OBSERVATIONS ON THE CHARACTERISTICS OF EMG SIGNALS RECORDED AT DIFFERENT DEPTHS

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The objective of this study is to report early results of an ongoing project which contains electromyographic signals taken from different depths on a straight path in muscle tissue. In this study, one dimensional investigation of potential field is studied on biceps brachii experimentally and the signals are processed so as to contribute on understanding the electrical behavior of muscle better.

1. Introduction

The electrical activity of muscle is studied for diagnostic purposes by inserting a recording electrode directly into the muscle. Recording of muscle's bioelectrical activity by needle electrode is known as electromyography (EMG). EMG has been used to detect and characterize disease processes affecting the motor units and to provide a guide to prognosis.

EMG signals recorded while muscle is contracting are described as "motor unit potentials". As defined by Liddll and Sherrington [1], the motor unit consists of a motor neuron and few hundred muscle fibres that it innervates. A single discharge of motor neuron gives rise to synchronous contraction of all muscle fibers innervated by the axon. Hence, even though individual muscle fibers represent the anatomic substrate, the motor unit constitutes the smallest functional element of contraction.

The needle electrode is inserted into the muscle near the innervation zone (the zone where the all muscle fibers belonging to same motor unit had their innervation) while it is relaxed so that the presence and extend of any insertion activity can be noted. During recording, needle electrodes placed in different depths in muscle tissue in order to sample more motor unit potentials. The placement of needle electrode in different depths may influence the characteristics of recorded signals. Such as, motor unit potentials recorded by a needle electrode that placed in close vicinity to muscle fibers will have larger amplitude and predominantly includes high frequency sinusoids. By placing the needle far away from the muscle fibers, new recorded signal's amplitude and high frequency contributors are expected to be observed weaker. However, this new position may yield to properly record new motor unit potentials that are different from the first one. The distance to muscle fibers is readily affect the signal but there may be other contributing factors, which are aimed to be investigated in this study.

2. Experimental Procedure

Experiments were carried out by seven healthy male and female subjects in ages between 25 and 35. The subjects were given sufficient information about the experiment and their consents were taken.

During the experiment the subject was asked to seat on a chair to hold his/her forearm was parallel to ground and were bent of 90^0 from his/her elbow. Arm movement of the subject was immobilized in order to record the signals during a stable position.

EMG signals were recorded in two stages according to the loading of the arm. The first one is the relax condition of the arm without loading. In the second stage, motor unit potentials were recorded during isometric contraction of the target muscle while muscle was contracting against sustained loading of 10 N.

For recording, biceps brachii had been chosen in the study because of its high electrical activity [2], and being appropriate to penetrate by using needle electrode in different depths. A monopolar needle electrode (TECA-902-DMG37, NY, USA) was used for recording. Needle electrode was inserted in the biceps brachii muscle near the innervation zone at different depths namely, 15, 10 and 5 milimeters, respectively (Figure 1). A surface cup electrode was secured at the tendon of biceps muscle as a reference lead. The activity was recorded for 20 seconds from three different depths in the muscle. The data recorded at the time interval from 5th second to 15th second are processed so as to avoid from the fluctuations during subject's adaptation to experiment and corruptive signals as a result of fatigue.

The EMG device (Key point version 5.3, Skovlunde, Denmark), used in the experiments, has four input channels, which enables to record the EMG signals from four separate muscles.

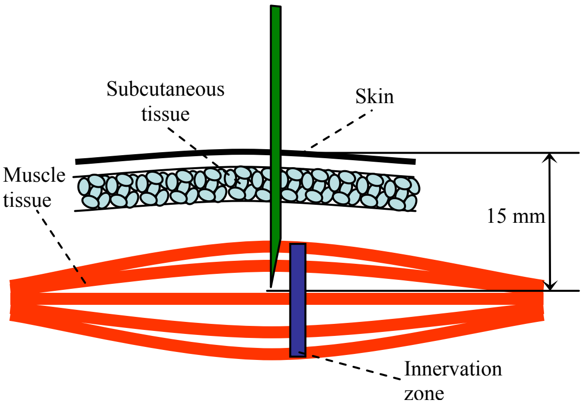

Figure 1. Penetration depth of needle electrode.

As it is known that there are too many parameters affecting EMG signal behaviour, great care must be taken during measurements. For example, to minimize crosstalk effect, the electrodes must be inserted exactly at the center of muscles.

