The EMG Signal

What is EMG?

The electromyogram (EMG) is an electrical manifestation of the contracting muscle – this can be either a voluntary or involuntary muscle contraction. Electromyography is the study of muscle function based on the examination and analysis of the electrical signals that emanate from the muscles. The EMG signal is a complicated signal which is affected by the anatomical and physiological properties of muscles, the control scheme of the peripheral nervous system, as well as the instrumentation used for detection and recording of the signal.

The basic functional unit of the muscle contraction is a motor unit, which is comprised of a single alpha motor neuron and all the fibers it enervates. This muscle fiber contracts when the action potentials of the motor nerve which supplies it reaches a depolarization threshold. The depolarization generates an electromagnetic field which is measured as a very small voltage that we call EMG.

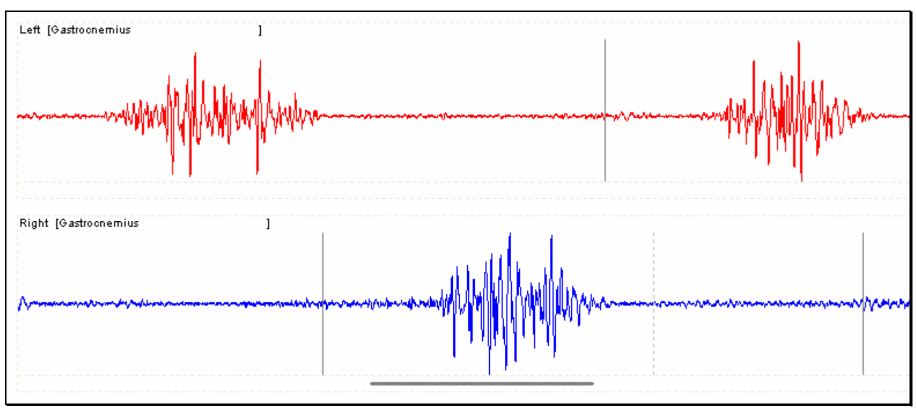

Figure 5 - An EMG signal showing clean muscle activation (recorded with an MA-300).

As you might expect from the brief description above, the essential nature of the EMG signal is complex and many people have devoted their lives to its study. We will devote the next four paragraphs to a very brief summary, working on the assumption that the reader can find many excellent books on the subject if they are interested in learning more about this fascinating field of biology.

While EMG can have many different types of voluntary or involuntary causes, the result is that an action potential rapidly propagates down a motor neuron to activate the branches of the motor neuron. These in turn activate the muscle fibers of a motor unit. When the post-synaptic membrane of a muscle fiber is depolarized, the depolarization propagates in both directions along the fiber. The membrane depolarization along with a movement of ions, generates an electromagnetic field in the vicinity of the muscle fibers. The time excursion of this voltage is called the muscle action potential.

The motor unit action potential is the spatial and temporal summation of the individual muscle action potentials for all the fibers of a single motor unit. Therefore, the EMG signal is the algebraic summation of the motor unit action potentials within the pick-up area of the electrode being used. The pick-up area of an electrode will almost always include more than one motor unit because muscle fibers of different motor units are intermingled throughout the entire muscle. Any portion of the muscle may contain fibers belonging to as many as 20-50 motor units.

As a result, the typical EMG represents the activation of multiple motor units. The collected data is an asynchronous series of action potentials that vary in amplitude and duration due to the differences in the distance of the electrode from the muscle fibers and the length of the axon extending to the muscle fiber. The EMG is a composite of the two mechanisms used to increase muscle force, recruitment of additional motor units and a more rapid firing of the same motor units.

A single motor unit can have 2-3,000 muscle fibers. Muscles controlling fine movements have smaller numbers of muscle fibers per motor units (usually less than ten fibers per motor unit) than muscles controlling large gross movements (100-1,000 fibers per motor unit). There is a hierarchy arrangement during a muscle contraction as motor units with fewer muscle fibers are typically recruited first, followed by the motor units with larger muscle fibers. The number of motor units per muscle is variable throughout the body and may vary from one subject to another.

Why is EMG measured and studied?

EMG contains two types of important information, timing of muscle activity and its relative intensity. Other information is also present (e.g. frequency spectrum and acoustic information) but most clinical diagnostic reports are based on the muscle activity and intensity components of the EMG signal. This information can be used within a wide variety of fields of study:

Numerous neuromuscular disorders present aberrant EMG signals while performing functional tasks like posture and locomotion. This may be any combination of inappropriate muscle activation or errors in muscle activation intensity.

Biomedical engineers often use EMG signals derive volitional control of an artificial limb or brace through the interpretation of the EMG signal.

Biomechanists and other scientists can study the balance mechanism by which humans maintain postural stability in the presence of perturbations.

Gait analysis laboratories study the precise control of the musculo-skeletal system during ambulation or other complex human movements.

Doctors often evaluate the temporal sequence of the recorded activity to address questions of CNS control. Often called “nerve conduction”, this is a rapidly growing field of study that is quite separate from the multi-channel, muscle activation, studies that this manual addresses.

Researchers study multi-channel EMG data together with biomechanical parameters, such as muscle force to investigate the relationships between different muscle contractions.

EMG alone can be used to differentiate normal gait from pathologic gait by comparing recorded EMG timing to the normal EMG timings for a given subject population for any gait activity.

For the purposes of this manual, there are two main types of electromyography:

Clinical EMG – sometimes called “diagnostic EMG” or “Nerve Conduction EMG” is typically done by physiatrists and neurologists. This is the study of the characteristics of the motor unit action potential for duration and amplitude. These studies are typically done to help diagnostic neuromuscular pathology. They also evaluate the spontaneous discharges of relaxed muscles and are able to isolate single motor unit activity. Generally, these types of studies focus on a single muscle or group of muscles.

Kinesiological EMG – this is the type most often found in the literature regarding movement analysis. This type of EMG examines the relationship of muscular function to movement of the body segments and evaluates timing of muscle activity with regard to the movements. Additionally, many studies attempt to examine the strength and force production of the muscles themselves. Kinesiological EMG almost invariably looks at the actions, and interactions, of several muscles simultaneously.

Both the ***EMG Analysis*** and ***EMG Graphing*** software applications focus almost exclusively on providing information from the viewpoint of Kinesiological EMG studies that involve multiple muscle contractions during physical activity. As a result, the rest of this manual will discuss EMG from a Kinesiological point of view.

Relationship of EMG to physical parameters

There is a direct relationship between EMG and many biomechanical variables. With respect to isometric contractions, there is a positive relationship between the increase of tension within the muscle and the amplitude of the EMG signal recorded. There is a lag time, however, as the EMG amplitude does not directly match the build-up of isometric tension. As a result, it is difficult to estimate force production from the EMG signal, as there is questionable validity of the relationship of force to amplitude when many muscles are crossing the same joint, or when muscles cross multiple joints.

When looking at muscle activity, with regards to concentric and eccentric contractions, it is common to find that eccentric contractions produce less muscle activity than concentric contraction when working against equal force. As the muscle fatigues, one sees a decreased tension despite constant or even larger amplitude of the muscle activity. There is a loss of the high-frequency component of the signal as it fatigues, which can be seen by a decrease in the median frequency of the muscle signal. Thus, during movement, there tends to be a relationship with EMG and velocity of the movement.

There is an inverse relationship of strength production with concentric contractions and the speed of movement, while there is a positive relationship of strength production with eccentric contractions and the speed of movement. One can handle more of a load with eccentric contractions at higher speed. For example: If a weight was very large and you lowered it to the ground in a fast, but controlled manner, you handled a large weight at a high speed via eccentric contractions. You would not be able to raise the weight (concentric contraction) at the speed you were able to lower it. The forces produced by the fibers are not necessarily any greater, but you were able to handle a larger amount of weight and the EMG activity of the muscles handling that weight would be smaller. Thus, we have an inverse relationship for concentric contractions and positive relationship for eccentric contractions with respect to speed of movement.

Joint motion

Kinematic plots of joint angular motion can be compared to the EMG plots to see if one can explain the other. Addition of kinetic plots serves to clarify the picture of the subject's activity. Muscle function in gait is one of control, with onset of eccentric activity for protection against motion occurring in the opposite direction.

