Cardiac muscle is found in the heart. Smooth muscle is typically found in the internal organs, such as the intestines, the stomach, and the esophagus. Smooth muscle contractions are involuntary, meaning that they are controlled by the autonomic nervous system. Skeletal muscle, on the other hand, is under voluntary control. Skeletal muscle refers to the muscle cells that are attached to the bones in the body, allowing movement. When a person desires to move a limb for example, neural inputs from the brain travel down the spinal cord, project from the spinal cord along efferent nerve fibers, and synapse onto target muscle fibers responsible for controlling the limb. These electrical impulses cause the muscle to contract. Muscles are attached to bone by tendons. Therefore, when the muscle contracts, the tendon pulls on the bone and movement occurs. The action potential is the mechanism responsible for muscle contraction. Surface electrodes placed on the skin above a muscle can measure these action potentials collectively termed electromyogram (EMG). The EMG is a summation of all action potentials occurring in a muscle at a single time.

Monitoring EMG has lead to a greater understanding of muscle properties, given insight into how muscles work together to coordinate tasks, and yielded information about neuromuscular disorders. In this lab, you will record EMG signals from muscles in your upper extremity. You will learn how EMG relates to muscle force and fatigue.

Equipment required:
- CleveLabs Kit
- CleveLabs Course Software
- Five (5) Snap Electrodes and Snap Leads
- Calibrated Weights (Approximately 2.5, 5, and 10 lbs)
- Microsoft® Excel, MATLAB® , or LabVIEW™

Background

Brain Control over Muscle Movement

Voluntary control of skeletal muscle originates from the cerebral cortex of the brain. When a person wishes to contract a muscle to generate movement, the signal originates from the motor strip in the cerebral cortex. The motor cortex (Fig 1) can be broken down into three areas including the primary motor cortex, the premotor cortex, and the supplementary cortex. Each area is organized topographically with different parts of the body represented in different parts of the cortical area. In fact, over 50% of the motor cortex is responsible for manipulating the hand muscles and speech. The premotor cortex is responsible for coarse movement of muscle groups. The premotor cortex prepares muscles for a specific task, such as positioning the arms and shoulder to initiate writing. The supplementary motor cortex works along with the primary cortex to create muscle movement. The supplementary motor cortex is known to provide bilateral control. Torso positioning is accomplished by the supplementary motor cortex. Experiments measuring blood perfusion to the brain using functional MRI have shown that the supplementary motor cortex is also responsible for the mental conception of movement. Researchers have found that when a person thinks about moving their fingers increased blood flow to the supplementary motor cortex occurs, even though no action is being performed. These signals from the motor cortex are then transmitted down the spinal cord over motorneurons and activate the muscle fibers.
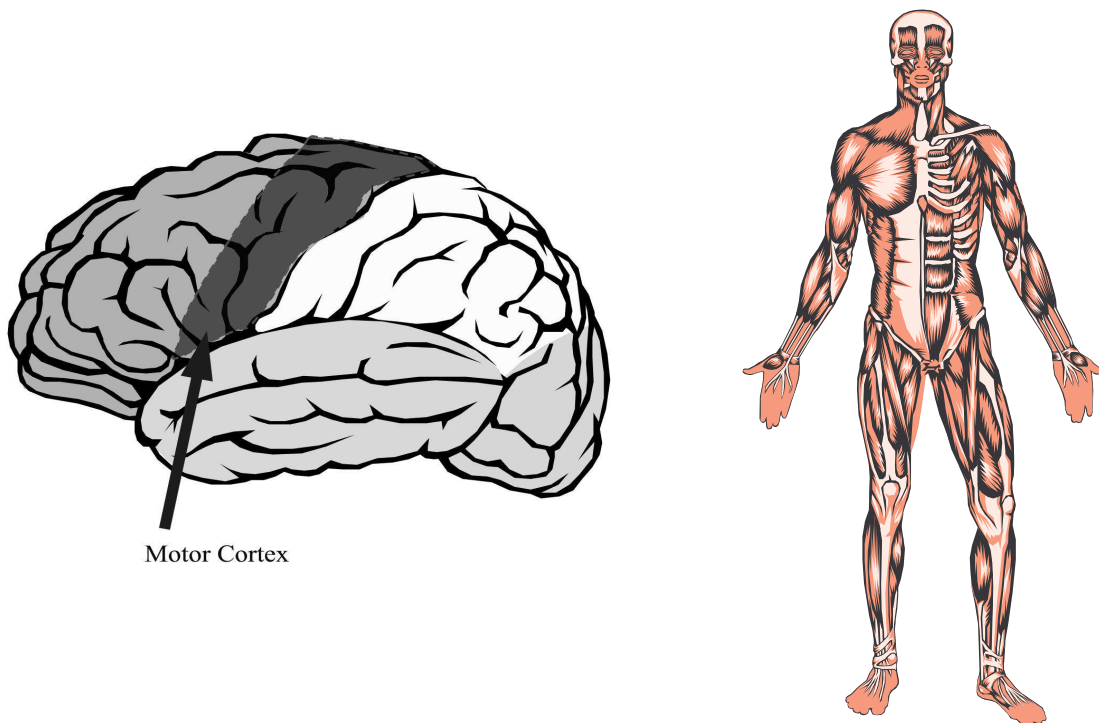

