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ScienceDirect

Procedia Computer Science 61 (2015) 448 – 453

Procedia Computer Science

Complex Adaptive Systems, Publication 5
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2015-San Jose, CA

# Gender Effects in Surface Electromyographic Activity of the Biceps Brachii Muscle during Prolonged Isometric Contraction

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**Abstract**

The muscle activity, electromyographic (EMG) signal steadiness and relationships between the EMG signal and endurance time among males and females have long been investigated and continue to be a subject of controversy. The aim of this study was to explore the electromyographic effects on the biceps brachii (BB) muscle of male and female subjects during prolonged isometric contraction (for 90 s). Twenty right-handed (10 male and 10 female) subjects participated in this study. The EMG analysis was accomplished in the time domain by calculating the amplitude content of the signals as the root mean square (EMG-RMS). The statistical analysis included linear regression to examine the relationships between the EMG amplitude (%MVC) and the endurance time, repeated-measures ANOVA to assess differences among the variables, and calculation of the coefficient of variation (CoV) to assess the steadiness of the signal. The results revealed that the linear slope coefficient of the EMG as a function of time ($r^2 = 0.56$, $p < 0.05$) obtained for male subjects during contraction was significantly greater than that obtained for females ($r^2 = 0.11$, $p > 0.05$). Additionally, the EMG signal activity generated by the male BB muscle (10.25%) exhibits less variability than that generated by the female BB muscle (12.11%). The experimental results indicate the suitability of developing an EMG prosthetic hand controller and the use of EMG analysis in the fields of neuromuscular system research, rehabilitation engineering and movement biomechanics, which may help separate male and female subjects.


Peer-review under responsibility of scientific committee of Missouri University of Science and Technology

*Keywords:* Electromyography; EMG; Biceps Brachii; Gender; RMS; Contraction

## 1. Introduction

Electromyography (EMG) signals, which are always stochastic in nature, are generated by muscles of the human skeleton through muscle fibre contraction [1,2]. Surface EMG (sEMG) is extensively used to detect and record the function of skeletal muscles. Compared with the indwelling and invasive EMG measurement technique, sEMG


Peer-review under responsibility of scientific committee of Missouri University of Science and Technology
doi:10.1016/j.procs.2015.09.185

EMG is painless and has exhibited superior reliability [3-5]. Moreover, the non-invasive EMG-based technique provides effortless access to the physiological processes that cause muscles to generate force, produce movement, and accomplish the essential functions of everyday life. Furthermore, this technique can show the functional status of muscles [6,7].

Several researchers have shown that EMG signals vary between male and female muscles during movement and contraction [8,9]. For example, Pincivero *et al.,* evaluated gender and muscle differences in the EMG amplitude and median frequency as well as in the mean and standard deviation during maximal voluntary contractions of the quadriceps femoris [10]. Manjit *et al,.* then showed the changes in the complexity of surface EMG signals generated by the biceps brachii muscle between male and female subjects [11]. A previous study discussed and compared the EMG signals generated by the lower limb muscle from male and female volleyball players while performing a one-legged drop jump. The parameters used in the comparison were the time-frequency characteristics, amplitude and timing of recruitment of the EMG signal [12]. In another study, Cioni *et al.,* showed the effect of EMG on the male and female tibialis anterior muscles during maximum voluntary contraction. In their study, these researchers used the power density spectrum of the EMG signal to evaluate the RMS values of the EMG signal [13]. Bilodeau *et al.* contrasted the behaviour of the EMG power spectrum statistics (median frequency) and the mean power frequency obtained from the triceps brachii, anconeus and biceps brachii muscles of male and female subjects [14]. During the experiment, the subjects performed isometric contraction for 5 s. Another previous study investigated gender-specific motor control strategies during eccentric contraction in the shoulder region muscle [15]. Similarly, some other research studies have also evaluated the EMG effect on different muscles in male and female subjects [16,17].

