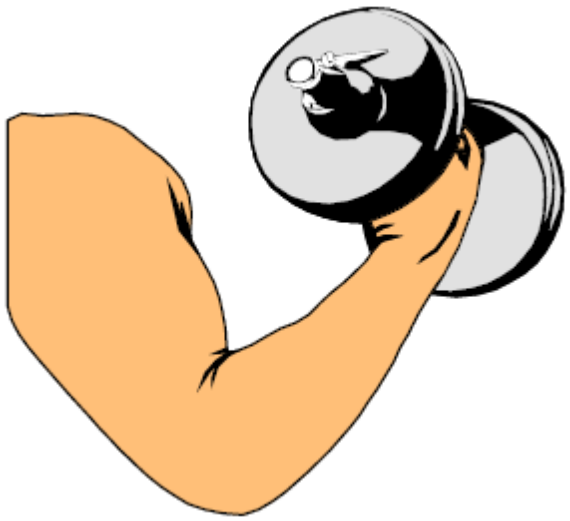
Lecture # 5

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.

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.

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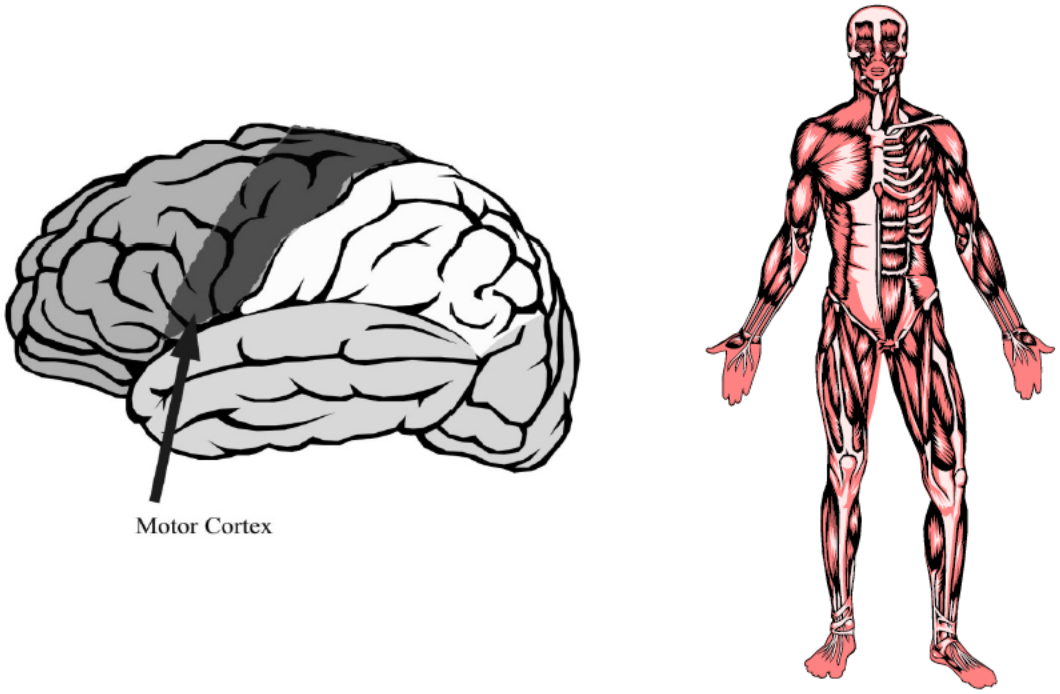

Figure (1): The body has over 250 skeletal muscles that are under voluntary control by the motor cortex of the brain.

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).

