SURFACE-ELECTROMYOGRAPHY: SKIN AND SUBCUTANEOUS FAT TISSUE ATTENUATE AMPLITUDE AND FREQUENCY PARAMETERS

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The purpose of this study was to identify the attenuating influence on surface-EMG amplitude (IEMG) and mean power frequency (MPF) by skin and subcutaneous fat tissue. The electrode-muscle-distance (ΔEM) of the left m. biceps brachii is determined by tissue thickness. This was established by ultrasound in 12 females and 15 males six times each during a 43-week period (n=162). IEMG and MPF were measured during isometric maximum voluntary contractions (MVC). ΔEM explained up to 31 % of the variance of EMG-amplitude during MVC, which corresponds to previous studies on submaximum and maximum contractions. MPF variation was explained by ΔEM with up to 16 % and requires further validation. These results are important for the assessment of long-term training studies and neuromuscular fatigue measurements.

KEY WORDS: MVC, subcutaneous fat, surface EMG, ultrasound.

INTRODUCTION: Amplitude and power spectrum of surface-EMG (sEMG) are commonly used to quantify neuromuscular activity and fatigue. Despite standardisation in measuring procedures and data analysis, inter-individual variations, in particular of amplitude, may be observed (Day, 2003). Petrofsky and Lind (1975) and Gandevia (2001) stated that sEMG may be affected by motivation, inhibition due to pain, electrode placement, and type and number of muscle fibres involved. An additional source of variation is the electrode-muscle-interspace (ΔEM), comprising skin and subcutaneous tissue. This has been suggested by several previous authors (Roeleveld et al., 1997; Farina and Rainoldi, 1999; Farina et al., 2002; Kuiken et al., 2003; Lowery et al., 2004). Hemingway et al. (1995) and Nordander et al. (2003) used various methods, such as ultrasound, Body Mass Index (BMI) and skinfold thickness measurements, to examine the effect of ΔEM on the sEMG-amplitude in vivo. They found ΔEM to vary from 21% (maximum voluntary contractions (MVC) of the trapezius muscle) to 81% (submaximum contractions of paraspinal muscles). Despite these findings little reference is ever made to ΔEM in sEMG-studies. Furthermore, while the possible decreasing effect of ΔEM on frequency parameters has been mentioned (Day, 2003) and examined in simulation studies (Lowery et al., 2002; Keenan et al., 2005), it has not been investigated adequately (Farina et al., 2004). The aim of this study was to evaluate the attenuating effect of ΔEM on amplitude as well as frequency measurements of sEMG in the m. biceps brachii.

METHODS:

Data Collection: Six ΔEM and EMG measurements were taken on the left m. biceps brachii from 27 healthy individuals (12 female of age 27 ±6.7 years and height 172.6 ±6.5 cm; 15 male of age 25 ±9.8 years and 181.6 ±5.8cm). A minimum period of 4 weeks separated two consecutive measurements (n=162 tests). ΔEM was measured by b-mode ultrasound (Hewlett Packard: Image Point, M2410A, Böblingen; Germany) on the anterior line two thirds of the distance between acromion and fossa cubitalis. This point was marked with a rubber band to ensure consistency during subsequent measurements (cf Seniam Project, (Freriks and Hermens, 1999) or ISEK Standards (Kinesiology, 1999). During ultrasound measurements participants were asked to lie horizontally, holding a weight which was equivalent to 10% of each participant's one repetition maximum (1RM) in the biceps curl. This guaranteed standardization of muscle tension and minimization of uncontrolled tissue compression. The probe was stabilized in order to ensure that only its own weight compressed the tissue. The ΔEM-value was taken as the mean of two consecutive measurements.

Bipolar surface-EMG recordings were taken at the same location as ultrasound measurements, using Ag/AgCl electrodes with a centre-to-centre distance of 2.1cm. An A/D-converter with a sampling rate of 1000Hz amplified the signals (x1000), which were then filtered with a lowpass filter of 500Hz and stored on a personal computer. EMG-signals were recorded during quasi-isometric MVCs on a biceps curler with the elbow flexed at 70° against a tension spring. Data obtained using an electronic goniometer (Biovision, Wehrheim, Germany) were stored on a personal computer for subsequent offline determination of marginal elbow angle changes. Strength was exerted gradually up to the maximum within 3 seconds. There was no cheering on or visual biofeedback during contractions.