Motor Cortex

Figure 1: The body has over 250 skeletal muscles that are under voluntary control by the motor cortex of the brain.

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Origin of the EMG Signal

To create voluntary muscle movement, an action potential must travel from initiation in the brain to the target muscle. It travels from the brain, into the spinal cord, and then to an efferent nerve which synapses on the target muscle fiber. Each muscle fiber is innervated by a single neuron. However, one neuron innervates several hundred muscle fibers. The number of muscle fibers innervated by a single neuron is called the innervation ratio. A lower innervation ratio corresponds to finer control of muscle forces.

The connection between a nerve and a muscle is called the neuromuscular junction. The action potential propagates down the motorneuron and causes the release of acetylcholine (Ach), a neurotransmitter, at the neuromuscular junction. As Ach is released, it travels across the neuromuscular junction and causes Ach gated receptors on the muscle fiber to open. When these gates open, sodium ions flow into the cell depolarizing it. This potential change activates voltage dependent sodium channels resulting in an action potential that propagates throughout the muscle fiber. The action currents create potentials in the extracellular space that are recorded as EMG.

These action currents travel deep into the muscle fiber by means of the transverse tubule system. These currents cause a potential change that triggers the release of calcium ions from the sarcoplasmic reticulum inside the muscle fibers. Inside the muscle fiber are two filaments, actin and myosin. Actin sites are normally closed, however, in the presence of calcium, these sites open. When these sites are open the myosin head can insert in the actin site. Once inserted, the myosin filament contracts to pull the actin site closer to itself, releases, and then repeats with the next actin site. Therefore, the amount of calcium that is released acts to grade the strength and duration of the muscle contraction. A fraction of a second later the calcium ions are taken back into the muscle cells, causing release of the actin and myosin elements, leading to muscle relaxation. This mechanism allows activation of a muscle fiber to occur 60 to 100 times a second.

The process described above occurs for a single action potential. A single action potential typically lasts 1-3 milliseconds, but the time of muscle contraction as a result of a single action potential will last 10-100 milliseconds. The contraction of a muscle as a result of a single action potential is called a twitch. If more action potentials come after the first one at a successive rate, the muscle does not have time to relax and the twitches begin to add. If the twitches occur with a high enough frequency, the force output of the muscle will plateau. This plateau is called a tetanus response. There are two types of tetanus, fused and unfused. In unfused tetanus, the frequency of action potentials is still fairly low, and so muscle twitches can still be seen. A fused tetanus occurs when the rate of action potentials becomes much faster, so much that the effects of the individual twitches can no longer be seen.

