CHANGES IN IMPEDANCE AT THE ELECTRODE-SKIN INTERFACE OF SURFACE EMG ELECTRODES DURING LONG-TERM EMG RECORDINGS

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Abstract- **Changes in the impedance at the electrode-skin interface of SEMG electrodes on tibialis anterior were assessed in nine subjects. SEMG signals were recorded using a bipolar electrode configuration that conformed to the SENIAM recommendations for SEMG data collection. Impedance measurements were made between a pair of bipolar electrodes using a custom-built device consisting of a PC and an impedance conversion circuit. The impedance device enabled the simultaneous application and recording of a waveform constructed of a known combination of sinusoids passed between the two electrodes. SEMG recordings at 10% of each subject's maximal voluntary force during ankle dorsiflexion were made for a 30-s period every 15-min over a two hour period. Impedance was measured immediately before and after each SEMG recording. All subjects gave their written informed consent.**
***Keywords* - Electromyography, impedance**

I. INTRODUCTION

Surface electromyography (SEMG) is a commonly used tool in the study of muscle activity since it provides the only non-invasive index of the level of muscle activation present [1]. Accordingly, SEMG has many applications such as the identification of the phasing of muscle activity during performance [2], calculation of muscle fiber conduction velocity [3], and identification of specific neuromuscular pathologies [4]. In addition to the applications outlined above, the SEMG signal can also be used to detect the onset of muscular fatigue. During isometric contractions the frequency component of the power spectrum of SEMG signals becomes compressed, resulting in a reduction in the mean and median frequency of the signal [5]. The observed shift of the power spectrum to lower frequency bands can then be used to identify the onset and progression of muscular fatigue [6].

The majority of investigations in which SEMG has been used as a tool to detect muscle activity have focused on the bursts of activity produced during movements. However, SEMG has also been used to detect changes in the activity of postural muscles during long-term recordings [7]. Unfortunately there are a number of problems associated with SEMG recordings of postural muscles, such as the masking of SEMG activity by other electrical activity and noise, and the relatively low signal to noise ratio. The presence of noise in a SEMG signal has a marked effect on spectral processing of the signal. For instance, when white noise is added to a SEMG spectrum (see Fig. 1), the median frequency of the underlying signal is substantially increased. In the example given, the addition of white noise to an SEMG signal increased the median frequency from 86 to 112 Hz, corresponding to an increase of 30%.

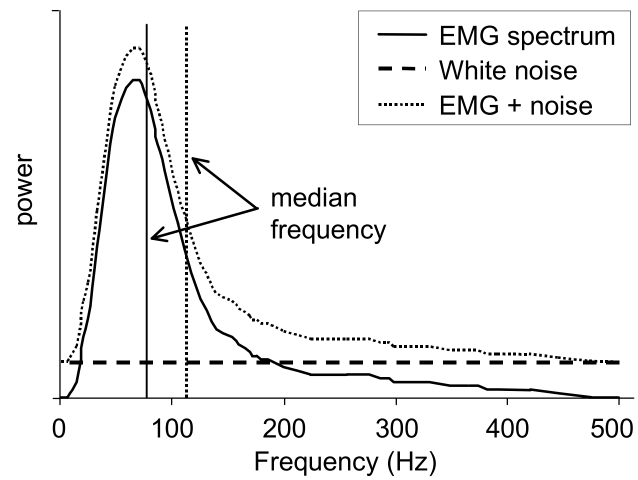

Fig. 1. Change in the median frequency of the SEMG spectrum with the addition of white noise.

Despite the clear effect that noise has on analysis of SEMG signals, there has been a lack of research in this area. In order to reduce noise during SEMG recording, it is necessary to identify the possible sources of noise, and ensure that they are kept to a minimum. The improvement in the design of modern amplifiers has reduced the magnitude of the noise from amplification equipment to less than 1 μV [8]. A potentially large source of noise is that caused by the electrode-skin interface. This noise component consists of a combination of voltage and current noise. The importance of current noise is greater when electrode-skin impedance is high.

