

## Considerations for the Use of Surface Electromyography

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### Abstract

EMG is used in rehabilitation research to provide a method to infer muscle function. This paper will present an introduction to interpretation of electromyography (EMG) data for physical therapists. It is important for the physical therapist to have an understanding of the collection and reduction of raw electrical data from the muscle to allow the physical therapist to interpret findings in a research report, and improve planning of clinical research projects with respect to data collection. We will discuss factors that affect the type of EMG collected and the ways in which various common methods of data reduction will impact the findings from a study that uses EMG.

**Key Words:** Surface EMG.

Although this paper is not intended to represent an exhaustive review of electromyography (EMG) procedure, we will present an introduction to interpretation of EMG data for physical therapists. Extensively used in rehabilitation research, EMG provides a method by which muscle function may be inferred from the detection of action potentials (AP) propagated by the muscle. These APs represent summation of the depolarization-repolarization of a group of muscle fibers innervated by the same motor nerve, known as a motor unit (MU) (Lamb and Hobart, 1992). All muscle fibers depolarize asynchronously within the MU due to differences in the size of collateral branches of the motor nerve and spatial relationship of the fiber to the motor endplate (Lamb and Hobart, 1992). The way in which an external observer may attempt to directly detect this depolarization is twofold. First, fine wires, either bare or contained in a needle can be

imbedded within the muscle; second, and less invasive technique, is to record the muscle AP via electrodes on the skin surface commonly denoted as surface EMG or sEMG (Basmaijan and De Luca, 1985; Soderberg, 1992).

sEMG is predominantly used to detect the gross electric signal from a group of muscle fibers within a depolarizing muscle or muscles. The ability to detect signals from smaller muscles is limited (Basmaijan and De Luca, 1985). This difficulty in 'cleanly' measuring the signal from small muscles, is far outweighed by the advantages of sEMG (Basmaijan and De Luca, 1985; Soderberg, 1992), the most predominant of which is ease of application. The remainder of this paper will discuss the factors that contribute to and influence the characteristics of the EMG signal and the subsequent interpretation of the sEMG. We believe that it is important for the physical therapist user of

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sEMG data to have an understanding of the collection and reduction of raw electrical data from the muscle to facilitate two things: 1) allowing the physical therapist to make an independent informed decision when interpreting findings in a research report, and 2) improving planning of clinical research projects with respect to data collection.

sEMG is measured by placing electrodes upon the skin over the muscle of interest. In this situation the skin and subcutaneous tissue become a source of resistance or impedance to measurement of the APs and, in essence, work as a high pass filter by attenuating the lower frequency components of the signal (Basmajian and De Luca, 1985). Skin preparation; abrasion or cleaning with alcohol, is done to decrease the skin impedance, and improve the interface between the electrode and the skin or electrolyte (Basmajian and De Luca, 1985; Soderberg, 1992). In sEMG, this interface is some form of gel (pre-amplified electrodes do not require the gel to be conductive) (Soderberg, 1992). Impedance also occurs within the muscle tissue. Muscle tissue serves as a distance dependent filter, with greater attenuation of the electrical signal as the detection device is separated from the source. Thus, recording parallel to the direction of the muscle fibers will lower resistance compared to recording perpendicularly.

Consideration must be given to the task for which sEMG data is required when choosing the type make and size of electrodes (Basmajian and De Luca, 1985; Soderberg, 1992). The spacing of the electrodes is not standardized but recommendations are made by several authors (Basmajian and De Luca, 1985; Loeb and Gans, 1986; Soderberg, 1992) about electrode diameter and spacing. Basmajian specifically recommends

an inter-electrode distance of 1 cm (Basmajian and De Luca, 1985). Quite often when bipolar electrodes are used, the electrodes are pre-made and mounted thus eliminating decisions regarding electrode size and spacing. A downside to the bipolar configuration is that any preamplifier built into these electrodes amplifies the difference in potential at each electrode resulting in band-pass filtering of the signal (Soderberg, 1992). Any AP with a peak to peak sinusoidal wavelength equal to the inter-electrode spacing will not register on a differential amplifier (Basmajian and De Luca, 1985). Inter-electrode distance influences recorded values derived from the EMG signal at higher activation levels (Melaku et al, 2001) and Soderberg (1992) proposes that the smaller the muscle of interest, the smaller the inter-electrode distance (Soderberg, 1992). The practical application is that it would not be beneficial to use 2 cm diameter electrodes placed 10 cm apart, for collection of data from a specific forearm muscle, while this arrangement may be appropriate for general interpretation of activity in the quadriceps muscles.