Two other important issues in this research field are the contraction type and the duration of the contractile activity during EMG signal recording. The literature search revealed that researchers have used eccentric, concentric, isometric and isokinetic contractions to assess muscle activity using EMG variables [18-21]. In contrast, researchers have used either short or prolonged periods for signal recording. However, as revealed by an extensive literature search, no previous study has assessed the gender differences in the effect of EMG signals during prolonged isometric contraction by calculating the amplitude content of the signals as the root mean square (EMG-RMS). Main reason to use the RMS feature is that*,* it denotes the square-root of the average power of the electromyographic signal for a given period of time. This is well-known as a time domain variable since the amplitude of the signal is measured as a function of time. Thus, the aim of this study was to fulfil this research gap through an analysis of the effect of EMG signals using RMS feature.

## 2. Methodology

### *2.1 Participants*

Ten male (aged 25.3 years) and ten female (23.6 years) right-handed subjects participated in this study. The entire experimental protocol was approved by an Independent Ethics Committee (IEC), and all of the participants provided written informed consent based on the Declaration of Helsinki.

### *2.2 Instruments*

A wireless Shimmer™ sensor (Real-time Technologies Ltd., Ireland) was used to record the EMG signals. A pair of active surface electrodes and a single reference surface electrode was used with the Shimmer™ sensor EMG system to measure the electrical signals from the muscle. These surface electrodes were circular in shape (diameter = 11.4 mm) and were composed of silver/silver chloride (Ag/AgCl) material. A digital handgrip dynamometer (Digital Hand Dynamometer, Saehan Corporation, Korea) was used to perform the grip force exercise to generate the isometric contraction of the muscle.

### *2.3 Procedures*

For electrode placement on the muscle, the skin of the BB was prepared using a skin cleaning gel (Sigma gel) and an alcohol swab. The surface electrodes were then placed on the muscle belly and positioned parallel to the BB muscle fibre direction. The exact placement of the electrodes followed the recommendations of the SENIAM [24]. The belly of the BB muscle was recognized through manual palpation. The centre-to-centre distance between 2 sensors was approximately 2 cm. The reference electrode was attached to the lateral epicondyle of the humerus of the right arm (approximately 1 inch from the olecranon of the elbow). After electrode placement, the subjects were asked to sit comfortably on a specially designed chair with their right elbow on a padded support. The elbow joint was fixed to an angle of 90º, as determined using a goniometer. The subjects were asked to hold the handgrip dynamometer and perform the grip force exercise with maximum effort for 90 s (prolonged experiment). This measurement was performed three times (three trials) with a 2 min rest between each pair of trials, and the average of the three measurements was considered the maximum isometric voluntary contraction. The force (kg) exerted by the subject was visible on the dynamometer. Figure 1 shows the experimental setup for a male subject during the handgrip force exercise.


Fig. 1. Experimental setup during surface EMG data recording

### 2.4 Surface EMG Signal Recording and Pre-processing

The EMG signals from the BB muscle of each subject were recorded using a Shimmer™ sensor at a sample rate of 1000 Hz, a CMRR of 95 dB, and an input impedance of 100 MΩ during a handgrip force exercise performed at the 100% MVC level for 90 s. The raw EMG signals were then amplified with a fourth-order Butterworth bandpass filter in the frequency range of 5 to 500 Hz and stored on a computer. The filtered EMG signals were digitized offline using an A/D converter (16 bit) on the MATLAB 2010 software environment (The MathWorks Inc., USA). After digitizing, the root mean square (RMS) of the amplitude of EMG signal was extracted for each 30 s of the total 90 s period (one value per 30 s segment per subject).

### 2.5 Calculated Features

The root mean square (RMS) is one of the most commonly accepted features used to describe the signal amplitude of a surface EMG signal. As a result, in this study, the RMS was used to calculate and analyse the surface EMG signals. RMS is the quadratic mean used to statistically investigate the magnitude of a time-varying signal. The mathematical definition of the RMS feature is the following [22,23]:

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \tag{1}$$

The EMG RMS values were then normalized in terms of the maximum voluntary contraction, *i.e.*, the individual RMS values during the contraction were considered the 100% MVC. The filtered EMG activity was normalized for each subject by dividing the observed EMG value for the BB muscle by the maximum value recorded during the three maximal tests. The mean (RMS) normalized EMG activity was then calculated as the mean of the sum of the normalized EMG percentages from all of the subjects in each age group. The maximum peak-to-peak value of the EMG was considered a relative measure of the motor activity (the positive portion of the peak was defined as the peak maximum). It should be noted that this normalization procedure only presents information at the level of muscle activity with regard to this peak value (*i.e.,* shape of the EMG pattern). Figure 2 shows a sample waveform obtained during contraction (raw signal, *i.e*., without filtering).