There are two methods the body uses to recruit muscle force. These methods are temporal and spatial summation. For most muscle contractions, the firing rate of action potentials is usually higher than 8 Hz, but not usually higher than 25 Hz during times of concentrated contraction. This method of summing the action potentials to create muscle contraction is known as temporal

or frequency summation. As the frequency of the neural input to the muscle increases, the force output of the muscle increases. Another method of recruiting muscle contractions is through spatial summation. Spatial summation occurs when several muscle fibers are recruited in parallel, causing greater contractile force than the contraction of a single muscle fiber. Combining both temporal and spatial summation will lead to a strong contraction of the muscle. The force output of a muscle can be related to the amplitude of the recorded EMG signal. For weaker contractions, fewer muscle fibers are recruited, and as a result, the EMG signal is relatively small. However, for large forces, spatial summation is used to recruit more muscle fibers, and consequently the EMG signal is larger. The EMG signal is a summation of the signal produced by many muscle fibers at the same time. All of these fibers do not fire synchronously. The action potential produced by each fiber has both positive and negative components, so this summation produces a waveform that is essentially random but whose overall amplitude is related to the number, size, and frequency of recruited motor units. EMG signals are typically measured in the millivolts range (Fig 2).
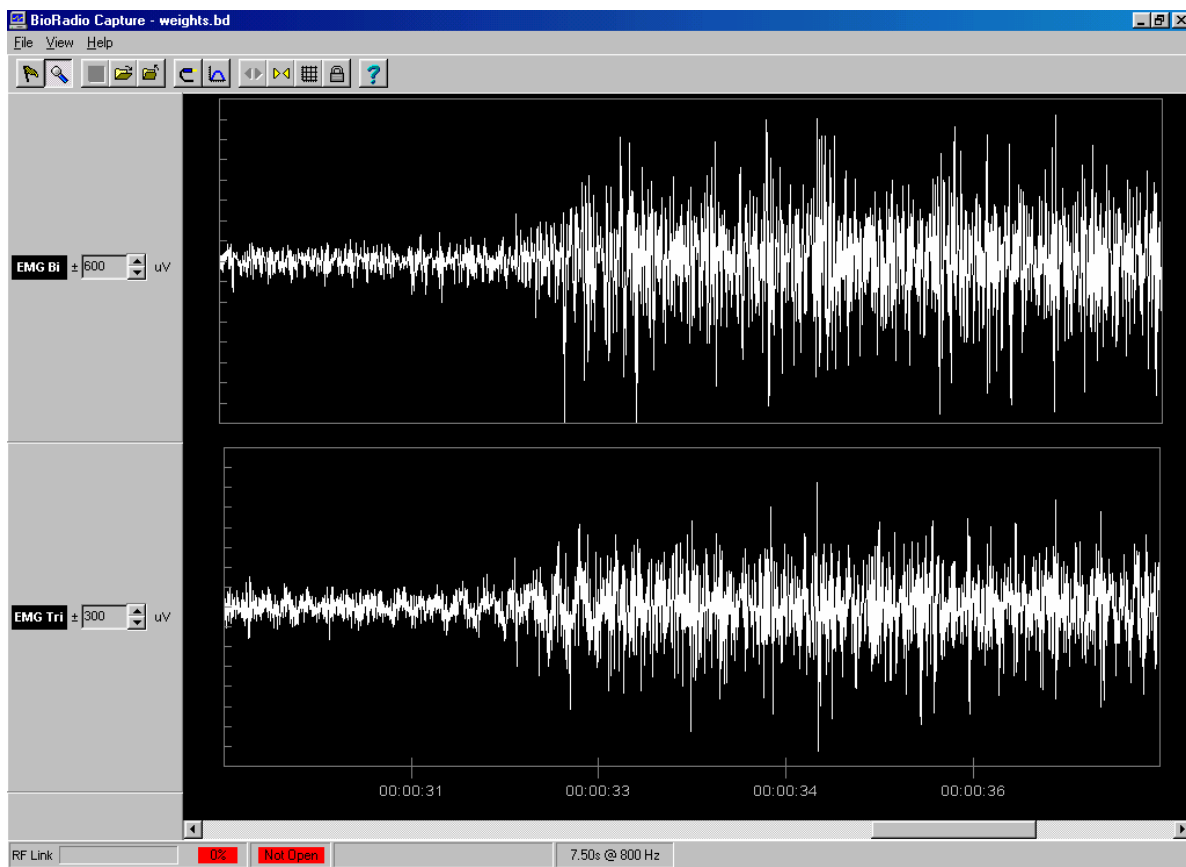

Figure 2: A typical, high pass filtered EMG signal illustrating that when a subject contracts their muscle the amplitude of the EMG signal increases.