Data Analysis: EMG raw data were full-wave-rectified and filtered (Moving Average). The integrated EMG (IEMG) [μV*s] was calculated using Simi Motion (Unterschleißheim, Germany) for the interval of one second following the point when maximum strength value was reached. The mean power frequency (MPF) [Hz] was calculated from the original data using a Fast-Fourier-Transformation (Hamming) with Statistica 5.0, being computed for the same interval as the IEMG. Differences between values were examined with t-tests; correlations between ΔEM, IEMG and MPF were established.

RESULTS: Female ΔEM (0.31 ± 0.10 cm) was significantly stronger ($t_{0.01,\ 160}$ -3.351; $p < 0.01$) than male ΔEM (0.24 ± 0.14 cm). Male IEMG was 0,599 ± 0,331 μV, therefore being significantly higher ($t_{0.001\ 160}$ 5.614; $p < 0.001$) compared with the female IEMG (0.355 ± 0.177 μV). There was a negative correlation between ΔEM and IEMG which was significant (r = -0.559; $p < 0.001$) for all individuals combined, as well as for men (r = -0.545; $p < 0.001$) and women (-0.430; $p < 0.001$) separately. Results for correlations are graphically shown in figure 1.

MPF values (male: 79.1 ± 11.6 Hz; female: 77.4 ± 11.7 Hz) showed no inter-sex differences, but there was a significant negative correlation between MPF and ΔEM (all: r = -0.362; $p < 0.001$; men: r = -0.412; $p < 0.001$, women: r = -0.275; $p < 0.05$).

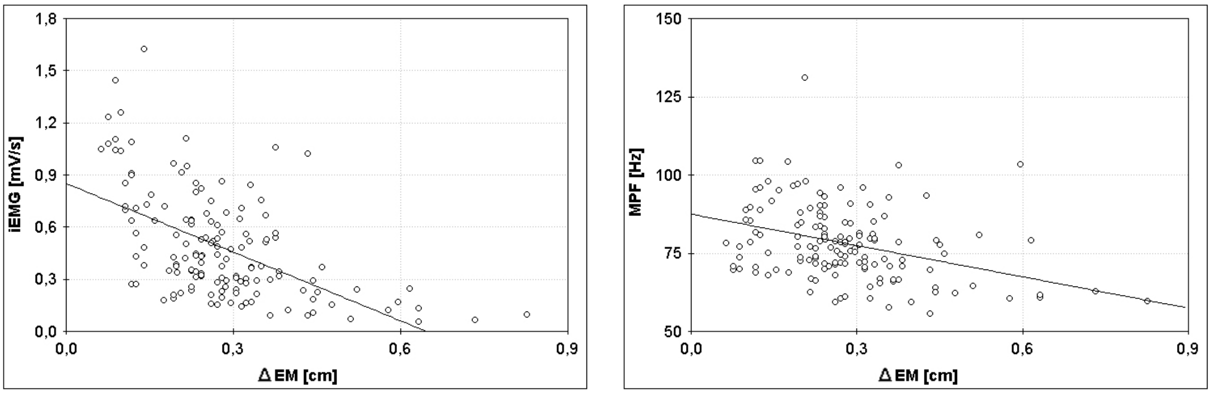

Figure 1: Left: ΔEM and surface-EMG amplitude (as integrated EMG) are negatively correlated in males and females. Right: ΔEM and mean power frequency (MPF) in males and females are also negatively correlated. Slope is smaller than for amplitude function. Both figures: n=162.

DISCUSSION: The values of ΔEM and IEMG as well as MPF recorded as part of this study correspond well with those of previous investigations. As hypothesised, sEMG amplitude decreased with increasing ΔEM during maximum contraction. IEMG variance was explained by ΔEM (r^2 = 25-31%). There was also an inverse relationship between MPF and ΔEM (up to r^2 = 15%), the slope of which was smaller than in the IEMG – ΔEM function.