Force

The amplitude of EMG signals derived during gait may be interpreted as a measure of relative muscle tension. The EMG processed through a linear envelope has been widely used to compare the EMG-tension relationship, especially if the tension is changing with time. For constant tension experiments, it has been reported that the average value of the rectified EMG is a measure of tension. This can be derived from a long time constant linear envelope circuit. Both linear and non-linear relationships between EMG amplitude and tension have been reported.

Basmajian & De Luca define Motor Unit Action Potential as the name given to the detected waveform consisting of the spatiotemporal summation of individual muscle fiber action potentials originating from muscle fibers in the vicinity of a given electrode or electrode pair.

The relationship between force and linear envelope EMG also holds during dynamic changes of tension. The signal obtained by passing the rectified EMG through a 2nd order Butterworth filter was found to lag behind the EMG. The physiologic delay was reported to be due to the fact that the twitch corresponding to each motor unit action potential (MUAP) reaches its peak 40-100 ms afterward. Thus as each motor unit is recruited, the resulting summation of twitch forces will also have a similar delay behind the EMG. The timing relationship of the MUAP is affected by a number of factors including tissue between the muscle and electrode, electrode type, electrode placement.

Velocity

There is agreement with the fact that increased velocity elongates the period of muscle activity by leading the activity that starts earlier or lasts longer. It has been found that the EMG amplitude increases with increasing walking speed and that the EMG activity is minimized with subjects walking at their comfortable speed. It has been suggested that without a speed constraint, subjects selected a walking velocity associated with a minimum of muscle activity.

Muscle Fatigue

Fatigue has been found to not only reduce the muscle force, but also to alter the shape of the motor action potentials. An auto-correlation has shown that there is an increase in the average duration of the recruited MUAP. The EMG spectrum is also shown to have shifted to reflect these changes. It has been found that higher frequency components decreased with fatigue.

Measurement of EMG Signals

How is EMG measured?

The EMG signal is obtained from the subject by either measuring non-invasively with surface electrodes, or invasively with wire or needle electrodes. The measured signal is then amplified, conditioned and recorded to yield a format that is most convenient for answering the clinical or scientific question of concern. The measurement and recording of a complex analog signal such as EMG is a complex subject as the signals of interest are invariably very small (in the order of 0.00001 to 0.005 of a Volt). In addition, the signals are usually found in combination with very large spurious signals from motion artifact, as well as induced voltages from nearby AC power lines, florescent lights, cell phones and other electrical equipment such as computers, monitors etc. – all of which are potent sources of interference. As a result, a quality EMG system and a versatile analog signal recording system are essential if you are planning anything more than the most casual of analysis functions.

Recording Systems

Three types of recording device are commonly used - these are strip chart recorders, multi-channel analog tape recorders, and computer-controlled data recorders. In each case, the frequency response of the recording device must be at least equal that of that of the EMG signal being recorded. For surface EMG signals, this is generally considered to be 10-500Hz, while needle (fine-wire) recordings directly from the muscle may produce signals in the range of 2-1,000Hz.

Direct, on-line recording of the EMG signal directly into the computer is the preferable system today, especially when the EMG signal is analyzed as part of a gait or motion study. The advances in processor speed, memory size and disk access times all have contributed to the popularity of this method. There are a large number of data collection systems available for personal computer systems and most clinical gait analysis systems include or offer analog data collection options. Both the Motion Lab Systems ***EMG Analysis*** and ***EMG Graphing*** programs are compatible with the files produced by many common motion capture manufacturers systems.

Motion Lab Systems offers a wide range of cabled EMG systems that offer superior performance at competitive costs.

The transmission of EMG signals from the subject to the recorder can be either by cable or by telemetry. Cabled EMG systems tend to offer higher signal bandwidths and better reliability than telemetry systems but require that the subject be attached in some way to the recording system. Telemetry EMG systems usually offer the subject a greater freedom of movement than cabled systems but are almost always heavier, have lower signal bandwidths, are more prone to signal artifacts, interference and usually considerably more expensive.

The quality of the recorded EMG signals is principally controlled by two factors. These are the *sampling rate* of the recording system and the amount of *artifact*, or non-EMG components in the recorded signal.

Sampling Rate

The sampling rate is the frequency at which the EMG data is sampled or measured. Thus a sampling rate of 1000 Hz means that the EMG signal is measured 1000 times every second. This would mean that the theoretical maximum rate at which the EMG signal can change, and still be accurately reproduced, is 500 Hz. In practice, it is recommended that the EMG signal be sampled at least 4 to 5 times faster than the highest frequency component that is expected to be present in the signal if any signal analysis is to be performed. At a minimum, the EMG signal must be sampled at least twice as fast as the highest frequency component within the signal.

Thus, while an EMG signal that is recorded using surface electrodes could be sampled as slow as 1000 Hz, the optimum sample rate is 2000-2500Hz. Fine wire (or indwelling) EMG signals would need to be sampled at a minimum of 2000Hz and optimally at rates as high as 4000-5000Hz.

It is beyond the scope of this manual to cover the issues involving data sampling techniques but it is essential that the recorded signal is low-pass filtered prior to the recording to remove any signal components that change faster than the system can measure. In the examples above, (surface EMG and indwelling EMG recordings) the signal would have to be filtered at 500Hz and 1000Hz to eliminate the possibility of artifact.

If your EMG system does not include a low-pass filter then it will be necessary to determine the frequency response of the system and sample the EMG data at least four times that value to avoid aliasing artifact problems. This is because an EMG system claiming a bandwidth of up to 500Hz is usually quoting the 3dB point – the frequency at which the input signal is half the amplitude of a mid-band signal (250Hz in this case). Thus the unfiltered EMG system in this example can produce low-level signals above the quoted 500Hz bandwidth. These “out-of-band’ signals, if present at the input of the analog sampling system can produce significant amounts of aliasing artifact and appear as signals in the DC to 500Hz range.

Artifact

To have an ideal, valid recording, the incoming EMG data, presented to the recording system, should contain no artifact components. Since the vast majority of EMG studies are performed on moving, live subjects this is virtually impossible to achieve. Mechanical artifacts are common and occur when the EMG signal cables move as the subject is in motion, as well as from any movement of the EMG sensor electrode on the skin surface. Cable artifact can generate low frequency signals as the cables shift during the subjects’ motion. This is a particular problem with passive surface electrodes if the cables to the electrode are long and are often not secured to prevent undue motion.

Artifacts can be generated by movement occurring at the electrode-skin interface if the electrodes are not attached to the subject correctly and the electrode or preamplifier is free to move against the surface of the skin. These artifacts are usually of a low frequency - generally below 20Hz but can be much larger than the EMG signal that you are attempting to measure.

Other muscles in the body can generate EMG – if these muscles are close to the testing site then cross-talk can be recorded. There is some evidence that intra muscle cross-talk can be reduced by the use of a special double differential preamplifier electrode but close attention to electrode placement is the best remedy to reduce cross-talk.

In addition, EMG recordings anywhere close to the subjects heart may detect the subjects pulse (the QRS complex has signal components above 50Hz) as a regular beat underlying the EMG signal that is being collected for investigation.

Another artifact that can be a major problem is AC line interference (50 or 60Hz depending on where you live), which is often a symptom of poor electrode application or a faulty EMG preamplifier. Modern EMG preamplifiers with high Common Mode Rejection Ratios (CMRR) of greater than 100dB have largely eliminated this as a problem.

Under some circumstances high frequency artifact can be generated if there is a high RF signal level in the recording lab from a local radio transmitter.

In addition, aliasing artifact can be generated by the EMG recording system if there are components of the incoming signal that are higher in frequency than twice the recording system sample rate. This can occur because of faulty EMG system design that permits RF or other out-of-band signals to enter the EMG inputs, or because of faulty data collection systems that respond to out-of-band signals.

The Problem of Aliasing

Aliasing is a sampling problem in any data acquisition system. It can cause erroneous results and occurs whenever the incoming EMG signal contains frequency components that are at, or higher, than half the analog sampling rate. If the incoming EMG is not filtered to remove these frequencies, they will show up as aliases or false lower frequency components is the recorded EMG signal that cannot be distinguished from valid sampled data. The alias signals are actually at a higher frequency, but are “folded back” by the sampling process to create false low frequency signals below half the sampling rate. This new, and completely false signal, is completely indistinguishable from a signal in the source EMG signal.