Different Muscle Types

One skeletal muscle is comprised of many individual skeletal muscle fibers. Each of these individual fibers that make up a muscle are classified into types depending on their speed of contraction and metabolism. The three major types of muscle fibers are fast oxidative (FO), slow oxidative (SO), and fast glycolytic (FG). Each of these concepts is explained below.

Skeletal muscle fibers may be separated into fast and slow fiber types. Whole muscle groups may be comprised of both fast and slow fibers, however, they exist in different proportions depending on the muscle group. Fast fatigue muscle fibers have the ability to rapidly contract and relax and generate large amounts of force. However, these muscles will fatigue quickly. The other major muscle type is slow fatigue muscle fibers. These fibers contract slower than fast fatigue muscle fibers, however, they are more resistant to fatigue. A muscle fiber that is resistant to fatigue can output the same level of force for a longer period of time before the force output begins to decrease. Fast fatigue muscle fibers are almost twice the size of the slow fatigue muscle cells. Therefore, the brain uses what is known as the "size principle" to recruit muscle fibers in a whole muscle action. The smaller fibers are recruited first and the larger fibers are recruited last. This makes sense because the smaller fibers can perform longer for everyday tasks without a decrease in force. Larger fibers are only recruited when large amounts of force are needed since they fatigue quickly.

In addition to the speed at which a muscle fiber contracts, there are also differences in their metabolism. Two different metabolism processes can occur in a muscle. Ideally, aerobic (or oxidative) metabolism occurs in the muscle cells. This process requires oxygen to convert energy from food to ATP. ATP is required for cell metabolism. Oxidative metabolism occurs so long as oxygen is present. However, there may be times of a decreased oxygen supply to the muscles, such as during exercise. When this occurs, the body switches to anaerobic (or glycolytic) metabolism. This process metabolizes glucose molecules without the presence of oxygen. In the first stage of anaerobic metabolism, glucose is split into pyruvic acid, and energy is released to create ATP from the original glucose molecule. During the second stage of anaerobic metabolism, the pyruvic acid reacts with oxygen to create even more ATP molecules. However, if oxygen is still not present, the pyruvic acid is converted to lactic acid, which then enters the bloodstream. The soreness that some people feel after intense exercise is due to this build-up of lactic acid in the muscles. This glycolytic process of metabolism is able to create ATP 2.5 times faster than the oxidative pathway, making it useful for times of intense activity, however, only for short durations. Therefore, the aerobic pathway is used for times of prolonged muscle activity, and the anaerobic pathway is utilized when large amounts of energy are briefly needed.

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Processing of the EMG Signal