Additionally, electrode location on the muscle belly can significantly alter the mean power of the electric signal collected (Hogrel et al, 1998; Melaku et al, 2001), however little standardization is established related to electrode location. Falla et al (2004), in the cervical spine, and Rainoldi et al (2004), for the lower extremities, have identified electrode placements that provide reduced intersubject variability on testing sEMG and improve signal quality. In general, the following electrode arrangements have been recommended: high density, multielectrode grids may be more useful for motor unit topography and recognition; small

linear arrangements for muscle fiber conduction parameters; and monopolar or bipolar electrodes for amplitude and timing (Zwarts et al, 2000).

Placement of the surface electrodes is usually done to ensure that there is minimal motion of the electrodes relative to the underlying fibers. Any such motion changes the amplitude of any AP to be measured by changing the distance from the electrode to the muscle fibers of interest and may affect the charge gradient at the electrode-electrolyte interface (Basmaijan and De Luca, 1985). Also, the possibility of detecting signals from other muscles increases as the electrodes move relative to the subtended muscle. Given that sEMG is the summation of all underlying APs, any muscle within 'range' of the electrodes will contribute to the signal that is recorded - the larger the electrode size, and the farther apart the recording electrodes, the larger the area and potential muscles from which data is collected. Attention should be given to minimize the 'cross-talk' from muscles other than that subjected to study (Basmaijan and De Luca, 1985; Soderberg, 1992). For example, when measuring sEMG from the human biceps, poor electrode placement may result in the recording of APs from the triceps brachii, which would obfuscate the nature of muscle activation during elbow flexion-extension. Similarly, the electrode, once correctly placed on the belly of the biceps brachii, records the depolarization of not only the biceps but of the brachialis also.

Once the AP reaches the electrode, the signal must be amplified to render it observable (Basmaijan and De Luca, 1985). Gerlman and Cook (1992) report that amplification of the muscle APs has several functions: to isolate the signal source and the recording instrument, conversion of current to voltage, voltage gain,

and noise reduction. The most import stage of amplification is the first stage or preamplifier. At this stage, the conservation of signal power depends on input impedance of the preamplifier. In general this impedance needs to be larger than the source impedance otherwise power is lost from the EMG signal resulting in a drop in voltage. Preamplifiers are often built into bipolar electrodes which decreases movement artifact and improves the signal to noise ratio (Gerlman and Cook, 1992).

Noise represents any external signal that may contribute to the sEMG signal being recorded (Basmaijan and De Luca, 1985; Gerlman and Cook, 1992). Common sources include electric generators and electric fields from the wiring within the walls of the testing area. It is advantageous to minimize ambient noise so that the predominant signal under amplification is that from the muscle depolarization. This can be accomplished by isolating the test area from external electric fields. An instrumentation alternative building an isolated test area is referred to as common mode rejection (Basmaijan and De Luca, 1985) and reported as the common mode rejection rate (CMRR). If one can imagine that in a bipolar system, ambient noise will be common to both poles of the recording device. A differential amplifier will summate the common signal to zero removing it from the overall sEMG (Winter, 1990).

The most obvious application of sEMG for the physical therapist is the timing of muscular events, that is, whether the muscle is 'on' or 'off'. This information allows insight into the 'functional' anatomy of a muscle - when is the muscle active during the selected activity and for how long. There is, however, a small delay between the onset of electric activity and the

generation of muscle tension. This 'electromechanical delay' is muscle dependent and represents the time required to take up the 'slack' in the tendon. The 'onset' of muscle activity can be determined from visual inspection, however more objective techniques are available. The concept of threshold is applied to the sEMG data whether raw or processed. Even when a subject is at rest, there will be electric data recorded and available for inspection, given a large enough gain within the amplifier. The threshold represents some increase in value above some base line. This can be done automatically by appropriate software, or manually by the physical therapist. The time of 'on' activity of the muscle will be, therefore, directly dependent on the threshold value set. Often the threshold is set as two (Bishop et al, 2004; Bishop et al, 2000; Brunt et al, 2000; Di Fabio, 1987; Fiolkowski et al, 2002; Fiolkowski et al, 2003; Soderberg, 1992) or three standard deviations above the base line mean EMG.

A second use for sEMG data is the extrapolation of a force-EMG relationship. If all muscle demonstrated a linear relationship between the sEMG signal and force generation, this would be a simple task. However, the muscular anatomy and properties will greatly affect the sEMG signal that is generated. Skeletal muscle contains different fiber types, the names of which are based on intrinsic properties that have been identified by staining techniques or histochemical testing (Williams, 1994). Measurement of a specific concentration of similar type muscle fibers would give a linear relationship (Woods and Bigland-Ritchie, 1983). However, most muscles consist of combinations of fiber groups (Williams, 1994). Further, muscle fiber arrangement alters the cross-sectional area,

length-tension and velocity of shortening properties of the muscle. Each of these factors can affect the force-sEMG relationship.