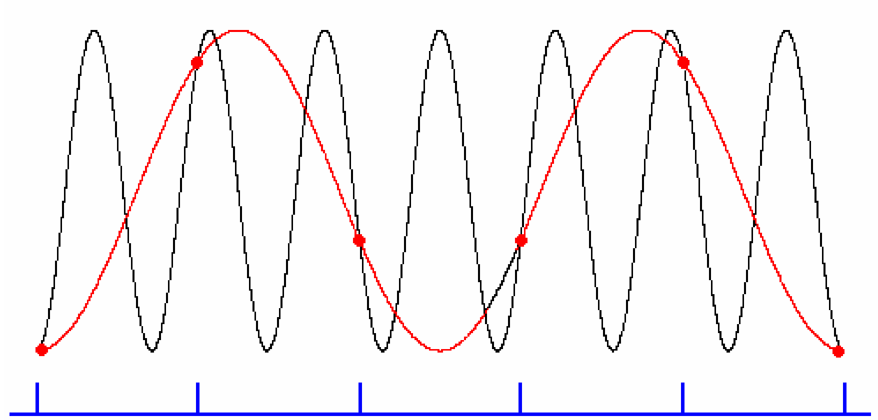

Figure 6 - The signal (black) is sampled too slowly (blue) creating the false (red) artifact.

For example, with a sampling rate of 1,000 Hz, any EMG components in the signal that are above 500 Hz will be aliased to appear as EMG signals in the range of DC to 500 Hz (the actual range of EMG signals that the sampling system is capable of recording) thus leaving errors in different locations throughout your data each time you use an A/D converter.

While it may appear that the aliasing problem can be eliminated by sampling the EMG signal at a very high rate, such over-sampling of data requires faster A/D conversion - often at rate that are not supported by many analog recording systems. It also produces larger files that contain more data to process and does not guarantee that aliasing will not be a problem.

The only practical way of avoiding the possibility of aliasing errors is to filter the bandwidth of the sampled EMG signal so that the signal presented to the A/D sampling system does not contain any frequency components above one-half of the A/D sample rate. This is easily done with a good quality low-pass or anti-alias filter on each A/D input channel prior to the A/D converter. Low-pass filtering must always be done before the signal is sampled as there is no way to remove the aliasing errors from the original signal once it has been digitized.

As dictated by the Nyquist theory, the EMG signal needs to sampled by the A/D converter at a rate that is, at a minimum, twice as fast as the highest frequency component within the EMG signal. This rule applies to any sampling system and the filter point is often referred to as the Nyquist frequency and all frequency components above this point must be removed before sampling.

A perfect a low-pass filter would pass all EMG signal components with frequencies from DC to the filter cutoff frequency while completely suppressing all frequencies above the filter point. Unfortunately, it is not possible to build a perfect filter with an exact cut off point and all analog filters pass some frequencies above the cut off point. This is called the roll-off or attenuation slope where small amounts of signals are still present, although at a much lower level than the original. These attenuation slopes are normally greater than 40-50 dB/octave and attenuate the frequency components in the original signal that are greater than the cut-off point by 80 to 100 dB.

It is important to realize that high-frequency components in any signal presented to an A/D system can result from a number of different sources that are unrelated to the EMG signal from the muscle. High frequency signals above the Nyquist point may come from the inherent noise of the EMG system itself, and from noise or interference, broadcasting stations, and mechanical vibrations. High-frequency components also are inherent in any sharp transitions of the measured signal such as may occur when equipment subject to any unexpected vibration (e.g. dropped etc). Low-pass filters generally can eliminate alias errors from the recorded EMG signal as long as the filters precede the A/D converter. A low-pass filter serves as an important element of any data acquisition system in which the accuracy of the acquired data is essential.

Aliasing artifact can be eliminated as a potential problem by paying close attention to the actual bandwidth of the signal being recorded and by filtering the signal before sampling. When selecting a filter frequency and sampling rate remember that many filters do not have very sharp cut-off points. As a result, a filter set to give a 500Hz cutoff may still pass measurable frequencies up to 600-700Hz depending on the quality of the filter.

Signal Levels

Most modern EMG recording system are Analog to Digital Converter (ADC) based system – these system work by repeatedly measuring and recording the EMG signal level – usually at very high speed across multiple channels.

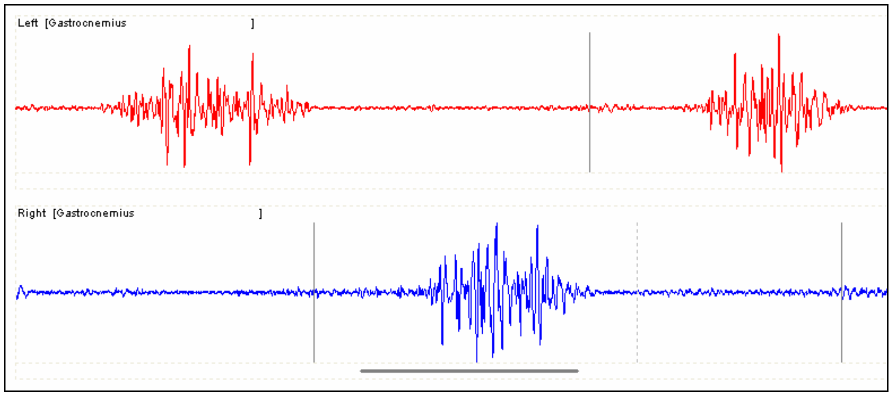

Figure 7 - EMG recorded at the correct level is large enough to be analyzed but does not clip.

Most ADC recording systems store the sampled EMG data as series of numbers with a limited range, usually either 2^{12} or 2^{16} unique values (i.e. 4048 or 65536 unique values) which represent the entire signal – both positive and negative values usually over the range of ±5 volts. As a result, it is important that all of the EMG signals presented to the ADC recording device use the entire recording range and should look very much like the illustration in Figure 7. This signal allows the signal peaks to be clearly distinguished (they are not clipped or squared off at the top and bottom of the signal) and shows a moderately quiet baseline signal in between the bursts of EMG activity.

Selecting the correct ADC recording range is very important - if your ADC collection is set-up for ±10 volts and your EMG system is producing EMG signals that are in the ±1volt range (after amplification) then you will lose resolution – the ability to distinguish small changes in the recorded signal. This is shown in Figure 8 where it is very difficult to determine the precise onset and cessation of the EMG activity because the recorded EMG signals are too low.

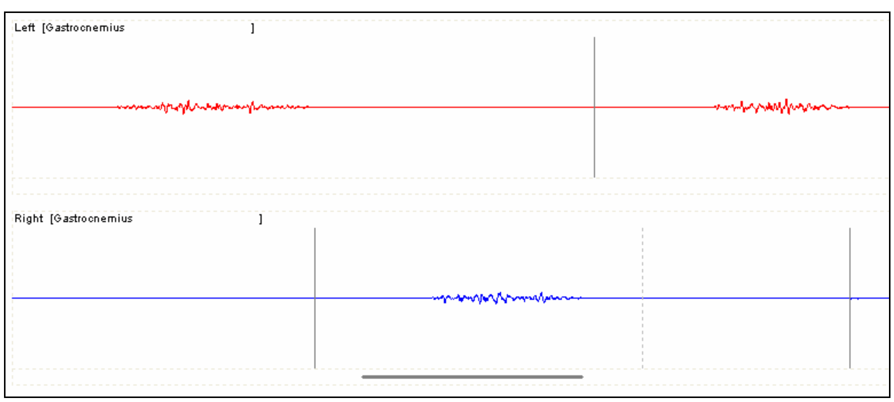

Figure 8 - EMG recorded at too low a level is difficult to observe or analyze.

However, having the gain set too low is not as bad as the results of setting the gain too high. If your ADC collection system is set-up with an input signal range of ±5 volts and your EMG system is producing (after amplification) signals in the ±10 volt range then you will find that the EMG signal is clipped at ±5 and appears to have a lot of baseline noise. This is illustrated in Figure 9 where all of the EMG bursts can be seen to stop at a single point at the top and bottom of the display – this distortion of the recorded signal is called “clipping”. The clipping of the EMG waveform means that you have no way of measuring any change in the EMG signal above the ±5 level and the apparent increase in baseline noise can lead to interpretation errors in some cases. In addition, the frequency content of the clipped signal is altered, invalidating any frequency or power analysis of the recorded signal.

Therefore, it is very important that the software and hardware arrangement used to record the EMG signal allows for optimization of the collected voltage range within the measured range. Generally, this requires that the EMG system used provide a wide range of gain settings to allow the optimum EMG level to be presented to the ADC recording system.