EMG from skeletal muscle recorded from the surface of the skin has a frequency range of 2-500 Hz and the amplitude can range from 50uV to 5mV. There are many different techniques for processing a raw EMG signal. Movement artifact typically occurs at a frequency much lower than that of the EMG information. Therefore, the EMG signal can be high pass filtered to help reduce motion artifact. Another simple method for processing the EMG signal is rectification. Rectification simply computes the absolute value of a signal. Electronically, rectification is typically done with a set of diodes, but in a computer, it is quite simple to take the absolute value of all the samples (Fig 3). After rectifying, one can find the average value of the EMG waveform.
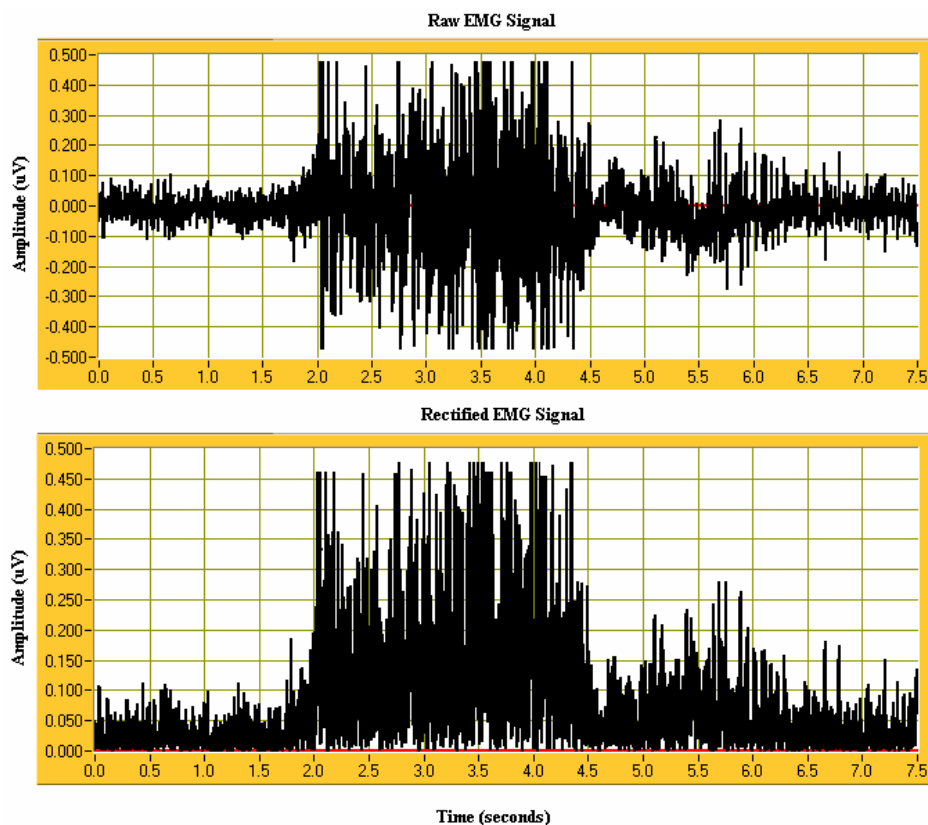

Figure 3: Raw and rectified EMG signals are illustrated.

Another way to process the EMG signal is to find the average power. In order to quantify the average power in the EMG signal, a type of processing known as RMS power is performed. RMS power stands for root mean square. The RMS power of a periodic waveform is defined as:

$$P_{rms} = \sqrt{\frac{1}{T_0} \sum_{n=0}^{T_0} [f(n)]^2}$$

This means that the waveform is first squared (a different way of rectifying the signal) and then the average value of the squared waveform is calculated. Finally, the square root of that number is calculated yielding the RMS (root mean square). For a waveform, the RMS value provides a descriptor of the average power in a signal. The equation above uses a summation instead of the more traditional integral since the data being acquired is discrete. For continuous signals, replace the summation with an integral.