It is difficult to study the electrode-skin interface, as the primary cause of differences in impedance is the different property of the skin between individuals [9]. Although thermal noise from the real part of the electrode-skin impedance is often assumed to be the major contributor to the noise from the electrode-skin interface, studies have shown that thermal noise can account for as little as 10% of the electrode-skin noise signal [9]. The electrode-skin noise signal can be broken down into two components corresponding to the electrode-electrolyte interface and the electrolyte-skin interface. Noise from the electrode-electrolyte interface can be measured by placing electrodes face-to-face, and is typically of the order of 1 μV [9]. The noise from the electrolyte-skin interface can then be estimated from measures of noise taken from recordings on the skin, and has been shown to vary between 1 and 15 μV [9].

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Abstract

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Measurements of the impedance spectrum can be obtained by applying an alternating current through two electrodes and recording the voltage differences of a pair of voltage sensing electrodes [10]. When a range of frequencies are applied it is possible to produce a Z-locus plot. Typically, the current is applied in a swept fashion across the desired range of frequencies. A novel technique to measure impedance was reported by Searle and Kirkup [11], who applied a 1-s white noise signal that contained currents over a range of frequencies. Using such a technique, the authors were able to obtain an instantaneous Z-locus plot.

Therefore, the aim of this investigation was to measure impedance at the electrode-skin interface of SEMG electrodes during long-term recordings. Knowledge of changes in impedance over time may be of use to improve the detection on postural SEMG signals.

II. Methodology

A. Subjects

Nine subjects (7 males and two females) participated in the study. Subjects' mean age, height and mass were 31.1 ± 3.7 y, 175.6 ± 7.0 cm, and 72.5 ± 12.7 kg respectively. All experimental procedures were approved by the regional ethics committee (Reference: Champagne-Ardenne Consultative Committee for the Protection of Subjects in Biomedical Research, 2 May 2000). All subjects who participated gave their written informed consent.

B. Electromyography

Surface EMG signals were recorded from tibialis anterior on the right leg of each subject using a bipolar electrode configuration. The electrodes were reusable surface electrodes (Beckman Ag/AgCl electrodes, Beckman Instruments Inc., Fullerton, CA, USA), with an inter-electrode distance of 20 mm. The electrodes were applied to the skin after the electrode site had been shaved, cleaned with alcohol, and left to dry. All parameters of the electrode configurations conformed to the SENIAM recommendations for SEMG data collection [8]. The electrodes were placed approximately 1/3 of the way along a line between the tip of the fibula and the tip of the medial malleolus, between the motor point and the distal tendon. The electrodes were orientated in the direction of this line.

C. Impedance

Measurements of the electrode-skin impedance were made between the pair of electrodes using a device that consisted of a PC with a data entry window, and an impedance conversion circuit. The measurement of impedance consisted of an assembly reverser with an operational amplifier (Texas Instruments TL 082 CP). In order to avoid any electric risk for the subject, the system was limited in intensity to 50 µA and was isolated at each end by an insulating amplifier (Burr Brown ISO 122 Capacitive Barrier) powered by batteries. Due to the nature of this device, the input and output signals were out of phase by 180°. For the acquisition of the impedance data, a waveform was applied via a digital to analogue converter (DAC) and was simultaneously recorded through the data acquisition system. The waveform was constructed of sinusoids, the frequencies of which were selected in order to ensure an even distribution on a logarithmic scale. The frequencies used ranged from 1-512 Hz. Owing to the a priori knowledge of the frequencies of the sinusoids contained in the signal passed between the electrodes, it was possible to calculate exactly the impedance at the electrode-skin interface.