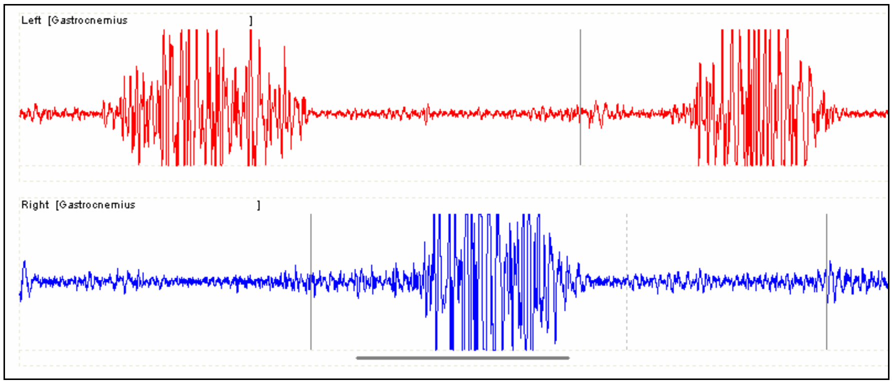

Figure 9 - EMG recorded at too high a level is distorted and provides limited information.

If in doubt – always select a lower signal gain than a higher one as low-level EMG signals can be amplified by the ***EMG Analysis*** and ***EMG Graphing*** programs to produce accurate results. Setting the EMG gain too high and causing the EMG signals to clip and be distorted, renders most analysis techniques useless.

EMG Electrodes

The EMG signal is measured either non-invasively with surface electrodes or invasively with wire or needle electrodes. Since typical EMG signal levels are in the region of 400 µV to 3 mV (depending on many factors), the measured EMG signal is almost always pre-amplified, amplified and conditioned to yield a format that is most convenient for answering the clinical or scientific question of concern.

The detection electrode for kinesiological EMG is typically bipolar, and the EMG signal is amplified differentially. The waveform of the observed action potential will depend on the orientation of the detection electrode contacts with respect to the active fibers.

EMG can be recorded from the skin surface or by placing an electrode directly within the subject’s muscle – this is usually referred to as a fine-wire recording. Surface EMG is generally recorded with either passive or active electrodes placed on the intact skin surface over the belly of the subjects muscle, while fine-wire recordings use a wire electrode that is inserted into the muscle by a trained (and, in most cases, licensed) professional. Each electrode type has specific advantages and disadvantages.

With regards to recording the EMG signal, the amplitude of the motor unit action potential depends on many factors which include: diameter of the muscle fiber, distance between active muscle fiber and the detection site (adipose tissue thickness), and filtering properties of the electrodes themselves. The objective is to obtain a signal free of noise (i.e., movement artifact, line frequency interference, etc.). Therefore, the electrode type and amplifier characteristics play a crucial role in obtaining a noise-free signal. For kinesiological EMG there are two main types of electrodes: surface and fine wire.

Surface Electrodes

Surface electrodes used in EMG recordings can either be "active" or "passive". In the passive electrode type, the electrode consists of a simple silver/silver-chloride detection surface that senses a current on the skin through the skin-electrode interface. This type of electrode is normally used when the electromyographer requires precise placement or if the EMG equipment in use is older. Active electrodes place a preamplifier either within the electrode or very close to the EMG data collection site. The advantages of surface electrodes are that there is minimal pain with application, they are more reproducible, they are easy to apply, and they are very good for movement applications. The disadvantages of surface electrodes are that they have a large pick-up area and therefore, have more potential for cross talk from adjacent muscles.

Surface electrodes are easy to apply and use and they provide a good indication of muscle activity with minimum impact, or discomfort to the subject. However the ability of surface electrodes to record the activity of small muscles, or muscles located deep within the body such as the Tibialis Posterior is very limited. In spite of this limitation, surface EMG recording are the most common type of kinesiological EMG recordings.

Passive Electrodes

Passive electrodes generally require that they be used with an electrode gel to ensure a good skin contact. The principal advantages of this type of electrode are that they are reusable and that they are small enough to be mounted close together in areas that would be very difficult to measure with any other method. This allows the electromyographer to position the EMG pickup areas with great precision. However, they are often very messy to use and have generally been replaced by disposable electrodes when a passive electrode is required.

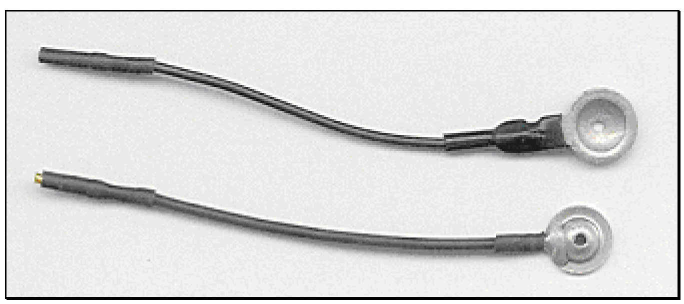

Figure 10 – Typical Silver/Silver Chloride (Ag/AgCl) Electrodes

Disposable gel electrodes, suitable for surface EMG recordings, can be purchased from Motion Lab Systems, Inc.

Disposable electrodes are widely used for EKG monitoring and are commonly available in a bewildering variety of shapes and sizes. The majority of these commercial electrodes are designed for long term (24 hours) adult EKG monitoring and as a result are less than ideal for most EMG applications. The ideal EMG electrode should be small and lightweight – specialized EKG electrodes designed for pediatric intensive care units usually work quite well. The principal advantages of disposable gel electrodes are that they are very easy to use, they allow the electromyographer complete control over the placement of the EMG measuring location and that they can be disposed after a single use.

It is very important that the signal cables used to transfer the EMG signal from the electrode on the skin surface to the EMG equipments must be very carefully secured to reduce the possibility of motion artifact appearing in the EMG signal. Motion Artifact appears as very low frequency shifts in the baseline of the EMG signal and can overwhelm the EMG signal in extreme instances.

Passive electrodes rely on cables to transfer the very low level EMG signal some distance (anything from 2 to 20 feet) to the amplification equipment. Since the EMG signal is collected at the skin surface, it has a relatively high impedance (typically in the order of 50,000 to 100,000 ohms). While is it desirable to lower this skin resistance figure as much as possible, this requires the use of conducting gels and extensive skin preparation – both of which can contribute additional problems to the EMG recording. Research papers often quote lower figures for skin resistance (in the orders of 5,000 to 10,000 ohms) but these are not generally attainable in the kinesiological EMG setting without considerable discomfort to the subject due to the extensive skin debrading necessary to produce these numbers.

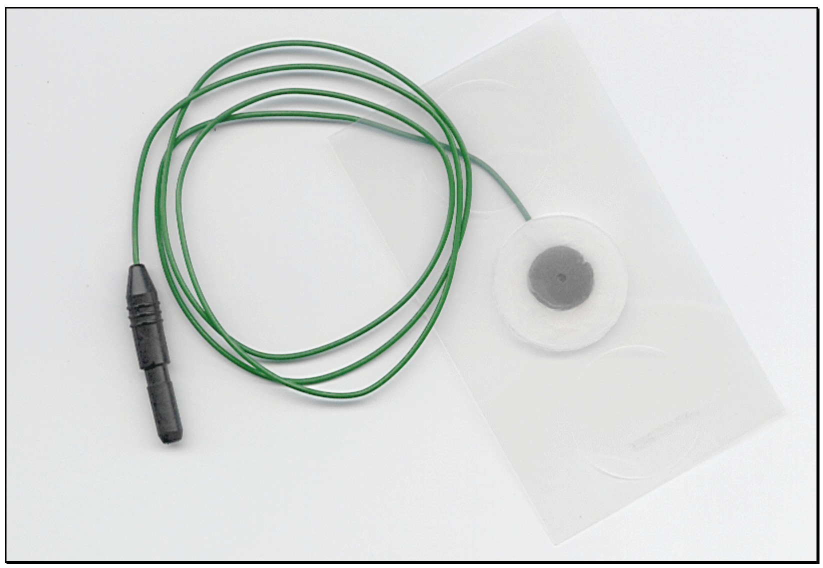

Figure 11 – A disposable electrode with DIN connector

Thus signal transferred from the passive electrode, through the cable, is both low level and highly sensitive to external interference from a wide variety of external sources while it is transferred through the cabling. As a result, the available signal to noise ratio decreases and any movement artifacts picked up by the cable are amplified along with the actual signal once amplification occurs.

