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The influence of wrist posture on the time and frequency EMG signal measures of forearm muscles

Danuta Roman-Liu *, Paweł Bartuzi

Laboratory of Biomechanics, Department of Ergonomics, Central Institute for Labour Protection – National Research Institute (CIOP-PIB), ul. Czerniakowska 16, 00-701 Warsaw, Poland

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ABSTRACT

This study investigates how altering wrist posture influences the relationship between the time and frequency measures of the electromyography (EMG) signal of extensor digitorum communis (EDC) and flexor carpi ulnaris (FCU). Thirteen participants exerted handgrip force related to maximum voluntary contraction (MVC) in four tests: 20%MVC and 50%MVC in neutral wrist posture and 20%MVC in full wrist flexion and extension. EMG measurements from EDC and FCU were used to calculate normalized values of amplitude (nRMS) and mean and median frequency of the power spectrum (nMPF, nMF). During muscle shortening (wrist flexion for FCU and wrist extension for EDC) nRMS was approximately twofold higher than in neutral posture for FCU and fourfold for EDC. All measures obtained at 20%MVC in neutral posture were significantly different from 20%MVC in wrist flexion for FCU and 20%MVC in wrist extension for EDC ($p < 0.05$). Differences between 50%MVC and 20%MVC at neutral posture (nRMS) were significant for both muscles, although in nMPF and nMF for EDC only. Muscle shortening changed the pattern of statistical significance when the time and frequency domain measures were compared, whereas muscle lengthening did not. It can be concluded that muscle shortening caused by altering wrist posture influences the relationship between the time and frequency measures in both muscles. This suggests that in studies using EMG in different wrist postures, changes in the relationship between the time and the frequency measures should be considered.

1. Introduction

The EMG signal reflects phenomena related to muscle contraction at the junction of neurons and muscle fibers. Measures calculated in the time domain (the amplitude of the sEMG signal) and in the frequency domain (characteristic spectral measures calculated on the function of the power density of the EMG signal) may be used to describe specific aspects of the characteristics of the signal. Analysis of EMG signal has numerous applications, e.g. to determine muscle fatigue [1], to analyze gait [2] or to diagnose muscle dysfunction [3].

The level of muscle contraction, determined by exerted force, is a factor which determines both the time and frequency measures of the EMG signal [4–6]. An increase in the sEMG amplitude during increase in muscle contraction has been proved [7,8]. An increase in spectral measures such as median frequency (MF) or mean power frequency (MPF) during increase in the level of contraction is also common [9]. However, there are contradictory results, too. Some researchers reported minor changes in spectral measures [9–11] and in some cases these parameters decreased [12]. This indicates that the relationship between spectral measures and the level of muscle contraction is ambiguous.

The EMG signal is also influenced by muscle length, with a higher amplitude usually recorded in shorter muscles [13,14]. However, study results have not always been in agreement on this issue either. Some studies indicated no impact of muscle length [15,16] or even a decrease in the EMG amplitude with a reduced muscle length [17,18]. Muscle length as determined by joint position also affects the spectral characteristic of the EMG signal [9,10,19].

The length–contraction relationship is especially important for the upper limb, with its numerous degrees of freedom which make adopting a variety of postures possible. The association between joint position and EMG signal characteristics has been studied in relation to elbow joint muscles, where changes in muscle length are evident during changes in the joint angle. Those studies examined the larger upper limb muscles, e.g. biceps brachii [9,10], triceps brachii or brachioradialis [9]. Forearm muscles (flexors and extensors) play an important role in many activities, e.g. during gripping. Therefore, alteration in the geometry of forearm muscles caused by alterations in wrist posture, although not as obvious as in the case of the elbow joint, may be significant in the study of EMG characteristics.

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* Corresponding author. Tel.: +48 22 623 3275; fax: +48 22 623 3282.
E-mail address: daliu@ciop.pl (D. Roman-Liu).

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Duque et al. [8] and Chye et al. [20] showed that handgrip in flexion required a much greater engagement of muscle flexors than handgrip in extension, whereas Chen et al. [21] showed that wrist flexion and extension had a significant effect on flexors but not on extensors.

Those studies provided data on arm muscles related to time domain measures; however, there was no analysis of forearm muscles with respect to time and frequency domain measures influenced by wrist posture. It is, therefore, important to investigate how alteration in muscle contraction of forearm flexors and extensors caused by gripping force and simultaneous flexion and extension in the wrist affects the time and frequency characteristics of the EMG signal recorded from those muscles. The aim of this study was to investigate, if wrist posture influences the relationship between the time and frequency domain measures of the EMG signal.

