CHANGES IN MUSCLE ACTIVATION AND FORCE FLUCTUATIONS DURING LOWER LIMB MUSCLE CONTRACTION: EFFECT OF GENDER

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Abstract— The purpose of this study was to examine force fluctuations and strength of the muscle contraction in lower limbs for young men and women across various force levels. Surface Electromyogram (sEMG) signals were recorded when subjects performed isometric contraction at various levels of force (25%, 50%, 75% and 100% Maximal Voluntary Contraction). Steadiness in maintaining the level of contraction was determined as the coefficient of variation in the recorded force output. Strength of the contraction was computed as the Root Mean Square. Logarithmic plots of these features were used to identify the significance of gender in force fluctuations and strength of muscle contraction. Statistically higher coefficients of variation were observed at 25% of the Maximal Voluntary Contraction and decreased linearly with the increase in Maximal Voluntary Contraction. The results also suggested that there is a significant difference in the coefficient of variation between genders.

Keywords— muscle strength, force, gender, sEMG, lower limb

Resumo— O propósito desse estudo foi examinar as flutuações de força e também a força de contração muscular nos membros inferiores de jovens homens e mulheres em vários níveis de forca. Sinais eletromiográficos de superfície foram registrados quando os indivíduos realizaram contrações isométricas em vários níveis de força (25%, 50%, 75% e 100% da máxima contração voluntária). A estabilidade na manutenção do nível de contração foi determinada como o coeficiente de variação da saída de força armazenada. A força de contração foi calculada pela raiz quadrada do valor médio. Parcelas logarítmicas dessas características foram utilizadas para identificar a importância do gênero em flutuações de força e na força de contração muscular. Estatisticamente maiores coeficientes de variação foram observados em 25% da máxima contração voluntária decrescendo linearmente com o aumento da máxima contração voluntária. Os resultados também sugerem que existe uma diferença significativa no coeficiente de variação entre os gêneros.

Palavras-chave— contração muscular, força, gênero, EMG, membros inferiores

1 Introduction

Force steadiness, which refers to the ability to perform muscle contractions with minimum fluctuations in force while matching a given force level (Rose et al, 2013) is another metric that could provide information of motor control. Force steadiness is typically quantified in absolute terms as the standard deviation or relative as the coefficient of force variation. Less variability implies better force control. The triceps surae muscle group is interesting in this respect since it is comprised of three muscles with different fibre compositions having a shared function of plantar flexion and dorsiflexion movements. It is also believed that the triceps surae muscle group contributes in generating forward propulsive force during gait (Neptune et al, 2001).

It is a known fact that men have greater muscle strength than women and can therefore generate greater forces (Svendsen and Madeleine, 2010). Consequently, the relative amount of force men must control is smaller than women for the same target force level. It was reported that fluctuations and control strategies differ between moderate and low force levels (Taylor et al, 2013; Heyward et al, 1986) in upper limbs and that men generally have larger and stronger muscles than women in which contribute to the lower limb force steadiness as well (Miller et al, 1993). In another report, male subjects showed larger fluctuations than female subjects, but the target forces were different between males and females because these forces were defined relative to maximal forces (Endo and Kawahara, 2011).

The purpose of this study was to investigate the variation in force steadiness in the calf muscles in healthy young men and women during isometric dorsiflexion and plantar flexion test protocol. The dorsiflexor muscles are functionally important for locomotion, posture, balance (Wolfson et al, 1995), and the prevention of falls in older adults (Cavanagh et al, 1996).

Furthermore, habitual use of the dorsiflexor muscles may make men and women less susceptible to disuse deconditioning than use of muscles more typically involved in high-power activities (e.g., quadriceps femoris), which are not often used by older adults. Moreover, reduced force steadiness has been associated with higher demand for appropriate neural activity in cortical centers (Yoon et al, 2014).

Research on force steadiness and Surface Electromyography activity will help in understanding the key cortical areas associated with control of the lower leg in healthy subjects thereby establishing a foundation for identifying the plasticity of these areas with impaired motor function that can occur with aging or neurological conditions.

2 Material and Methods

2.1 Subjects

Twenty healthy subjects without orthopedic or neurological injuries (12 males and 8 females with ages ranging from 23-34 years) participated in this study. The average height of the participants was 167.5 ±10.3 cm and Body Mass Index (BMI) was 23 ±4 kg.m^{-2}. All subjects signed a written document of informed consent before testing that was approved by the RMIT Human Research Ethics Committee. Prior to affixing the electrodes, the skin above the lower limb muscles was prepared by abrading and cleaning with alcohol swabs.