Active Electrodes

An active electrode contains an electronic circuit that will amplify the EMG signal close to the site of the signal pickup. These devices are commonly referred to as pre-amplifiers because the EMG signal is amplified prior to being transferred to the main instrumentation amplifier. The EMG pre-amplifier within the active electrode boosts the level of the electrical signal from the skin surface (typically in the range of 0.00001 to 0.001 Volt) to levels closer to 0.01 to 1.0 volts, depending on the degree of amplification (gain) provided. In addition to amplifying the EMG signal, the active electrode also provided two other important functions by rejecting any common mode interference from AC line interference, and by providing a low impedance signal from the active electrode to the rest of the EMG data collection system. This greatly improves the signal to noise ratio of the EMG signal and, in addition, eliminates any possibility of picking up motion artifact in the cable from the pre-amplifier to the rest of the EMG system.

The measure of the ability of the EMG preamplifier to eliminate the common mode signal is termed the common mode rejection ratio. The higher the common mode rejection ratio, the better the cancellation of any signals that are common to both amplifier inputs – these are almost invariably noise signals. A value of 100dB or high is desirable.

Active surface electrodes are available in two basic types - those that require a separate “indifferent” or “ground reference” electrode and those that include a third reference pad in the electrode package.

The failure to use a ground reference electrode is the major cause of AC power line interference in the recorded EMG signal.

Always follow the electrode manufacturer’s recommendations for maximum signal quality – if a separate ground reference electrode is recommended then it must be used. Generally, a ground (or indifferent) electrode is a single gel or pad electrode that is attached to some convenient point on the subject to provide a neutral reference to the EMG recording system.

There are several preamplifier characteristics that need to be considered when recording either surface of fine-wire EMG signals. The first of which is the signal to noise ratio of the preamplifier. This can be quoted in two different ways, as the ratio of the wanted signal to the unwanted signal, or as a simple noise level, usually with respect to the input signal. In either case, it is a measure of the quality of the amplified signal – high signal to noise ratios and low noise figures both indicate a high quality preamplifier in most cases. Minature EMG preamplifiers at the site of, or including, the EMG electrode are almost invariably the best at providing a very large signal to noise ratio.

The gain of the preamplifier is also important. This is the amount of amplification applied to the EMG signal. Higher gains provide a greater amplification of the EMG signal and any signal artifact – for this reason, it is a good idea to use a relatively low gain preamplifier at the muscle site to avoid overloading subsequent amplification stages if large artifact signals occur. Too large a gain at the muscle site may cause the EMG signal to disappear in the presence of low frequency artifact as the larger artifact signals may saturate any additional amplifiers, causing the EMG signal to be distorted or lost.

Another important characteristic of the amplifier is the bandwidth. This is simply the range of frequencies that the amplifier will pass. This needs to be selected to reject the low frequency movement artifacts and to attenuate the signal as little as feasible. In practical terms, this means that the preamplifier should operate over a range from 10-20Hz to 500 Hz for surface electrodes and 2Hz to 1,000 Hz for fine wire electrodes. Using the Nyquest Theorem, this means that one must sample at a minimum of 1,000 Hz for surface electrodes and 2,000 Hz for fine wire electrodes in order to assure capturing the entire signal.

While it is possible to process the recorded EMG data with software to filter movement artifacts after collection, it is usually more practical to take some precautions to reduce the amplitude of any low frequency motion artifacts at the preamplifier by limiting the low frequency response. This can greatly reduce the amplitude (size) of any motion artifacts and prevents large artifact signals from saturating the amplifiers, causing intermittent loss of signal. When making decisions about filtering it is important to make sure that any filter applied to the EMG signal has a low phase shift – in a perfect world, all applied filters should have zero phase shifts.

Fine Wire Electrodes

30mm and 50mm fine wire electrodes can be purchased in individually sterilized packs from Motion Lab Systems, Inc.

Many Motion and Gait Analysis laboratories make their own fine wire electrodes using instructions provided in "Muscles Alive" by Basmajian and De Luca (1985) pp. 29-33. Wire for the electrodes can be obtained from a number of sources; one of the most common is the California Fine Wire Company who supply "Stablohm 800A H-poly Nylon Green" which is commonly used for in fine wire electrode manufacture.

The general procedure to make fine wires electrodes is to use two lengths of wire, and flame one end of each with a heat source. This removes, or loosens the enamel so that it can come away with gentle rubbing. The bare ends of the wire are then cut back to be about 2-3 mm long. The two wires are then threaded through an intramuscular needle Needles (25 gauge, 38mm). The bare ends are turned back round the tip of the needle and the whole assembly is then sterilized in an autoclave.

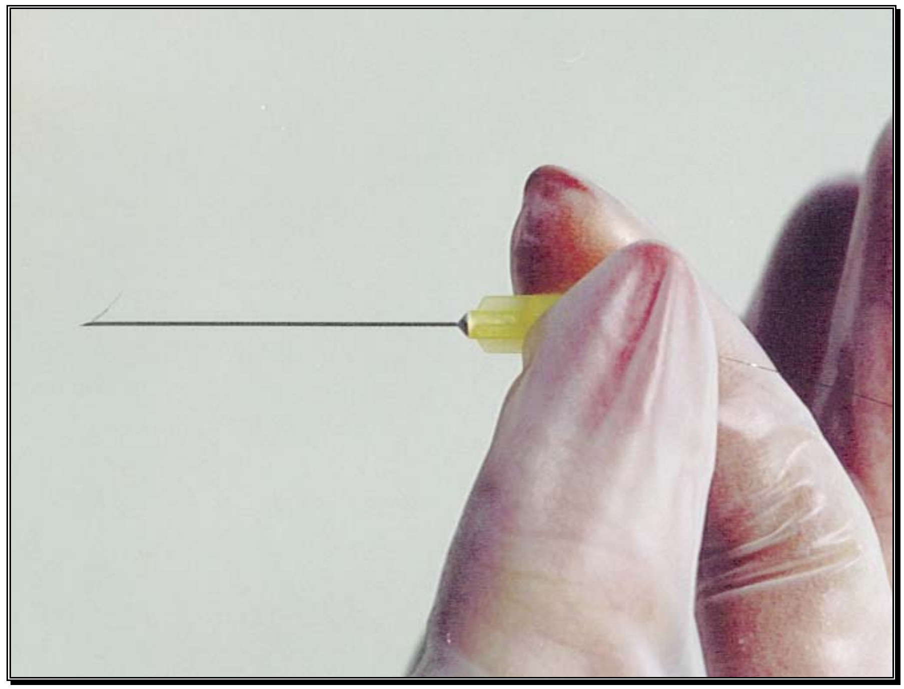

Figure 12 - Fine Wire Electrode

For good quality signals it is important to use a separate ground reference electrode when making fire wire recordings.

In use, the needle is inserted into the muscle to position the tips of the wire within the bally of the muscle – the needle is then withdrawn, leaving the fine wire electrodes in place. The two ends of the wire outside the muscle are then connected to the pre-amplifier inputs, making sure that any motion of the subject will not pull on the inserted wire. Make sure that you remove any insulation on the wire ends before connecting the wires to the preamplifiers.

Surface electrodes are generally used to detect EMG signals consisting of the electrical activity from numerous individual motor units within the pickup area of the detection surfaces. They are easy to use and are not invasive – most subjects do not find them uncomfortable as they are simply taped to the subjects' skin surface.

Fine wire electrodes are usually used in controlled situations. These would include assessing a function of a muscle, which is only accessible by the indwelling electrode. These electrodes have the advantage of minimizing cross talk but this method of collection does raise the issue of whether the sampling area is representative of the whole muscle function. The small pickup area makes it more suitable to detect individual motor unit action potentials. Of course, there is added discomfort to the subject when using indwelling electrodes that may affect the subjects' behavior, and it may not always be practical for regular use in a clinical setting.

The advantages of fine wire electrodes are an increased band width, a more specific pick-up area, ability to test deep muscles, isolation of specific muscle parts of large muscles, and ability to test small muscles which would be impossible to detect with a surface electrode due to cross-talk. The disadvantages are that the needle insertion causes discomfort, the discomfort can increase the tightness or spasticity in the muscles, cramping sometimes occurs, the electrodes are less repeatable as it is very difficult to place the needle/fine wires in the same area of the muscle each time. Additionally, one should stimulate the fine wires to be able to determine their location, which increased the discomfort of using this type of electrode. However, for certain muscles, fine wires are the only possibility for obtaining their information.