Bin integration can also be performed after rectification (Fig 4). Bin integration is another way to quantify the EMG signal. Bin integration works by taking a small window over the EMG recording, say 5 points, and integrating the area in that window. Then the window is slid to the next 5 points, and integration is performed again. The result of bin integration is a time varying waveform that describes the muscle contraction from the EMG recording.
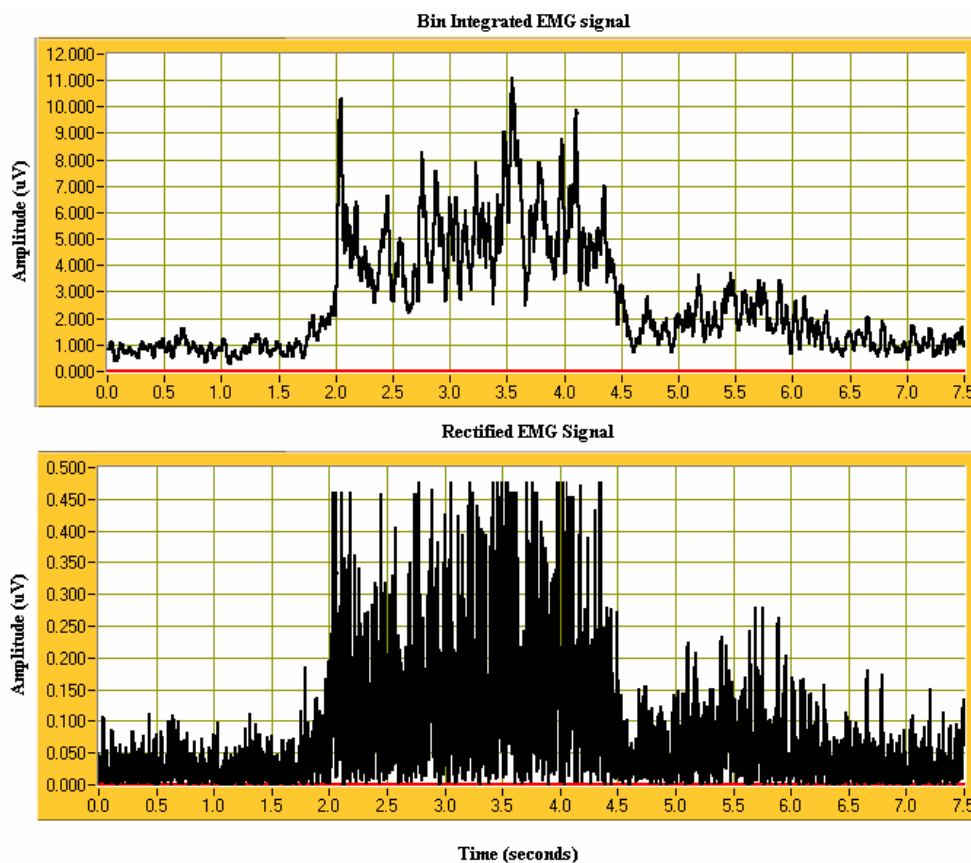

Figure 4: Rectified and bin integrated EMG signal are illustrated.

Experimental Methods

Experimental Setup

During this laboratory session you will record two channels of EMG from your upper extremity. You will record one channel from your biceps muscle and another from your wrist extensor muscles. You should be sure to watch the experimental setup movie included with the CleveLabs software before beginning the initial setup in the experiment.

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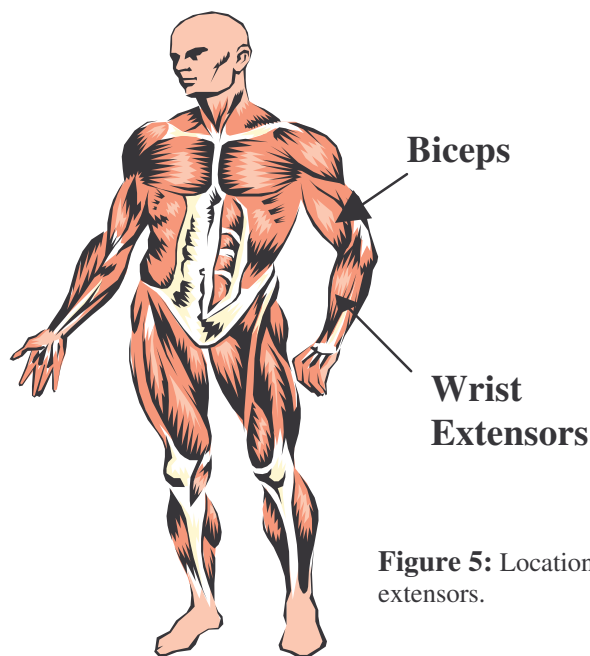

Biceps

Wrist Extensors

Figure 5: Locations of the biceps and wrist extensors.