D. Data Acquisition

Data acquisition was performed using a PC and a software program written using Labview software (National Instruments Corporation, Austin, TX, USA). Impedance data were acquired at 2048 Hz. The SEMG signal was collected at a frequency of 1000 Hz using a custom-built EMG amplification system.

E. Experimental Protocol

The subjects sat on a chair with their foot right placed on an adjustable footplate. The position of the footplate was adjusted so that subject's ankle joints will be set at 100°, i.e. at 10° of plantar flexion. A strap was placed around the foot and connected via a pulley system to a suspended mass. Subjects were able to lift the mass using dorsiflexion of the ankle. The weight used was calculated as 10% of the voluntary maximal force of each subject during a preliminary test. Subjects were required to lift the weight until the ankle joint was at 90° of flexion, and then sustain an isometric contraction in this position for 30 s. Recordings of SEMG were made throughout each isometric contraction period. Ten consecutive measurements of the impedance between the electrodes and the skin were made before and after each 30-s epoch of SEMG recording. The mean of the 10 measurements was used for all subsequent analyses. Data collection was performed every 15 minutes over a two-hour period.

III. Results

A. Impedance

There was a large between-subject variation in the impedance levels recorded, with values ranging from 2360 to 135 000 kΩ (initial impedance values at 1 Hz after 15 min). The initial impedance recordings of all subjects are shown in Fig. 2. As expected, the patterns of change in impedance across frequencies were related to the initial impedance level of each subject. Subjects with high impedance levels at 1 Hz had a far greater reduction in impedance at increased frequencies than did subjects with lower impedance at 1Hz. In respect to the effect of time, impedance decreased by 48 ± 25 % between the recordings at 15 and 120 min.

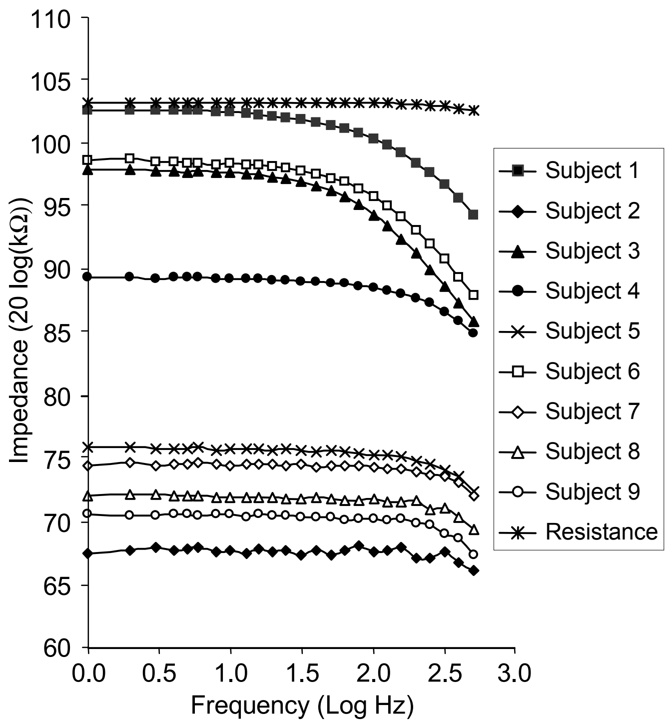

Fig. 2. Impedance of all subjects after 15 min.
A resistance at 140 kΩ is also displayed.

B. Cut-off Frequency

The reduction in impedance levels at higher frequencies may act as a low-pass filter for SEMG signals. Thus it would be interesting to calculate the cut-off frequency value of this filter. The cut-off frequency was calculated as the frequency at which the impedance level was attenuated by 3dB (half-power point) in comparison to the initial impedance value at 1 Hz. An example of the change in cut-off frequency over time for a typical subject (subject 3) is shown in Fig. 3.