2.2 Experimental Protocol

Sensors were placed on the surface of triceps surae muscles – Tibialis Anterior (TA), Lateral Gastrocnemius (LG), Medial Gastrocnemius (MG) and Soleus (Sol). Electrode positioning followed the SENIAM recommendations and a reference electrode was placed on the lateral malleolus. EMG signals were recorded when the subjects performed isometric plantar flexion and dorsiflexion movements as shown in fig. 1.

sEMG was recorded using DELSYS (Boston, MA, USA) sEMG acquisition system. The system gain is 1000 with bandwidth 20–450 Hz. The sampling rate of the system was 1000 samples/ second for each channel. At the start of the experiment, the maximum voluntary contraction (MVC) was determined for each subject.

Subjects performed the isometric contraction at their 25%, 50%, 75% and 100% MVC. In order to maintain the force level, the feedback of the force sensors was displayed on the computer screen to the volunteers. Subjects were asked to maintain the contraction level for 10 seconds. This was repeated three times for each of the various contraction levels. For analysis, five seconds of data was used where the subject maintained the level of force with respect to the feedback provided.

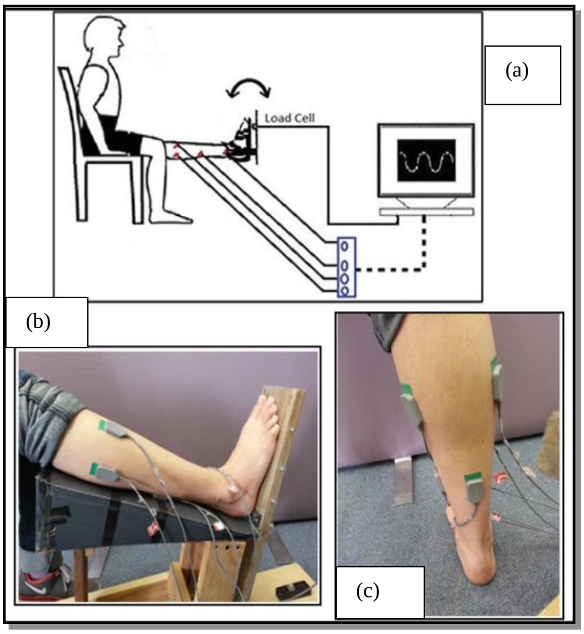

Figure 1: (a) Experimental setup used to acquire sEMG data from triceps surae muscles. (b), (c) Electrode placement as per SENIAM recommendations on Tibialis Anterior, Lateral Gastrocnemius, Medial Gastrocnemius and Soleus muscles.

3 Data Analysis

In order to measure the changes in the force and strength of activation, the following time-domain features were computed:

a) *Coefficient of variation* (CoV): Force fluctuations were quantified by determining the coefficient of variation, CoV was calculated by expressing the standard deviation of the exerted force as a percentage of the mean of the exerted force. CoV is a measure of the regularity with which the motor unit is discharging. The smaller the coefficient of variation, the sharper and higher will be the peak corresponding to the firing rate in the magnitude of the Fourier transform.

$$\mathrm{CoV}(\%) = \frac{\text{standard deviation}}{\text{mean}} \times 100$$

b) RMS: Root mean square of EMG signal

$$\mathrm{RMS} = \sqrt{\frac{1}{n} \sum_{k=1}^{N} [x_k]^2} \quad k = 1,2,\cdots,N$$

where N is the number of samples in the signal x[k].

4 Results

4.1 Force fluctuations

The force steadiness was quantified by calculating the standard deviation (SD) and coefficient of variation (CoV) values of the force signals for both genders. These values were was log transformed to normalize and better observe the variations. Standard deviation values decreased linearly with increasing MVC levels for both plantar flexion and dorsiflexion movements across both the genders. (fig. 2, 3). In both the movements, it was observed that the females had a higher SD values.

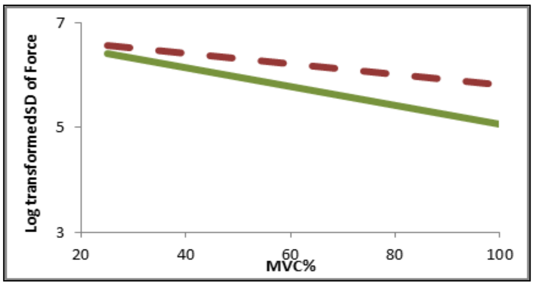

Figure 2: Natural logarithm of Standard Deviation of force during dorsiflexion at isometric force control testing at 25, 50, 75 and 100% MVC levels in males (green) and females (red).