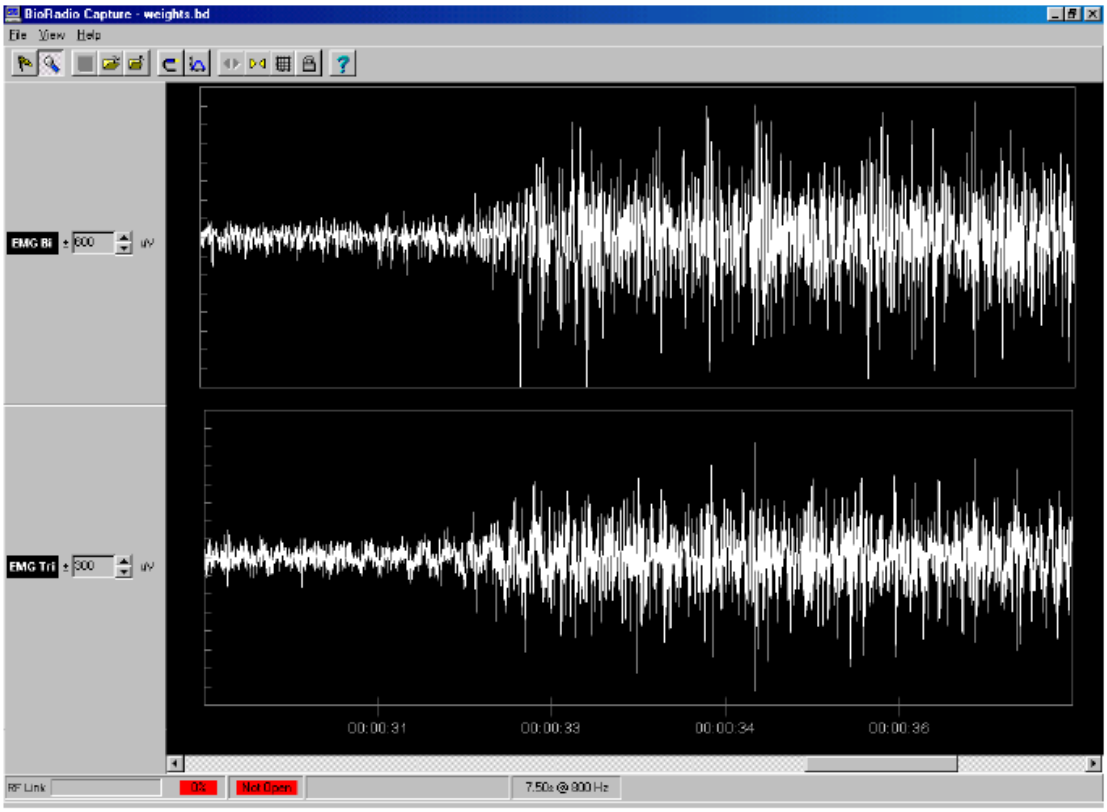

Figure 2: A typical, high pass filtered EMG signal illustrating that when a subject contracts their muscle the amplitude of the EMG signal increases.

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.

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.