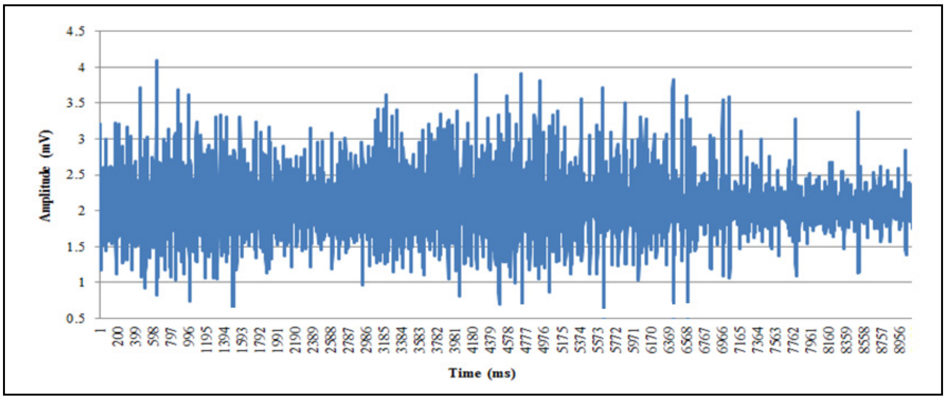


Fig. 2. Sample waveform of the surface EMG signal (raw) during prolonged isometric contraction

## 2.6 Data Analysis

Descriptive statistics, including the mean, standard deviation (SD) and coefficient of variance (presented as a percentage, CV%), were calculated for each of the 10 male and 10 female subjects for each 90 s isometric contraction period. Significant differences were detected through repeated-measures analysis of variance (ANOVA) in the force and EMG amplitudes (RMS) obtained during the three phases of the contraction between the two groups, and post-hoc tests were applied to test the significance of the differences using a significance level set to $\alpha = 0.05$ with a 95% ($P < 0.05$) confidence intervals for all of the variables. Regression analysis was performed to analyse the relationship between the EMG amplitude (RMS) and time (s) variables. The null hypothesis corresponding to the linearity of each regression was tested using the F-test. Finally, each individual dataset from the trial was fit with by linear regression in the logarithmic space to obtain a function of the form $y = a + bx$. All of the statistical analyses were performed using the Minitab™ software (version 13.32) statistical package. Linear regression is used to determine the responses as a function of time. In addition, the coefficient of determination ($r^2$) was used to test whether there is an association between the signals and the time lag. Additionally, the slope of the regression relationship was used to test whether the relationships are consistent for the subject's BB muscle at different periods during static contraction.

## 3. Results and Discussion

Table 1 summarizes the means and standard deviations of the EMG parameters (from the RMS feature) calculated in this study. As shown, the values obtained for all of the subjects for both males and females were low in the initial period (first 30 s contraction periods) compared with the other two time-lags (second and third 30 s period). Table 1 also presents the coefficient of variance (CoV) values, which were used to assess the steadiness of the EMG signal, and the findings indicate that the signal is steadier in the last 30 s of the 90 s contraction period in males, whereas the signal is steadier in the middle 30 s period in females. The straight lines indicate the linear regression relationship between the EMG signals and the endurance times during the three contraction periods for both the male and female groups (see Figure 3). As shown in the figure, EMG activation is significantly different ($p < 0.05$) among the three contraction periods in male but not females, as determined by the linear regression coefficients ($r^2$) with the $F$-ratio.

The main issue addressed in the current study is the quantification of the relationship between the EMG signal and the time course (90 s period) in the BB muscle of male and female subjects through linear regression analysis. As shown in Figure 3, the slope of the EMG-time relationship in the male's BB muscles is higher than that in the female's BB ($r^2 = 0.56$ and F-ratio = 42.6; $r^2 = 0.11$ and F-ratio = 3.42, respectively). Additionally, the highest significance level ($p = 0.001$) was found for the EMG signal as a function of time in the BB muscle of male subjects. In contrast, the results yielded no significant correlation between the EMG values and endurance time in the female's BB muscle ($p = 0.72$). In Figure 3, the linear regression equation is written in the form y = a + bx, where y (EMG) is presented as a function of x (time).