Monopolar vs. Bipolar

Differences between the recording of surface and fine wire electrodes, in part, are related to the differences in the bandwidths. Fine wire electrodes have a higher frequency and can pick-up single motor unit activity as the fine wire electrode bandwidth ranges from 2-1,000 Hz, whereas surface electrode bandwidth ranges from 10-600 Hz. Whether using surface or fine wire electrodes, there are some electrode configurations that can also decrease unwanted noise.

A monopolar arrangement is the easiest as it is a single electrode and a ground. However, this arrangement picks up more unwanted signals than any of the other potential configurations.

Bipolar arrangements are widely used in movement analysis. In this arrangement, there are two active electrodes and a ground. The process is to look at what is common with the two active electrodes, determine that this is noise, and throw it away, keeping what is different in the two electrodes as the signal of interest. This is termed a differentially amplified system and is less prone to interference from adjacent and deeper muscles.

A third arrangement is that of a double differentiated system. This is a system that has three active electrodes and one ground, therefore, possessing the ability to have two pairs of bipolar signals, which are then again differentially amplified. This gives a smaller pick-up area, therefore, even less noise than the bipolar electrode by itself.

Crosstalk

In addition, the issue of crosstalk also needs to be considered. Crosstalk is the recording of activity from a muscle, other than the one under investigation at the recording site. This can occur at three places; collection, processing, and recording of the EMG signal:

Crosstalk at the data collection point is primarily a problem with surface measurements. If a surface electrode is not be placed directly over the belly of the muscle, or the muscle generates only a very weak signal compared to other muscles close by then you may see crosstalk in the recorded EMG signal. This type of problem can be very difficult to detect – generally, you will find that the recorded EMG signal level is lower than expected and, in any activity involving repetitive motion, the EMG signal timing is out of phase with the expected timing for the muscle in question.

Crosstalk during the signal processing is a problem within the EMG system itself – this is usually fairly easy to spot in multi-channel systems as the EMG signal from one channel will appear (often at a lower level) in all other channels. Contact your EMG system manufacturer to arrange for repair if you suspect that you are seeing crosstalk within your EMG system.

Finally, crosstalk during data recording can be a problem with almost any kind of data recording system. Generally, crosstalk during recording (or data sampling with most modern digital systems) results in a signal in one channel appearing in one or more adjacent channels. Depending on the system design, a signal in channel *n* will typically appear in channel *n+1* but not in *n-1*. This often indicates a data-sampling problem in computer-based ADC recording systems.

Making EMG Recordings

Preparation

The electromyographer must have a very good understanding of the anatomy of the human body as electrode location and placement is very important if a good quality EMG signal is to be obtained. First, make sure that the surface of the skin is clean in order to reduce any skin resistance. This simple task can reduce the resistance of the skin by 200% and improve the quality of the EMG signal by a similar amount. Some researchers recommend additional preparations including shaving and abrading the skin surface to obtain even lower skin resistance but this is almost never required for short-term (individual recording sessions of less than one to two hours) studies.

For almost all clinical EMG applications, the best signal is obtained when the electrode is placed directly over the belly of the muscle. To assure repeatability of finding the specific site for the electrode various bony landmarks are often used as a reference – this technique, among others, is described in numerous books and publications. Another widely accepted method of locating suitable EMG signal locations is the use of the motor point.

When using discrete electrodes you must also consider the inter-electrode distance and make sure that this distance is consistent throughout all subjects and trials to assure that the electrodes are over the same muscle fibers in each subject. This step can be skipped if you are using pre-amplified electrodes, such as supplied with Motion Lab Systems EMG systems as these have fixed electrode geometries.

Noise Sources

Good techniques and careful preparation before an EMG recording session will eliminate most forms of noise.

There are many sources of noise that can appear in an EMG study – almost any unwanted signal collected along side the wanted signal is "noise" even though it may be a perfectly valid signal (e.g. pacemaker or EKG signals). Some of the more common noise sources are: electromagnetic fields (power lines), motion artifact due to loose electrodes at the skin interface or loose leads on the wires, involuntary reflex activity (clonus), and any other electrical device that might be either in the room, or close by, when the EMG studies are occurring.

The majority of noise artifacts can be prevented by a few simple means. Proper cleaning of the skin is one such measure that is particularly critical if pre-amplified electrodes are not used. Using bipolar differentially amplified or double differentially amplified systems (e.g. Motion Lab Systems preamplifiers) also help dramatically in the removal of artifacts from the system by eliminating signals that are common to both electrode inputs. Attaching all loose electrode leads and making sure that there is some slack in these leads is important as well so that the electrodes on the recording site are not moved or stressed during the recording. Before the starting data collection, check that the electrodes are making proper contact, that there is no tension on the wires, and that all of the wires are plugged into all connectors correctly.

Always perform a Manual Muscle Test to verify the correct electrode placement on the muscle.

Once the electrodes are in position, the subject should have manual muscle tests applied for the specific muscles being tested to make sure that the EMG electrodes are picking up muscle activity appropriately. If certain electrodes seem to be working inappropriately, you can try switching the leads (if using discrete electrodes), or just switching electrode channels to see if this particular electrode works in another channel. If the signal is still bad after switching channels, then switch electrodes to see if the electrode itself is malfunctioning.

When testing different subjects it is important to remember that there is an attenuation of the EMG signal as the amount of adipose tissue over the muscle being examined increases. Therefore, it may be difficult to pickup normal EMG signal levels when dealing with obese individuals when using surface electrodes. Furthermore, do not fall into the trap of assuming that the measured EMG signal is proportional to muscle mass – EMG signal level is affected by many different factors but in the end, an active muscle will generate a larger signal than an inactive muscle.

Checking the EMG signal

Monitoring the EMG signal in real-time, as the muscles contract is an invaluable tool that will enable you to improve the EMG signal quality.

It is imperative that the raw EMG signal can be monitored in real-time, as it is recorded and as the electrodes are placed on the subject. Ideally, this monitoring must be performed as the EMG signal is recorded as it is often difficult to differentiate between signal and noise if any processing has been done to the EMG signal. One disadvantage of using some computerized collection systems is that many do not afford one the ability to see a raw EMG signal in real time. In this case we recommend using a separate EMG display system.

A novice electromyographer may have some trouble determining if any problems exist in the raw EMG signal. However, there are several items that can be quickly spotted - a wavering base line is a common indication that low frequency movement artifacts are present. Large, individual spikes can be also indicative of motion of the pickup electrode on the skin surface. Other things to look for are common signals across all channels (possibly a poor ground reference electrode) and/or an underlying 50 or 60 Hz line power signal superimposed on the signal. If the EMG signal does not look clean then we recommend that you attempt to fix the cause of the problem before deciding to filter the recorded EMG data. It is always better to fix the problems that cause artifact rather than attempting to filter the data after data collection.

Filtering the EMG signal

Filtering is the process of removing information from the recorded EMG signal. Use it cautiously!

There are two basic filters that can be applied to EMG signals – high-pass (passes the higher frequencies and attenuates lower frequencies) and low-pass (passes lower frequencies and attenuates higher frequency signals). Other filters such as notch and band-pass filters are just combinations of these two basic filters. Each of these filters comes in a range of different types such as Bessel, Butterworth, and Chebyshev etc.

Traditionally Butterworth filters are used to process EMG signals as this filter type produces relatively little phase and amplitude distortion in the EMG signal – in addition, in the days when all filters where built with integrated circuits and transistors, Butterworth filters were relatively easy to design. With the advent of digital signal processing other filter types have become available but in general, if

EMG data is going to be filtered then you should use either a Bessel or Butterworth filter type as these introduce less distortion than other filter types.

In general, you are likely to apply a high-pass and a low-pass filter to your data. The high-pass filter will remove motion artifact and other low-frequency noise from the EMG signal while the low-pass filter will remove unwanted high-frequency noise.

Careful preparation and attention to recording a clean EMG signal from the subject will often eliminate the need to filter the recorded EMG signal.