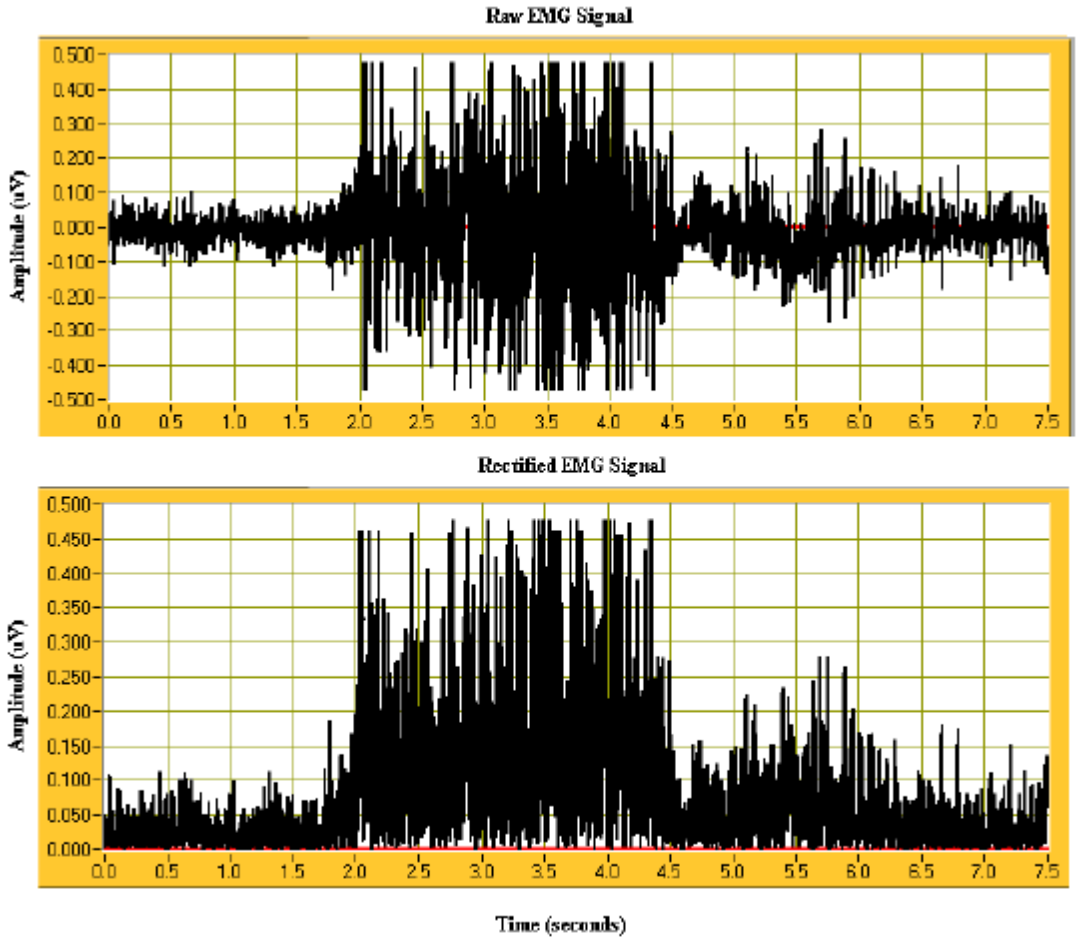

Figure 3: Raw and rectified EMG signals are illustrated.

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.

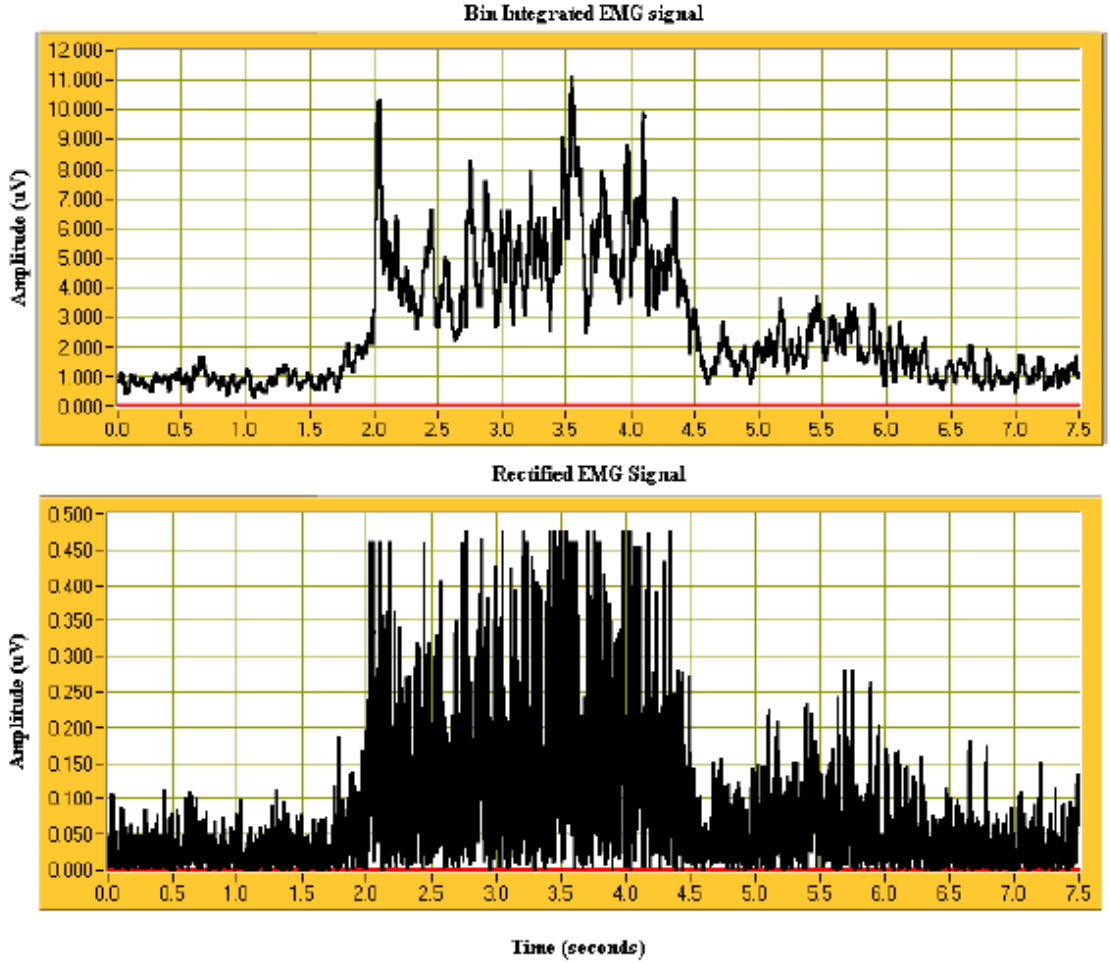

Figure 4: Rectified and bin integrated EMG signal are illustrated.