For each muscle there exists a relationship between length and tension; that is, isometric muscle tension changes relative to the length at which that muscle is stimulated (Williams, 1994). Physiologically most muscles however, are more affected by the angle at which the joint, subtended by the muscle, is maintained. This deals more with lever arm-tension specifically, but muscle length will change as joint position changes. It should be evident then, that if the muscle is not tested with strict maintenance of length and joint angle, it will be less likely for there to be a linear increase in force from submaximal to maximal. Situations in which the joint is moving and therefore muscle length is changing, present the physical therapist with several problems with respect to interpretation of EMG data. Initially, one must consider that the relationship of the electrodes to the underlying muscle fibers will be altered as the muscle shortens (concentric action) or lengthens (eccentric action). The fibers from which the sEMG are recorded will change as the muscle length changes.

Second, the velocity at which the muscle shortens affects the tension generated by that muscle (Bishop et al, 2000; Woods and Bigland-Ritchie, 1983). For concentric actions, force decreases as speed of contraction increases. During eccentric actions the muscle tension controls the lengthening undergone by the tendons and soft tissues. It is well established that integrated EMG is less for eccentric muscle actions than concentric muscle actions when performing the same amount of work, while peak EMG amplitude is greater during eccentric

actions (Bishop et al, 2000).

Muscle architecture affects the number of muscle fibers in any given cross-sectional area. Pennate muscles have an increase in the number of fibers under the recording electrode. As sEMG measures the summed APs under the recording electrodes, the larger the size of depolarizing fibers and the larger the number of fibers, the larger the amplitude of the sEMG signal. The amplitude of the sEMG measured increases will also increase with the rate at which these motor units depolarize. Further, synchronization of motor unit firing will result in increased sEMG amplitude (Bishop et al, 2000; Farina et al, 2004; Reilly et al, 2004; Semmler et al, 2003).

A difficulty that is now presented to the physical therapist is how to compare sEMG between subjects. This is likely to depend on the activity under examination. Soderberg (Soderberg and Knutson, 2000) suggests that if comparison is only to be made between activities performed by one subject, on the same day, without removal of the electrodes, then no particular transformation should be performed. Otherwise it is best to 'normalize' the sEMG data; that is, to express the sEMG relative to some activity (Allison and Singer; 1993; Basmajian and De Luca, 1985; De Luca, 1993; Knutson et al, 1994). Most commonly the comparison is made to a maximal voluntary isometric contraction (MVIC) (Isear et al, 1997; Nakajima et al, 2003; Uhl et al, 2003; Van Leemputte and Willems, 1987; Vezina and Hubble-Kozey, 2000). In cases where the joint angle and muscle length are kept constant during the task of interest, this should work very well for comparison (Gagnon et al, 2004; Nakajima et al, 2003). The underlying assumption is that as sEMG of the MVIC

represents the electrical activity of the muscle during maximal effort, comparison with submaximal actions can reveal information regarding the force-EMG relationship; that is, a contraction that has a normalized sEMG value of 50% is generating less tension than 75% is less than 90% and so on.

In studies of a dynamic nature, an isometric contraction may not be the best activity for comparison. Often the reference activity is related to the task performed. Comparing the activity of the calf muscles during walking to activity during gait termination is an example of this premise (Araujo et al, 2000; Bishop et al, 2004; Bishop et al, 2003).

But what sEMG value should now be used for the normalizing process? Peak EMG? Mean EMG over a certain duration? No standard value is suggested and therefore a rationale should be presented by each investigator with respect to the value of choice. If the question under examination is related to maximum activation potential, perhaps a peak activation value should be used for normalization. However, if performance over time in a dynamic task is being tested, a different value should be selected. Even in healthy subjects large variability in EMG variables can be measured from MVIC (Araujo et al, 2000).

Perhaps the simplest method for determination of sEMG parameters is visual inspection of the raw sEMG signal, a method which remains in common use (Brunt and Robichaud, 1996; Brunt et al, 2000; Brunt et al, 1995). Inspection of the raw signal is necessary for the detection of artifact prior to higher order processing but the limitation of this is the subjectivity of judgments made about temporal and kinetic events. Processing and filtering the data improve objectivity and there are a variety of techniques

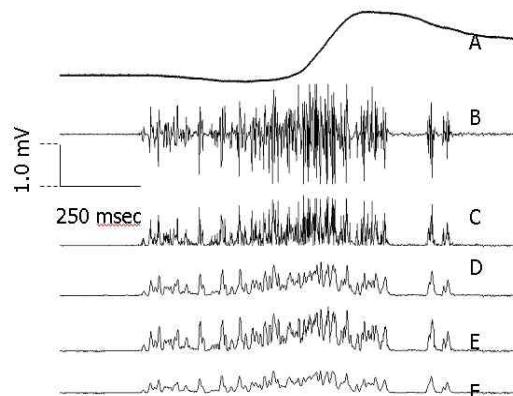
to accomplish this purpose. However, each type of processing will affect the volume and density of the recorded sEMG, and therefore the value used as the reference during normalization. Processing may also affect the onset and offset criteria used to determine when the muscle is actually working. Figure 1 shows the same data from a subject performing a trial of sit-to-stand under different processing.