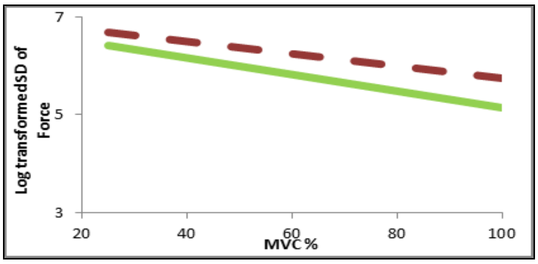

Figure 3: Natural logarithm of Standard Deviation of force during plantarflexion at isometric force control testing at 25, 50, 75 and 100% MVC levels in males (green) and females (red).

CoV values increased with increasing force levels during dorsiflexion (fig. 4, and Fig.5). However, in women, the values decreased significantly in dorsiflexion. Males are observed to have lower CoV values in both the gestures meaning their force steadiness was relatively better.

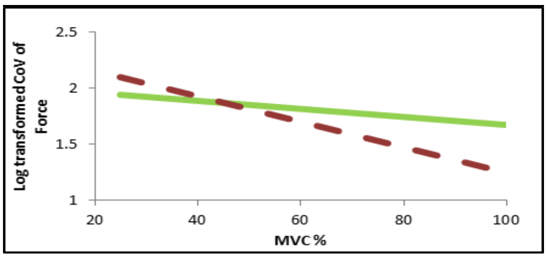

Figure 4: Natural logarithm of Coefficient of Variation of force during dorsiflexion at isometric force control testing at different MVC levels in males (green) and females (red).

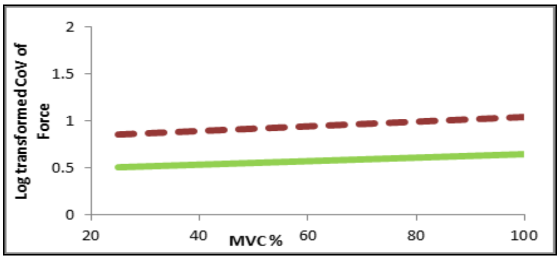

Figure 5: Natural logarithm of Coefficient of Variation of force during plantarflexion at isometric force control testing at different MVC levels in males (green) and females (red).

4.2 EMG Activity Results

In both gestures, the values of RMS exponentially increased with the intensity of contraction. It was observed that the females had a higher RMS of TA and Sol during dorsiflexion and lesser RMS of MG and LG as compared to the corresponding values in males. (fig. 6, 7). In both contractions, across all the subjects, the slopes of the agonist for EMG activity were significantly ($p<0.05$) higher than those of the antagonist. Consequently, during dorsiflexion, TA was observed to higher RMS-EMG values than its antagonist counterparts and MG showed higher muscle activity during plantarflexion.

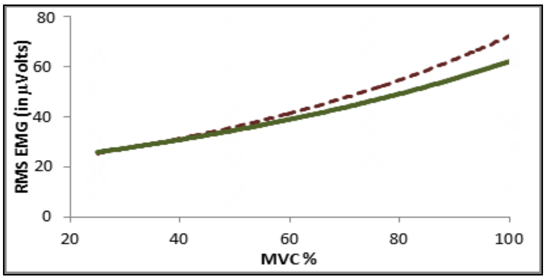

Figure 6: RMS of EMG of TA during dorsiflexion at isometric force control testing at different MVC levels in males (thick lines) and females (dotted lines).

During plantar flexion, males were observed to have much higher muscle activity than females. (fig 8,9). In both the genders, the RMS-EMG of MG was higher in comparison to the other muscles.

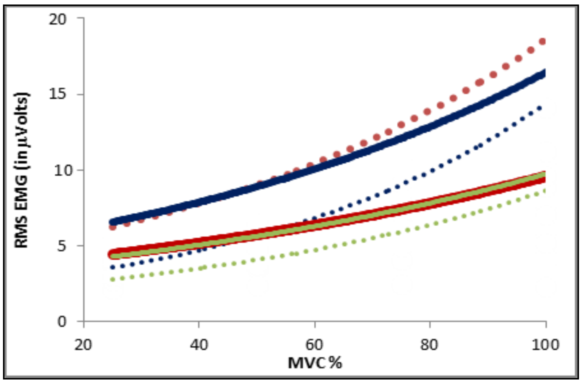

Figure 7: RMS of EMG of MG (blue) , LG (green) and SOL (red) during dorsiflexion at isometric force control testing at different MVC levels in males (thick lines) and females (dotted lines).