Most EMG data is high-pass filtered at 10-15 Hz or higher, depending on the activity (10 Hz for normal walking and 15 Hz for more rapid movements) to remove movement artifacts. Clinical EMG data is usually low-pass filtered at 300-600 Hz for surface EMG, or 1,000 Hz or higher for fine wire EMG recordings. The choice of whether to filter the data or not, and the filter points to use, depends partly on the quality of the raw data and partly on the intended use of the processed data. If you are collecting EMG data for research then you should filter the data according to your research protocol – document the filter settings carefully and, if at all possible, archive a copy of the original (unfiltered) data.

EMG data for clinical motion analysis use tend to be more heavily filtered – partly to remove motion and other artifacts that may be unavoidable in clinical subjects, and partly because the timing of muscle activity is (in most cases) more significant than the fine details of the content of the EMG activity.

It is occasionally necessary to add an additional notch filter to remove line frequency noise (50/60 Hz signals depending on the line frequency in your country) but in general, this type of interference indicates a problem with your EMG equipment (possibly a loss of Common Mode Rejection) that should be investigated to eliminate this type of noise. It should never be necessary to apply a notch filter to EMG data collected with an EMG system manufactured by Motion Lab Systems.

Analysis techniques

Once we have a clean EMG signal, we can begin to look at the data and try to figure out what it is telling us about the muscles. The primary information to be gained is timing (on/off) information. In most movement analysis situations this timing information can be read directly from the raw EMG signal, no processing other than that which is used for cleaning up the raw signal (high and low- pass filters) is required.

However, there are many common forms of processing that are done with EMG signals. The most common are:

Half-wave rectification (deletion of all negative aspects of the signal).

Full-wave rectification (absolute value of the entire signal).

Linear envelope (low-pass filtering of the full-wave rectified signal).

RMS or root mean square (basically square the signal, take the mean of a timed determinant window about 100-200 ms, then take the square root).

Integrated EMG (area under the rectified curve can be determined for the entire activity or for pre-set time or amplitude values).

Frequency analysis (typically determined via fast Fourier analysis and looking at the power density spectrum).

Depending on your application, each of these processing techniques may have merit but each have disadvantages as well, since with any processing done to the data, information is lost.

For comparisons of EMG data from task to task or person to person, the data needs to be presented in a common format. Several means of normalization of the signal have been developed for both the time and amplitude domains - probably the two most widely used time-base normalization techniques are to either normalize to a task/cycle or to phases within the task/cycle.

As an example lets assume we want to look at the EMG of the back muscles with an individual who continually lifts items from the floor and places it in a bin. We can define a cycle as being from the initial movement of the object off the floor until the initial movement of the object off the floor for the successive lift. One would then just simply divide the time-base by the total amount of time it took to perform the task and then all movements would be with respect to the percent of the cycle. This works well for many cyclic tasks, but has disadvantages if the task contains more than one phase. Dividing the time-base to the percent of a phase works well for task with multiple phases.

Using the same lifting task, let us now define the lifting phase as being from the point that the object begins to move from the floor until the subject obtains a fully erect standing position. The second phase would then be from the point at which the subject reached the standing position until the item is placed in the bin and a third phase would begin at the point when the object was placed in the bin until the subject is back in position to lift another object.

Each one of these phases is handled as a separate event. Thus, the time it took to lift from the floor to the standing position would be used as the divisor to make a percent phase for the lifting phase, the time it took from the point when the body reached an erect standing position until the item was in the bin would be used as the divisor for the second phase, and so on for the third phase.

This type of time-based standardization is very useful when the task has clear phases that can be determined. For the sake of this example, lets say that the maximum EMG activity occurred just before setting the item down in the bin. It is much more meaningful to be able to say that the maximum amount of the EMG was found at 95% of the second phase than to say the maximum EMG was found at 55% of the task. From this point, you would have to go back and figure out what movement was going on at 55% of the task. Additionally, the intra and inter subject variability of setting the object in the bin at the same point in a multiphase cycle is typically large. For this reason, most people prefer to use percentages of phases of action whenever possible.

Amplitude Normalization

Many times the amplitude of the signal is normalized as well. Probably the most widely used is to standardize to the maximum voluntary isometric contraction (MVIC) for the specific muscle being used. Based upon published references for manual muscle testing, the examiner then applies a force to the body part in sufficient magnitude that the subject is unable to maintain a static position while exerting against the examiner with a maximum muscle contraction. This is fine in theory but in practice, it is debatable if it is possible to obtain a true MVIC that is consistent between subjects and examiners - therefore, several other techniques have been devised.

One of those is to use the maximum level of the signal across the entire task. In the lifting task previously described, this would mean to take the maximum EMG level from each specific muscle during the entire task then normalize to this value. Usually several peaks (three or more) are used – these are averaged to avoid the potential of using an erroneous high-spike as the maximum value.

Another means of normalization is to use the mean level of the signal across the entire task. However, this is much less sensitive to any rapid peaks that were obtained during the task and would heavily skew the data if the majority of the signal contained times when the muscle was not active.

A problem that exists when using the maximum or mean level across the entire task is that the EMG signal will vary based upon the velocity of the joints during the contractions. Therefore, unless one standardizes the velocity of the task, this method may not allow for comparisons across tasks.

Another technique very similar to the MVIC is to use a know level of force (e.g., divide by the amplitude of the EMG when lifting 20 lbs. at the specific velocity that the task will be performed). Another variation of this is to use the amplitude of the EMG signal when exerting a known force against an immovable object, therefore, eliminating velocity from the equation. All of these methods have positive and negative attributes and they are means of trying to compare amplitudes between muscles and individuals.

Additionally, if the subjects being examined have any pathological conditions that involve the muscles you are testing it will be virtually impossible to get a true MVIC and questionable whether the other normalization techniques are of any value as well. Regardless of the normalization technique used, whether it is time-based and/or amplitude based, one must remember that absolute information will be lost.

Caveats

The word *caveat* is Latin for *"let him beware"* - now that we have cleaned up the EMG data and completed any normalization that we may want to do, it is time to look at the processed signal and try to interpret its meaning. It is very important to understand that there is a large variability of the EMG signal itself. Whether this is task-to-task variability within the same person or person-to-person variability within the same task, many combinations of muscle activity can produce the same movements because of the redundancy present in the neuromuscular system. EMG can be variable from task to task because of this normal redundancy, velocity or cadence changes, or slightly different movement patterns even though under observation they look the same.

A normal range of EMG phasing will exist for a task but one must be very cautious of trying to define discreet points in the tasks where these patterns begin and end. This must be kept in mind when interpreting the EMG signals. Other factors enter into the equation with interpreting the EMG of individuals with pathological conditions that influence the task-to-task variability. The changes in velocity or cadence, the onset of fatigue, and the presence of pain can all affect the EMG patterns.

Another factor, which makes interpretation of the signal difficult, is cross talk. Cross talk is interference of the EMG signals from adjacent muscles or deeper muscles that are within the pick-up area of the electrode. There are no fixed solutions available at this point and the size of the patient and size of the electrode lead does play a major role in the ability to decrease or increase cross talk. For example, if your system has electrodes with fixed active electrode distances that are large and you are working with a pediatric population you can be assured that your data will have large amounts of muscle information from adjacent and underlying muscles that is not wanted with your data. Many examiners utilize fine wire electrodes in order to try to remedy this problem.

Interpretation

Now that we spent much time filtering and normalizing our data, it is time to discuss what the EMG signal can actually tell us. The muscle on and off timing patterns and relative increases and decreases in muscle activity are the two main parameters gained from the electromyography data. EMG data alone cannot tell us how strong the muscle is, if one muscle is stronger than another muscle, if the contraction is a concentric or eccentric contraction, or if the activity is under voluntary control by the individual.

The normalizing to the MVIC, the average, or the maximum level during the cycle are all attempts to allow us to be able to compare from muscle to muscle within the same person and from muscle to muscle between individuals. These are all common methods that attempt to make the EMG data produce results that allow us to compare contractions in-between subjects or activities but one must be cautious of interpreting the results due to the problems inherent with the collection techniques and the natural variability among muscles, individuals, and tasks.

Besides using EMG for determining the EMG patterns (times of activation and times of rest) many researchers use electromyography for evaluating the changes in the signals as the muscles fatigue or alternatively, to evaluate the change in tone and strength as muscle strengthen through exercise and physical therapy. All of these are valuable uses of electromyography in occupational biomechanics.

Application

Whenever using EMG for clinical or research purposes, care should be taken to ensure that you always use a common environment to collect and record the data and that the conditions be documented to allow others to reproduce your results.