2. For this laboratory you will need to use five 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 biceps, attach two electrodes about one inch apart on the wrist extensors (these muscles are located on the dorsal side of the forearm about half way between the wrist and elbow), and attach one electrode to the bony part of the elbow to use as the reference and ground electrode.
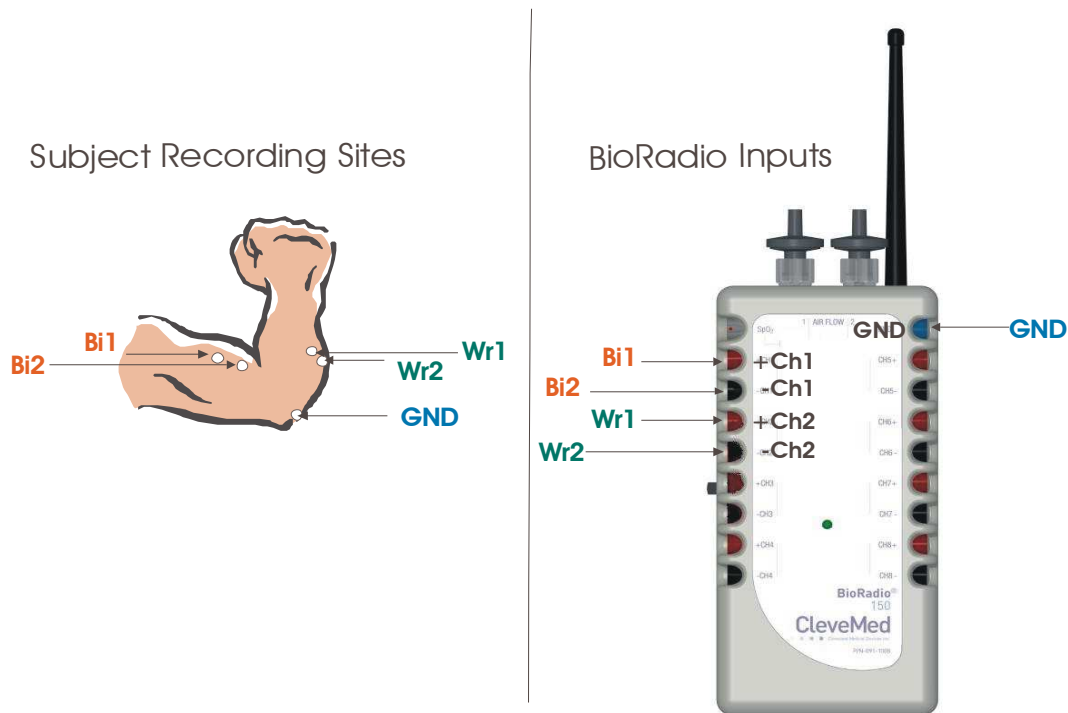
Figure 6: EMG Setup

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 for channels 1, 2, and the ground using the picture above as a reference (Fig 6). The leads on the harness are stackable allowing one snap lead to be plugged into more than one connector lead.

Procedure and Data Collection

1. Run the CleveLabs Course software. Log in and select the "Electromyography I" laboratory session under the Basic 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. Two channels of EMG should begin scrolling across the screen.

4. First you will record isometric EMG from your biceps and wrist extensors. 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. The subject can use their opposing hand for this experiment. Record and save a few seconds of

isometric biceps EMG by instructing the subject to hold the experimental hand position fixed in space, place the opposing hand on top of the experimental hand to resist the force, and then pull up against the opposing hand using the biceps muscle to create the isometric contraction.   Save a few seconds of this data to file and label the file "Isobiceps".

5. Repeat step 4 using the wrist extensor muscles. Save this data to a file named "Isowrist".

6. Now save a few seconds of data while you use your biceps to dynamically change the angle of your elbow. These are dynamic, unconstrained contractions since your arm will be moving in space and the length of the muscle will be changing. Save a few seconds of this data to a file named "Dynbiceps".

7. Repeat step 6 using the wrist extensor muscles.   Save this data to a file named "Dynwrist".

8. Now click on the Spectral Analysis tab and then click on the time domain tab. Select the channel to process to be channel 1 (biceps). Then instruct the subject to make quick elbow flexion and extension movements. Notice what happens to the raw EMG signal during the motion as a result of motion artifact. Save a few seconds of this data and also report a screen shot of this to your report.

9. Now turn on the high pass filter and set the high pass cutoff to be 20 Hz. Set the switch to filtered data. Now repeat the motion above and note what happens to the motion artifact. Save a few seconds of this data and also report a screen shot of this to your report.