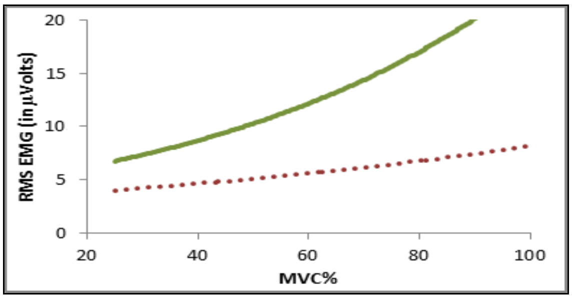

Figure 8: RMS of EMG of MG during plantar flexion at isometric force control testing at different MVC levels in males (thick lines) and females (dotted lines).

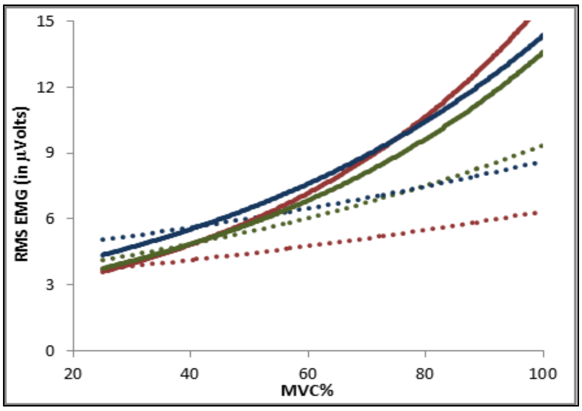

Figure 9: RMS of EMG of TA(blue), LG (green) and SOL (red) during during plantarflexion at isometric force control testing at different MVC levels in males (thick lines) and females (dotted lines).

5 Discussion

5.1 Force Steadiness

Results show that there is a higher steadiness in force output (lower force fluctuations) for males than females. Since strength and steadiness are related, such higher strength may allow for greater motor control. There are at least four features of the motor output from the spinal cord that could contribute to the observed differences in steadiness among male and female subjects. These include

- the average force produced by motor units (Brown et al, 2010; Christakos, 1982);
- the pattern of co-activation by the agonist and antagonist muscles (Wessberg and Kakuda, 1999);
- the amount of motor unit synchronization (Dietz, 1976) and
- the discharge behavior of motor units (Peyton and Bartlett, 2007).

The results of the present study suggest a probable role for the variability of motor unit discharge in the steadiness of muscle contractions in addition to these factors.

The impact of larger muscle mass, greater strength, and higher target tensions during exercise in men compared with women has been addressed in several studies. Other than showing lower muscle strength, women have been reported to have smaller twitch force of a whole muscle (Miller et al, 1993), higher proportion of type I fibers (Simoneau and Bouchard, 1989), and longer half-relaxation time (Hicks and McCartney, 1996) in some muscles. These features are similar to those seen in muscles of elderly persons.

5.2 EMG Activity

EMG amplitude reflects the number of recruited motor units (MU) and their firing rate in active muscle (Basmajian et al, 1985). It is also known that increase in EMG amplitude during isometric muscle contractions is due to increases in MU recruitment and the firing rate (DeLuca, 1984). In the antagonist and agonist, it is has been suggested that each motor neuron pool of the antagonistic muscle pair is controlled by a single input (i.e., excitatory and inhibitory) of the central nervous system during muscle contraction (Bernardi et al, 1997; Psek and Cafarelli, 1993). Bernardi et al. (1997) have suggested that because a similar motor unit recruitment strategy is applied to the agonistic muscle pair, the agonist and antagonist have similar characteristics. Moreover, because the intensity of the antagonist input is smaller, its motor-unit recruitment and firing rate are lower than those of the agonist.

In the present study, during isometric muscle contractions in plantar flexion and dorsiflexion, there was an increase of EMG-RMS values of the agonist and the antagonist muscles. This increase was more noticeable for the agonist than for the antagonist muscles. In addition, the antagonist had smaller amplitude than the agonist (Figs. 4 -7). The results of this study are consistent with physiological changes reported in the research studies (Psek and Cafarelli, 1993; Kim et al, 2008).

6 Conclusion

The purpose of this study was to evaluate the effect of gender on lower limb muscle force steadiness and muscle activation strategies across a range of submaximal forces. The triceps surae muscle group is important for healthy human locomotion, as it helps to maintain upright posture and generates the force required to extend the toes when performing tasks such as pushing a pedal, walking, climbing, and recreational activities that involve running or jumping. It is well established that Triceps surae strength and function are profoundly impacted by foot and ankle pathology (Aronow et al, (2006). Weakness in Triceps surae muscle and atrophy has also been associated with the risk for falls (Wolfson et al, 1995). Further assessing force steadiness of the triceps surae may provide important insight into neuromuscular plasticity after injury, with interventions such as surgery or rehabilitation, or with changes in physiological state that occur with aging, fatigue or reduced physical activity (Cavanagh et al, 1996).

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