This is especially important in the research environment where you should ensure that you use appropriate units when reporting EMG data. In particular, when referring to the amplifier gain, the units should be in a ratio or dB, and the input impedance should be expressed in ohms (e.g. $1x10^6$ ohms).

The common mode rejection ratio should always be stated, either as a ratio or in dB. The measured bandwidth of the signal should be stated in Hz – usually indicating the –3dB point of the processed EMG signal but it is important to indicate the flat portion of the signal bandwidth if at all possible.

The EMG level, when a raw, average or rectified signal, should be referred to in millivolts (mV). If the EMG signal has been integrated, then it should be expressed in terms of millivolt-seconds with the specific period of analysis. If the integrated EMG was time reset or voltage reset, then the specific time or voltage should be indicated. By clearly stating the precise environment used for data collection and data processing, you will enable others to reproduce the study that you have conducted.

EMG data collection from clinical analysis should always be performed in a comfortable environment for the subject. The room should be warm and well ventilated to eliminate shivering and sweating as sources of artifact and poor signal quality.

Surface EMG

This is the most common form of EMG recording in most gait and biomechanics environments – it involves the placement of two or more electrodes (often in a single physical package) on the surface of the subjects skin. It is easy to use, required very little preparation and produces good results for large muscles that are close to the surface. It is inappropriate for EMG signals from deep muscles, or from muscles that lie underneath other muscles.

Preparation

Use alcohol or a similar non-oily cleansing solution to removal of dirt, oil, and dead skin. Shave excess hair if absolutely necessary but this is not normally required – most research studies that state the shaving is *required* can trace this assumption to animal research (especially cats).

If the skin surface is dry, some electrode gel rubbed into the skin can dramatically improve the quality of the recorded signal provided that the amount used is very small – the skin surface should be wiped clean after applying the gel to make sure that none remains on the surface of the subjects skin.

Placement

There are several specific references for different ways to measure the subject for electrode placement (see page 114). The general guidelines for large muscle groups are that the electrodes should be placed over the largest mass of the muscle and aligned with the muscle fibers - use a motor point and motor point finder to locate these if you are not an experienced electromyographer.

Crosstalk

Intramuscular cross-talk is always a possibility with surface EMG recordings but is not usually a problem with clinical data collection from large muscle groups. Cross-talk can often be avoided by careful placement or by adjusting the electrode size and inter-electrode distance if you are using discrete electrodes.

Application

Skin placement techniques are all important when using surface EMG electrodes. It is vital that you prevent any movement of electrodes against the skin surface by using straps or tape to firmly secure pre-amplified electrodes in place or by ensuring that discreet gel electrodes are firmly affixed to the skin surface.

If using discreet gel or reusable electrodes then avoid bending the electrode leads in any way that might place a stress on the electrode during motion. Place the leads pointing in the direction that you want the wire to continue (e.g., for electrodes placed on an extremity, have the lead pointing towards the proximal end of the extremity so that the wire will not have to be bent in order to go in the proximal direction.)

Avoid any stress on the electrode wires by making sure that the wires are loose underneath the tape or wrap that is holding them in place. Be sure to check when the wires cross the joint that once the joint is fully extended the wires are not drawn taunt – this could place strain (and thus cause artifact) on the electrode/skin interface. Finally, avoid placing electrodes over scars.

Testing

It makes little sense to spend the time to record EMG if you are going to be in any doubt about the validity of the recorded signal. You should always perform a manual muscle test to ensure that you are getting a signal and that you are over the intended muscle – this should be part of your standard Quality Assurance and is very useful if questions arise later as to which muscle has actually been recorded.

Once you are confident that your electrodes are correctly placed, you should record a pre-trial session to check the EMG signal and to get the subject used to the setup and instrumentation. This trial session should be preserved as part of your control documentation – you may also wish to record and save an additional post-trial session after all the EMG tests have been performed to document any conditions or problems that may have occurred during the EMG recording session. If the recorded pre-trial and post-trial sessions are comparable then you can be confident of the session data.

Fine Wire EMG

Fine wire EMG is an invasive procedure and may be a legally regulated procedure in your jurisdiction. Always consult your physician or administrators for clarification before performing any fine-wire insertions on subjects.

Fine wire EMG involves the insertion of a pair of wire electrodes into the muscle body, usually via a needle, which is withdrawn once the wires are in place. Fine wire EMG is appropriate for small muscles, deep muscles that not accessible by surface electrodes, and to isolate specific muscles from a muscle group or adjacent muscles.

Preparation

Use alcohol or a similar non-oily cleansing solution to removal of dirt, oil, and dead skin. It is not necessary to shave excess hair for fine wire insertions unless it is required to enable the researcher to locate the insertion site with precision.

Paired fine wire electrodes can be constructed as described by Basmajian and others, or purchased from a number of commercial sources including Motion Lab Systems.. Fine wire electrodes are usually available with various canella lengths – make sure that you use fine wire electrode with sufficiently long wires for any study involving motion. The two wires typically connect to a local pre-amplifier or to fine wire connectors (springs, clips etc). In general some type of ground reference is used.

If desired you can use various topical agents to control pain associated with the needle and wire insertion. Typical agents are Ethyl Chloride - a vapocoolant (skin refrigerant) intended for injections and minor surgical procedures, and EMLA (lidocaine 2.5% and prilocaine 2.5%) a topical anesthetic for use on normal intact skin for local analgesia (pain relief). EMLA is contraindicated in patients with a known history of sensitivity to local anesthetics of the amide type.

Unlike surface EMG applications, an assistant is generally required for fine-wire applications to help in preparation, stabilize the extremity, or distract the subject during the insertion procedure if needed (having the subject blow out forcefully as the needle is inserted works well). It is usually easier to have the subject lying down and the muscle relaxed for insertion of the fine wire electrodes. Needless to say, clinical cleanliness, washing of hands and universal precautions are in order for this procedure.

Placement

There are several specific references for different ways to measure the subject for electrode placement (see page 114), the use of a cross sectional anatomy book or EMG guide to locate insertion point and the direction of application is highly recommended e.g. "Anatomical Guide for Electromyography: The Limbs and Trunk."

Always check the placement of the fine wires with either electrical stimulation or by manual muscle testing. Note that manual muscle testing is not a particularly useful test if the same movement needed for testing the selected muscle would activate adjacent muscles.

After inserting the fine wires and removing the needle secure the wires to the preamplifier or electrode clip. Then tape the wire in place to the skin with small loop of wire to allow for movement. Make sure that any motion of the subject will not strain the wire at the insertion site, as this will cause artifact during data collection.

It is a good idea to recheck the placement of the wires via electrical stimulation or manual muscle testing if questions arise during the collection process.

Crosstalk

Intramuscular cross talk is not usually a problem with fine wire recording if the fine wire electrodes are placed correctly. However, incorrect placement can produce crosstalk symptoms if the wires are either too deep, too shallow, or have missed the body of the muscle in any way.

Removal of the wires

You can remove the wires after the testing has been completed by gently pulling the wires out of the muscle. Check the ends of the wire to assure that no significant lengths of wire have broken off inside the body.

Sharps canisters are required for disposal of fine wire needles. For disposal of the wire and gloves, you should check with your infection control or OSHA office to determine what needs to be done at your facility to determine if a biohazard container must be used.

EMG Data Collection

It is preferred to do a minimum of processing of the EMG data during the data collection, as it is difficult or impossible to know if noise has corrupted your data before the processing. Some general rules are:

Record surface EMG signals at a sample rate of 1,200 samples per second for a recording bandwidth of 600Hz.

Record fine wire EMG signals at a sample rate of 3,000 samples per second for a recording bandwidth of 1500Hz.

Use a high-pass filter (prior to data sampling) with a cut-off of 5-15 Hz to remove motion artifact components from the EMG signal. The precise high-pass filter frequency depends on the subject activity – vigorous physical motion may require higher filter frequencies.

A low-pass filter (prior to data sampling) at 500-600 Hz for surface EMG and 1,000-1,500 Hz for fine wire EMG works well as an anti-aliasing filter. These filter frequencies must be decreased if your sampling rate is lower than the recommended rates listed above.

It is highly recommended that any EMG data collection system provide a means of monitoring all of the EMG signals in real time via some form of multi-channel display. This allows any signal quality problems to be quickly detected and fixed prior to sampling and recording the EMG signals.

EMG systems manufactured by Motion Lab Systems met all the requirements described above.