Detected EMG signals are applied to a filter that has 20 Hz lower frequency cut-offs. The sampling frequency of signals is 5 kHz.

3. Characterization of the Signal

In this study, in order to characterize and classify EMG signals with non-stationary characteristics, second order moments of the time and frequency domains, which are involves the statistical information of signal, are used.

First in time domain, power of signal, i.e. second order moment, is calculated. Then, for the frequency moments, signals are windowed by dividing the time length into 10 equal non-overlapping intervals. The power spectra, $P(\omega)$, of EMG segments are estimated by using periodogram approach [3]. The periodogram estimate of the power spectral density of a random signal $x(t)$ with a time duration of T is given by:

$$P_x(\omega) = \frac{1}{T}\left|X(\omega)^2\right| \qquad (1)$$

where $X(\omega)$ denotes the Forurier transform of $x(t)$. In statistical mean, periodogram estimation converges to signals power spectrum of random process. In our implementation, Discrete Fourier Transform (DFT) is used to calculate periodogram estimate of windowed signals.

Using short-time segments to analyze the frequency content of EMG signal allows us to tract the time-variations in the signal better than taking the whole spectrum. Then the DFT, $X_m(k)$, of short-time signal $x_m(n)$ is calculated, and the power spectral estimate is obtained:

$$P_m(\omega_k) = \frac{1}{N}\left|X_m(k)^2\right| \qquad (2)$$

$P_x(\omega)$ contains enough information to characterize the EMG signal and it is also used in previous studies [2,4]. However, for a signal of length N, it is required to calculate an N sample power spectral estimate, which means higher number of features and higher computational burden. Instead of the whole power spectrum, using a few features extracted from it will be a computational advantage [5]. In our study, after power spectrum estimation for the segments of EMG signal, second order time and frequency moments are calculated and used as the characterizing features. Moments carries the statistical information of a random signal [5] and can be calculated in time and in frequency domain for a signal $x(t)$ as follows:

$$\langle \omega^j \rangle = \int_{-\infty}^{\infty} \omega^j P_x(\omega)\, d\omega \qquad j = 0,1,... \qquad (3)$$

$$\langle t^i \rangle = \int_{-\infty}^{\infty} t^i P_x(t)\, dt \qquad i = 0,1,... \qquad (4)$$

Here, $\langle \omega_j \rangle$ is the jth order frequency moment and $P_x(\omega)$ indicates the density function of $x(t)$ in frequency, $\langle t^i \rangle$ is the i'th order time moment and finally $P_x(t) = | x(t) |^2$ is the energy density function of $x(t)$ in time.

4. Results and Discussion

It is very well known that, the signal which is recorded during an EMG measurement, does not contain only the effect of the motor unit activity in close vicinity of needle electrode but potential signals taken from other active muscle fibers also. As expected, closer potentials are dominant on specifying signal characteristics. As the muscle is considered as a medium, there is a dynamic (as a function of time and spatial coordinates) potential field in it.

In figure 2, data recorded at 3 depths (15mm, 10 mm and 5 mm from the skin) at rest and corresponding second moment values are shown at left column and data recorded at the same 3 depths while the subject was holding 10 N weight in his/her hand are shown at the right column. Each row contains the signal diagrams of different subjects. It can easily be seen that, the results on the right column (10 N loading) have higher amplitudes. Although the signal at rest of subject A has as high amplitudes as signal recorded with loading in many results, the differences between signals at rest are insufficient to determine a characteristic as a function of depth. 10 N seems to be a good choice of weight because in many sets of signals taken from subjects, the amplitudes show a decreasing trend according to decreasing depths consistently which means weight chosen is much enough to show the difference of signals coming from different depths and less enough not to fire so many motor units (interference) that can become a major problem in interpreting signals. Both time moment values and amplitudes of signals recorded at 15 mm are higher than 10 mm and 5 mm in 5 out of 7 subjects. In the records of two subjects of seven, the signal recorded at 10 mm has the higher amplitudes (Figure 2, Subject C). Although the maximum amplitudes of signals vary from subject to subject, the age, sporting activity level of person or sex doesn't change decreasing trend of amplitudes from 15mm to 5 mm depth. The second moment diagrams of signals show the situation more clearly. Moment values vary among the subject, but verifying the observation results of signals. Moment values of experiments at rest oscillate around certain values but it is not possible to say the same for loaded experimental results.