As the sEMG signal consists of both negative and positive values, to take an average of the sEMG signal will result in a zero value. This can be simply overcome by rectifying the signal either by eliminating negative values (half wave rectification) or taking the absolute values (full wave rectification) (Basmajian and De Luca, 1985). A smoothing effect can be created by taking a moving average of the rectified signal (Basmajian and De Luca, 1985). Alternately, the rectified signal is processed with a low-pass filter creating a linear envelope. The cut-off of the low-pass filter should be determined by the

activity in question and can be related to the frequency of the movement in question. Winter states that human movement rarely occurs faster than 6 Hz and suggest 6 Hz as a suitable filter frequency (Winter, 1990), however, values vary in the literature (Hase and Stein, 1998). These forms of smoothing provide a 'cleaner' signal (less noise) from which on and off times are more easily calculated.

An alternate method of smoothing the sEMG is the determination of the root mean square (RMS). This does not require prior rectification of the signal as the raw data is squared prior to averaging. Similar to the moving average above, there is a time interval over which the squared signal is averaged to be determined by the physical therapist. RMS is widely used in engineering applications and Basmajian recommends its use 'above all others' (Basmajian and De Luca, 1985).

The area under the curve represents the total amount of muscle activity occurring at one time



**Figure 1.** A comparison of the effects of post-collection processing. Channel A represents the force tracing of the task under assessment (in this case sit-to-stand). Channel A is not to scale. Channel B is the raw EMG signal collected from the tibialis anterior muscle using a bipolar electrode set up. Each subsequent channel shows the signal post processing: C rectification, D moving average over 5 data points, E RMS over 50  $m/s$ , F low-pass filtered data at 50 Hz. The vertical line is 1.0 mV. The horizontal line is 250 msec.

and is calculated by integrating the sEMG over a given time. As rectified EMG is positive, the continuing sum of sEMG will rise steadily unless periodically reset to zero. This value will necessarily be affected by the volume of signal that is removed by low-pass filtering, and maybe better applied to non-filtered data. If, for example, one were to run a low-pass filter at 6 Hz, the remainder of the signal above 6 Hz would be lost.

The total sEMG signal consists of a spectrum of frequencies related to the firing rates of the underlying motor units. Frequency analysis detects the common frequencies of the signal and may be used to determine the signal's energy (Basmaijan and De Luca, 1985). Low-pass filtering attenuates any frequencies above the cutoff set for the filter removing the high frequencies of that signal. The International Society for Electrophysiology and Kinesiology recommends that the portion of the signal between 10 Hz and 350 Hz be retained for analysis. A simple use for the frequency-power spectrum includes the determination of the concentration of signal energy. The mean and median frequencies of the spectrum have been used in examination of the effects of fatigue on the sEMG characteristics (Basmaijan and De Luca, 1985).

It is evident that the use of sEMG during the analysis of movement is a process of several decision-making steps. Once the muscle has been chosen, skin has been prepared to decrease impedance, the size, inter-electrode distance and site for electrode placement identified and standardized between subjects, and electrodes taped to minimize movement artifact, the physical therapist begins to collect the raw data that represents the electrical signal from the

muscle. After this, the physical therapist must decide on the normalization activity to be used based on the activity under examination. Will the activity be best represented by a dynamic or static baseline? Is peak EMG the best indicator of muscle performance or is mean activity of a certain time more important?

The actual values used for the normalization process will subsequently depend on the processing performed on the raw sEMG signal. This may not represent much of a dilemma if comparisons are limited to the relative activation, however absolute values will be very different dependent on the processing chosen. It seems from this review that the most useful information garnered for use during movement analysis is the temporal characteristics of muscle function, and the activation of the muscle relative to some baseline activity.

It should be evident that the final results of analysis of sEMG will be dependent on any and all of the above factors that directly affect the APs generated within the target muscle. The muscle morphology, neural activation characteristics, location and depth, and type of recording instruments used have dramatic influence. The type of activity to be analyzed and processing to which the signal is subject compounds this. Constraints, such as these, highlight the importance of accurately reporting the process by which the sEMG data was obtained in any research report that includes sEMG data. Additionally, the physical therapist should pay careful consideration to the conclusions drawn from the analysis of sEMG.

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