IV. DISCUSSION

The frequency range of 1-512 Hz that was used in this investigation was chosen to cover the frequency band in which the SEMG signal is located [8]. However, as impedance was still to decreasing at 512 Hz it was necessary to validate the impedance-frequency relationship across a higher range of frequencies. Additional recordings were made in a testing session in which impedance was calculated at frequencies up to 16 384 Hz. Even at such a high frequency, impedance continued to decrease steadily. Thus, the relationship identified over 1-512 Hz continues thereafter over the range of frequencies likely to be used when recording SEMG signals.

The impedance of skin can be electrically modeled with a network containing resistors and capacitors, as shown in Fig. 4. An early model was proposed by Thomasset in 1962 (Fig. 4a.). The presence of two resistors in the model can be used to define two cut-off frequencies, with a cut-off at both low and high frequencies. Another model that also includes two resistors was used by Searle and Kirkup [11] (Fig. 4b.). Such a model will also define a cut-off frequency at both low and high frequencies. However, the absence of a second cut-off frequency in the testing session that included frequencies as high as 16 384 Hz indicates that, in respect to SEMG applications, a simplified model containing only one resistor can be used (Fig. 4c.).

The next step of this investigation will be to examine the SEMG data. Of particular will be the presence of any relationship between impedance and the SEMG spectrum. The increase in the cut-off frequency over time and the possible effect on the SEMG spectrum will also be of interest. However, the presence of large between-subject variations in terms of impedance may make it difficult to draw any definitive conclusions.

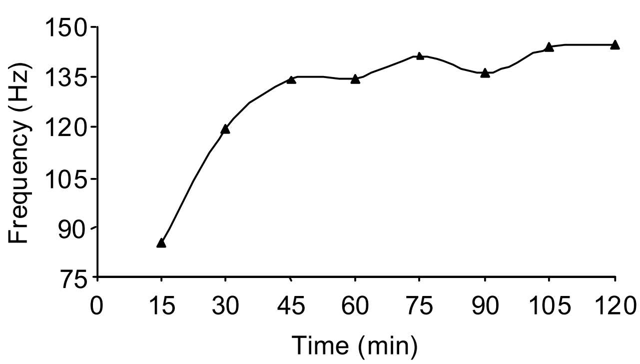

Fig. 3. Cut-off frequency for a typical subject.

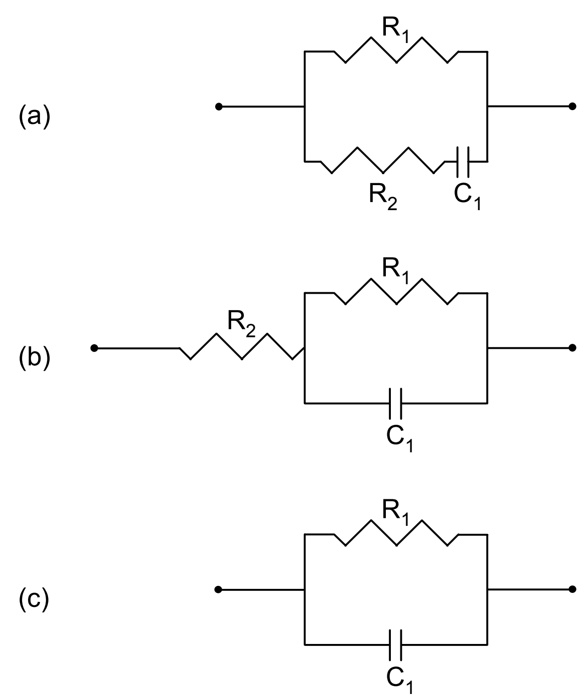

Fig. 4. Electrical models of impedance: (a) two-resistor model from Thomasset [12]; (b) two-resistor model from Searle and Kirkup [11]; and (c) simplified one-resistor model.

V. CONCLUSION

Impedance at the electrode-skin interface of SEMG electrodes can be model using a simple one-resistor model. Future investigations will attempt to ascertain whether there is a quantifiable relationship between impedance and the spectrum of SEMG signals.

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