Windowing is applied to examine the behavior of signals in a detailed way in time dimension. In Figure 3, the second spectral moments of windowed signals of two subjects are shown. At the left column, moment analysis of windowed EMG signals of subjects A and B recorded at rest are shown. At the right column the results of the same analysis of loaded recordings are shown. The symbols at the very right of each graph show the average moment value of windows. In the results of some subjects, moment difference according to depth can be seen clearly (Figure 3.a). Significant and continuous difference is kept during the whole time interval where 10 N weight is used. Even though the degree of difference is less, the same trend can be observed at the graph of 0 N case (Figure 3.b). In some results, the second moment values are looked wavy but averages over time interval show that potentials decrease from deep to skin. In some results, some unexpected peaks were seen after the mid time of experiment which may be as a result of pain or fatigue.

5. Conclusion

1. Loading other than the weight of the extremity is needed in order to analyze signal characteristics of skeletal muscle while it was contracting. However, loading too much weight may cause full interference of motor units which may dampen to analyze signal characteristics at different depths. 10 N loading seems to be plausible, because it recruits just enough motor units to contraction.

2. Time moment values calculated from 15 mm depth were higher than the ones recorded from 10 mm, and values recorded from 10 mm depth were higher than the ones recorded from 5 mm in 5 out of 7 subjects. The decreasing trend of moments from depth to surface may indicate that the motor units recruited to contraction are situated deeper. This is an observation which may be interpreted as motor units are situated in muscle by an order. However, in 2 subjects, signals acquired from 10 mm depth yielded higher moment values than the ones recorded from 15 mm. This observation can not be explained by foregoing explanation. This discrepancy may result from the fact that the needle electrode samples the activity of randomly distributed motor units, letting the muscle fibers have the highest amplitude situated in close vicinity.

3. Spectral moments also showed the same trend with the time moments. This may be an indication both for the recording characteristics of the needle and for the geometry of the motor units. If the current source localized deeper in the muscle, higher frequency sinusoidal contributors will have less and less power as the needle is being moved to surface.