10. Turn the filtering off and turn on the rectification. Begin saving data and name the file "weights". The subject should hold their arm at a 90-degree angle with their palm facing up. The subject will hold three weights for five seconds each. Approximate values of weights to use are 2.5, 5.0, and 10.0 lbs. After recording 5 seconds of relaxed arm muscle activity, have another lab group member gently place the lightest of the calibrated weights into the hand of the subject's test arm. The subject should maintain the arm position with the weight for five seconds. Repeat with the middle value weight and then with the heaviest weight. Then stop saving data. You should report a screen shot of the data at each weight level.

11. We will now examine the effects of fatigue on the EMG signal. Turn off the time plot and turn on the frequency plot. Click on the frequency tab. Turn all filtering off. We are now going to examine the frequency components of the EMG signal. Place the 10 lb weight in the subject's hand with them holding an isometric contraction as they did in the previous step.   However this time they will be instructed to hold the weight for approximately 2 minutes. Save the two minutes of data to a file named "fatigue".

Data Analysis

Calibrated Weights

1. Using Excel, MATLAB, LabVIEW, or the post processing toolbox, open the file "weights.dat". Plot Biceps EMG over time and print this plot.

2. Rectify the signal by taking the absolute value of it, and store the result in a column. Plot this column versus time. For each weightlifting segment of the rectified signal (a total of three), calculate the average value of the rectified EMG signal. You should have three data points. Make a plot of Average Rectified EMG vs. weight using those 3 data points.

3. Using MATLAB, create a band pass filter with a cutoff frequency of 15Hz and 50Hz. Rectify the signal from Channel 1 of the "Weights" data file, and apply the filter you just made. Verify the filter is working correctly by looking at the resulting signal's power spectrum. Find the standard deviation of the noise when the weights are being lifted.

4. Using the Post Processing Toolbox, open each of the data files that you collected during isometric and dynamic muscle contractions including "Isobiceps", "Isowrist", "Dynbiceps", and "Dynwrist". For each of the data files examine the frequency components of each of the recordings using the spectral analysis tab features. Note any differences in the frequency components between dynamic and isometric motions of the arm.

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

Discussion Questions

1. Which type of muscle fibers is recruited for tasks that need fine control over a long period of time? Which type of muscle fiber is recruited for a task that needs a short quick burst of energy?

2. What are the two mechanisms that the nervous system has to increase the force that a muscle is generating?

3. Using the plot from the calibrated weights experiment, what did you find the relationship between EMG and force was? Did this appear to be a linear relationship?

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4. Many special signal-processing techniques can be applied to extract or enhance certain properties of the EMG. Explain why one would use the RMS value rather than the average value of an EMG signal, and what signal property it enhances.

5. Discuss the differences in frequency components between the dynamic and isometric EMG data files.

6. What is a method that could be used to help reduce the amount of movement artifact in an EMG recording?

7. Discuss your observations of the JTFA analysis of the fatigue data file. What does the resulting plot appear as it does?

8. Sometimes when carrying a heavy box for an extended amount of time, and then removing the box from your arms, your limbs seem to keep on lifting, even though the weight is no longer on your arms. Why do you suppose this happens?

9. Sometimes EMG from the biceps and triceps both increase significantly at the same time. This is referred to as cocontraction since they are antagonist muscles. Explain why this happens. Hint: Think about the angle of the elbow during the task and the antagonist muscles that are being measured. In what other tasks might contraction occur and why is it important?

10. Explain why the "size principle" is an efficient process for the body to use.

11. Earlier, the innervation ratio was defined as the number of muscle fibers innervated by a single neuron. Explain why it is easier to grade the force produced by a muscle with a lower innervation ratio.

12. Botulism bacteria produce toxins that are lethal if a sufficient amount is ingested. However, some cosmetic physicians have found it useful in removing wrinkles, since it causes permanent muscle relaxation when applied to small areas of wrinkles. Knowing that acetylcholine is necessary for muscle contraction, how do you suppose small amounts of botulism toxin works to remove these wrinkles?

References

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

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

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