The b-mode ultrasound method provided an exact determination of tissue thickness at the point of EMG measurement (Ishida et al., 1992). In accordance with Hemingway et al. (1995), BMI was not used as a measurement of ΔEM as it does not reflect the ΔEM of the specific recording site but of the whole body. Nordander et al. (2003) reported that correlations between EMG amplitude and tissue thickness are smaller when determined by ultrasound as opposed to skinfold measurements. However, calliper measurements can only give an estimation of ΔEM. Combined with the fact that measurements of skinfold thickness directly over the recording site were not successful in Nordander et al.'s study, it cannot be necessarily concluded that the method with the highest r^2-values is the most precise one.

Previous studies using both models and in vivo investigations had postulated that sEMG amplitude is attenuated by up to 62 % by local tissue between the electrodes and the muscle (Keenan et al., 2005). The present study was able to confirm these findings. A possible explanation may be signal weakening by subcutaneous fat tissue. Fat tissues may distribute the potential more widely (Farina and Rainoldi, 1999), therefore producing more cross-talk, which results in an underestimation of the IEMG (De la Barrera and Milner, 1994; Kuiken et al., 2003). Additionally, action potentials of motor units located more distantly from the electrodes may not be recorded at all (Barkhaus and Nandedkar, 1994).
As a result, amplitude variation in the current study is explained to a lesser degree by ΔEM than in studies where submaximal contractions were used, and which found an explanation of sEMG amplitude variation of up to 81.2 % for paraspinal muscles (Hemingway et al., 1995). These deviations may be due to differences in the muscles investigated, as well as contraction type, quantification and amount of subcutaneous fat tissue and calculation of the sEMG-amplitude as root mean square (RMS). On the other hand, this study's correlations between IEMG and ultrasound match Nordander's results in the trapezius muscle ranging from r^2 = 21 % in MVCs to r^2 = 33 % for submaximal contractions (Nordander et al., 2003). The difference in r^2 between maximal and submaximal contractions may be due to the fact that the individuals being tested were not professional sports people. It is possible that pain inhibition or even lack of motivation influenced amplitude variance to a certain degree. As proposed by Hemingway et al. (1995), there may be a relationship between subcutaneous fat tissue and factors such as overall fitness, which in itself might result in the ability to develop higher activation levels.
The negative correlation of MPF with ΔEM was much smaller than that of IEMG with ΔEM. Although common sense suggests otherwise, ΔEM appears to have a much weaker influence on frequency parameters than on amplitude. Small amounts of higher frequencies are often reported in calculations of the power spectrum. This has often led to the conclusion that subcutaneous fat tissue has a lowpass filter-like effect on higher frequencies due to the shape of the action potential waves (Farina et al., 2002; Day, 2003; Farina et al., 2004; Lowery et al., 2004). Decreases of higher frequencies, especially in simulation studies, may have resulted from the misleading assumption that action potentials (AP) should be examined as sinusoidal excitations of stationary signals, (e.g., Lowery et al., 2004). Single motor units are known to be excited by short AP spikes of up to 1 kHz with short amplitudes (Jöllenbeck, 2004). This is independent of muscle fibre type. As a result of these signal characteristics, the frequently quoted decreasing effect of ΔEM on MPF is unlikely to be the main source of the observation in the power spectrum described above. This means that interpretations of the mechanical effectiveness of frequency spectra in fatigue measurements may have been incorrect so far. Type IIb muscle fibres can develop a force five times larger than type I muscle fibres, which should be visible in evaluations of the power spectrum. This requires further investigation, in particular using different and non-standard analyzing methods described elsewhere (Jöllenbeck, 2004).

CONCLUSION: The results of the study presented here show that there is an inverse relationship between ΔEM and sEMG amplitude as well as between ΔEM and MPF, albeit to a lesser extent. This means that interindividual variation of sEMG amplitude can be explained by tissue thickness, which should be taken into account in future sEMG studies. In particular, training studies which include sEMG measurements should be aware of the effect of ΔEM; assessing this effect should be part of the studies.

Additionally, it is recommended that separate future investigations are made regarding frequency attenuation and interpretation of the mechanical effectiveness of frequency spectra.

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