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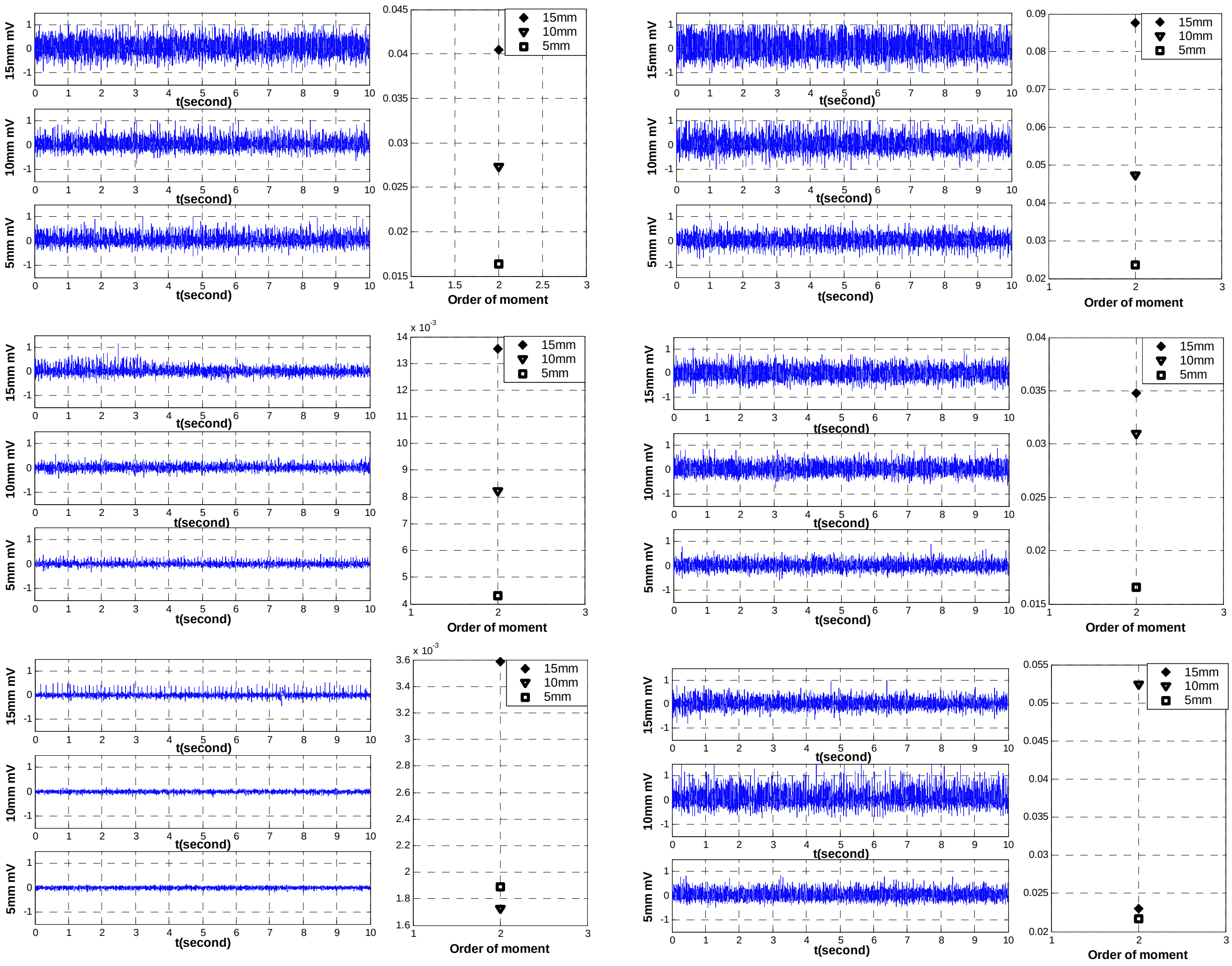
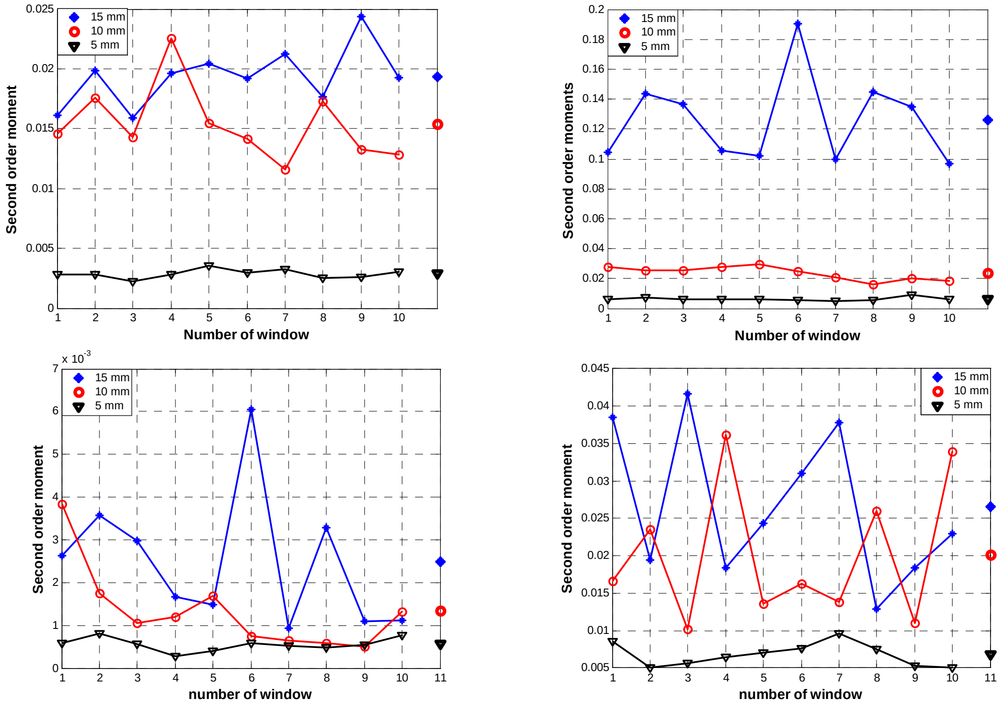


a) b)

Figure 2. a) Signals recorded during 0 N contractions from the subjects A, B, C and second order time moments, respectively. b) Signals recorded during 10 N contractions from the subjects A, B, C and second order time moments, respectively.



a) b)

Figure 3. Second order spectral moments of the windowed signals.