2. Methodology

2.1. Participants

Thirteen right-handed men with a mean age of 21.8 years old (range: 20–23), mean height of 181.6 cm (176–184) and mean body weight of 78.1 kg (69–92) participated in the study. They were all free from any neurological or musculoskeletal conditions. The participants provided informed consent after the experimental procedure had been explained to them.

2.2. Measurement

Each participant was briefly trained before the experiment to correctly perform the task. During the tests, the participants had to squeeze the hand dynamometer to measure the strength of the handgrip and the corresponding EMG signal. The first measurement determined MVC of the handgrip and the adequate EMG signal corresponding to maximum handgrip force. The strength of the handgrip and the EMG signal in three configurations of the wrist (neutral, full flexion and full extension) were then measured (Table 1). The order of tests was randomized to avoid potential systematic effects of fatigue influencing the results.

During the measurements, the participants stood with the upper limbs hanging down. The right upper limb was studied. The force at the determined level was exerted for 5 s, with a 5-min rest between each test.

EMG measurements were obtained from extensor digitorum communis (EDC) and flexor carpi ulnaris (FCU). Those muscles were chosen for their relevance to hand and wrist function during handgrip. These muscles were expected to have a similar proportion of type I and type II motor units [22] and a similar subcutaneous layer thickness.

The electrodes were placed on the skin over the muscle belly, along the muscle fibers. For the EDC, placement was at one-fourth of the distance between the lateral epicondyle of the humerus and the styloid process of the ulna. For the FCU this was at one-third of the distance from the medial epicondyle of humerus to the palmar aponeurosis.

Table 1
Characteristics of tests.

Test	Wrist posture	Force level (%MVC)
MVC	Neutral	100
50N	Neutral	50
20N	Neutral	20
20E	Extension	20
20F	Flexion	20

Note: MVC – maximum voluntary contraction.

Before the electrodes were fixed, the skin was prepared (disinfected with a cotton swab soaked in alcohol, shaved and disinfected again). The electrodes, were disinfected with alcohol and were fixed to the skin with double-sided adhesive tape. This ensured good contact between the electrode and the skin during the experiment.

2.3. Equipment

The EMG signal was measured with a Bagnoli-16 (Delsys, USA) device with a bandwidth of 20–450 Hz (± 10%). Bandwidth roll-off was 80 dB/decade, overall noise $\leq 1.2\ \mu$V (root mean square [RMS], R.T.I) and EMG amplification of 1000. This apparatus, in conjunction with a computer, registered a raw EMG signal with a sampling frequency of 4 kHz.

The EMG signal was recorded with double differential surface electrodes DE-3.1 (Delsys). The distance between the three electrodes was ~10 mm. Double differential electrodes were used to reduce the risk of crosstalk.

Handgrip force was measured with a force sensor in conjunction with an appropriate converter connected to a computer with CPS v 2.0 software to visualize the force as a line corresponding to 20 or 50%MVC. The participant tracked this line with another line, which was a visualization of exerted force and which was proportional to its value. A test was considered valid when the force was maintained within ±20%.

2.4. Data processing and analysis

Data were analyzed in four steps: computation of measures in the time (RMS) and frequency domains (MF and MPF), selection of fragments for analysis, normalization of data and statistical analysis.

To compute the measures, selected fragments of the EMG signal were divided into 1-s windows (boxcar windows; 50% overlap). The RMS was calculated from each window. Power spectral density was estimated from the Fourier transforms (1 s, 4000 samples, Hanning window, 50% overlap). MF and MPF were calculated on the obtained periodograms.

The next step involved preparing data appropriate for the analysis of each participant, each test variant and each tested muscle. Three-second fragments of the EMG signal with the most stable amplitude values were selected from the computed measures.

To eliminate the impact of individual factors, normalization was undertaken for each of the measures (RMS, MF and MPF) with reference to maximum muscle contraction measurements. In this way, a set of variables (nRMS, nMPF and nMF) was obtained for each test (20N, 50N, 20E and 20F) and for each of the 13 participants.

Nonparametric Friedman ANOVA followed by post hoc analysis showed pairwise comparisons. Wilcoxon signed rank test examined differences between the muscles in the tests. The statistical level of significance was set at $p < 0.05$. Statistica 6.0 was used.

3. Results

Table 2 presents absolute values of frequency measures obtained for neutral wrist posture.

The relative values of the analyzed measures (nRMS, nMPF and nMF) averaged over 13 participants, with 95% confidence interval, showed differences among the variants of load in both EDC (Fig. 1a) and FCU (Fig. 1b).

A comparison of the measures obtained in the neutral wrist posture showed the nRMS higher in FCU than in EDC at 50N. At 20N both muscles had very similar values. In EDC there was evident