Similarly to the results obtained in most previous studies, males generated a higher signal compared with female subjects, and there exists a linear relationship between the EMG signal and time in male but not female subjects. For example, Cioni *et al.,* studied the surface EMG signals from the tibialis anterior muscle of male and female subjects. In this research study, the female subjects were found to present significantly decreased values ($p < 0.001$) compared with the corresponding values obtained for the male subjects [13]. More recently, Garrison *et al.,* assessed the EMG activity generated by muscles in the lower extremity (gluteus medius, lateral hamstrings, vastus lateralis, and rectus femoris) of both male and female college soccer players during single-leg landing. Based on the RMS calculation, the male and female players displayed relatively similar muscle activities in the lower extremity during landing. In addition, no significant differences were detected between the genders [9]. However, the gender difference in BB muscle activity in terms of time lag during contractions has not yet been assessed. The current findings demonstrate that the BB muscle is more active in males compared with females, as determined through regression curve fitting (see positive slope of the linear regression curve shown in Figure 3(a)).

Table 1. Results of the EMG (RMS) value (mV) from every 30 s contraction period of total 90 s contraction duration for male and female groups

| Gender | Time slots (90s) | Mean±SD | Total (mV) | CoV (%) | Total CoV (%) | $r^2$ | F-ration |
|---|---|---|---|---|---|---|---|
| Male | 1st 30 s | 3.5±0.25 | 3.9±0.41 | 6.84 | 10.25 | 0.56* | 42.61 |
| | 2nd 30 s | 4.2±0.29 | | 7.11 | | | |
| | 3rd 30 s | 4.3±0.21 | | 4.78 | | | |
| Female | 1st 30 s | 2.6 ±0.31 | 2.78±0.34 | 11.75 | 12.11 | 0.11 | 3.45 |
| | 2nd 30 s | 2.8±0.31 | | 10.85 | | | |
| | 3rd 30 s | 2.8±0.37 | | 12.63 | | | |

* $P < 0.05$

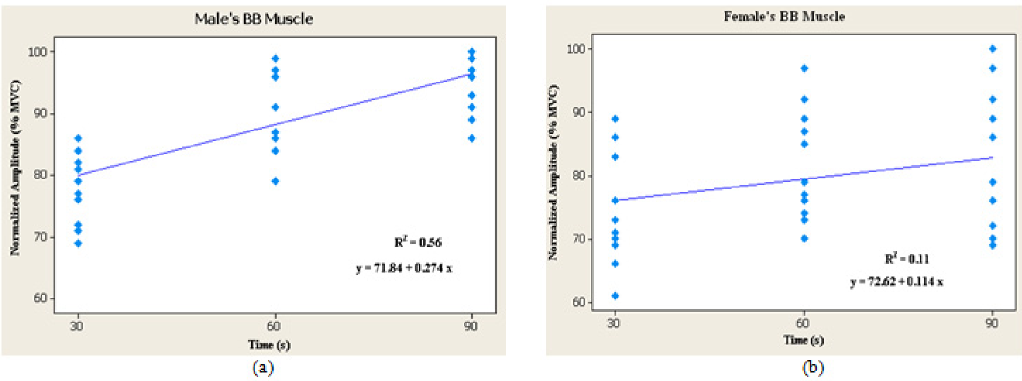


Fig. 3. Relationship between EMG and endurance time in the BB muscle of (a) male and (b) female subjects.

## 4. Conclusion

The purpose of the present study was to analyse gender-related changes in the biceps brachii muscle through EMG signal analysis. We found that the male subjects generated a higher and steadier signal than female subjects. Similarly, a modest albeit significant correlation was found between the EMG signal and time in males, but the linear regression results show a low correspondence between the EMG signal and time in females. The findings can be applied for the development of biomedical engineering applications for the analysis and control of the neuromuscular system as well as in the fields of ergonomics research, rehabilitation engineering, and movement biomechanics. Finally, the results improve our understanding of the mechanics of the upper limbs of individuals belonging to different genders and open new windows for further research.


## Acknowledgment

This research is supported by the University Malaysia Pahang (UMP) Research Grant, 2014 (No. RDU1403157).


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