High Density EMG Spatial Distribution of the Vastus Lateralis during Isometric Knee Extension in Young and Older Men and Women

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Abstract—**Multichannel surface electromyography (EMG) or high density EMG (HDsEMG) can be used to study spatial distribution and muscle characteristics in aging muscle. The purpose of this study was to compare spatial EMG potential distribution during isometric knee extension between young and older men and women. Torque and HDsEMG data were recorded from the vastus lateralis during maximal voluntary isometric knee extension (MVC) from 24 young men and women (ages 19 – 25 years) and 25 older men and women (ages 64-78 years). Spatial distribution was estimated using the RMS value for each of the 32 electrode grid locations and 2-Dimensional (2D) maps were developed for each participant. Peak torque, mean EMG RMS, intensity, were compared across age and gender. Analysis of variance indicated statistically significant differences in peak torque, mean RMS and intensity between age and gender groups. Strength, muscle activation and intensity differ due to age and sex during maximal isometric knee extension. Further research that includes a larger range of submaximal and maximal contractions may provide further insight into the impact of age-related changes in muscle morphology on spatial distribution during force development.**

Keywords— **High density electromyography, spatial distribution, aging, vastus lateralis**

I. Introduction

Muscle strength is an important determinant of functional performance and has been shown to decline with age. The decrease in maximal voluntary force in the elderly is related to a number of factors including sarcopenia due to loss of muscle fibers and atropy of type II fibers [1,2,4,5]. While lower limb muscles such as the quadriceps are critical for locomotion and activities of daily living, age-related changes in motor unit (MU) behaviour in these muscles remains unclear [6].

Muscular force production is determined by recruitment of MUs and the firing rates of the recruited MUs. The amount of MU activity during a muscle contraction varies with the magnitude of the force that is exerted, the speed of the movement, and the type of contraction [7]. Studies have examined the behaviour of MUs and the age related changes in the neuromuscular system [8,9], however the majority have used intramuscular electromyography which is invasive and may be challenging for older populations.

Multichannel surface EMG is non-invasive and can be used to evaluate properties of MU activity using multiple electrodes arranged on a two-dimensional plane [10,12,13,14]. The spatial distribution of multichannel surface EMG can be used to examine alterations in MU recruitment [15,16]. Previous studies have used multichannel EMG to show that spatial activation distribution in a muscle is non-uniform and that the EMG spatial distribution pattern can be altered by contraction levels or fatigue [10,12,13]. In addition, multichannel EMG can be used to non-invasively investigate MU activation of muscle during force production at varying levels of force contractions [14]. Gender differences in MU recruitment strategy during sustained isometric contractions is unclear and recently mutlichannel surface EMG was used to show that females exhibit more varied MU recruitment during sustained low-intensity isometric contractions than males [18].

The purpose of the study was to examine differences in HDsEMG spatial distribution of the vastus lateralis during knee extension in older and younger males and females. It was hypothesized that strength, mean spatial amplitude and spatial intensity would be higher in the younger, male group compared to other groups.

II. Methods

A. Participants

Fourty-nine individuals (n=49) participated in this study in four experimental groups, young males (n=12), young females (n=12), older males (n=13) and older females (n=12). The general characteristics of participants are shown in Table 1. All subjects were healthy and did not report any injury to the upper leg or knee joint. Prior to beginning the study, subjects were given a detailed explanation of the procedure and gave written consent. The experimental procedures were approved by the University of New Brunswick Research Ethics Board.

B. Experimental Design

The participants performed two maximal voluntary contractions (MVC) during isometric knee extension. During the contractions, multi-channel HDsEMG was recorded from the vastus lateralis muscle. Isometric knee extension contractions were performed on a Cybex Humac Norm

(CSMI Inc., USA) isokinetic dynamometer. Torque data was collected at 100Hz.

Table 1 Participant Characteristics

	Young Males (n=12)	Older Males (n=13)	Young Females (n=12)	Older Females (n=12)
Age (years)	22.2 ± 1.6	70.3 ± 3.5	22.4 ± 1.6	71.4 ± 5.0
Height (cm)	178.0 ± 8.3	177.3 ± 6.8	167.1 ±5.7	159.7 ±7.7
\Weight (kg)	81.9 ± 13.3	90.0 ± 16.5	62.5 ± 8.0	63.5 ± 9.6

C. Multi-channel EMG recording

Multi-channel HDsEMG data was collected at 1000Hz using a wireless high-density EMG (Trentadue, OT Bioelettronica, Italy, input impedance: >90 MΩ, CMMR: >96 Db, filter: 15 Hz low cut-off, 500Hz high cut-off, gain: noise: <2µVRMS) with a semi-disposable 32-channel electrode grid (ELSCH032NM6, OT Bioelettronica, Italy). The grid consisted of 8 rows and 4 columns of electrodes (1mm diameter, inter-electrode distance of 10mm). A double-sided adhesive foam grid was placed on the electrode matrix, and conductive cream was inserted into each cavity to provide electrode skin contact for each individual electrode. The electrode matrix was placed in line with the participants' vastus lateralis on their dominant leg (84% right-leg dominant, 16% left-leg dominant) so that the electrode 1 was in the most proximal lateral position. The middle of the electrode grid was on 2/3 line between the anterior superior iliac crest and the lateral border of the patella. Prior to the electrode placement, the area was first shaved to remove hairs, cleaned with alcohol, and abraded with paper towel. The ground electrode (Duo-Trode, Myotronics Incorporated, Washington, USA, diameter: 12.5mm, material: Ag/AgCl) was placed on the patella, with conductive gel to provide electrode skin conductance.

D. Experimental Protocol

Participants were seated on the Cybex with their dominant leg (self-reported dominance) strapped to the dynamometer approximated two inches above the ankle joint as shown in Figure 1. Once the isokinetic dynamometer was adjusted to the individual and grid of electrodes was placed over the leg, the participant was asked to complete practice contractions. The participant was encouraged to "push as hard as you can" throughout the contraction. There was a three-minute rest between following the practice trial before beginning the MVCs. The MVCs were five seconds in duration with two minutes of rest in between each. Participants received visual feedback and verbal encouragement throughout the trials.

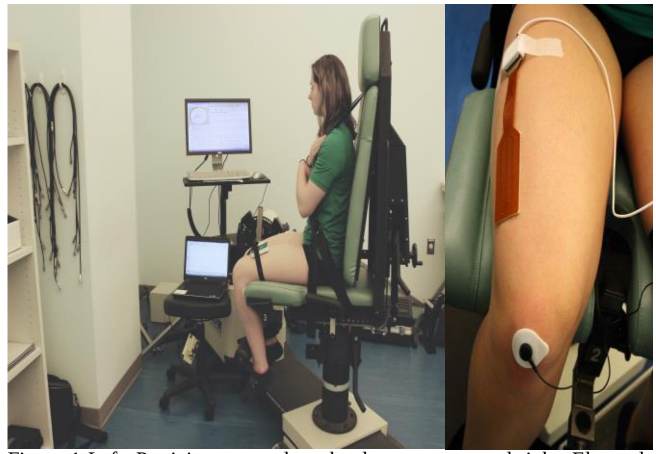

Figure 1 Left: Participant seated on the dynamometer and right: Electrode setup

E. Data Analysis

HDsEMG data was recorded using the product software (OT Biolab, Bioelettronica, Italy). EMG data was filtered with a bandpass filter 20-400Hz and the Root Mean Square (RMS) was calculated for every one-second interval for each channel (OT Biolab). EMG data were analyzed using a two-second interval centred at the midpoint of the contraction.

Spatial distribution was estimated using the RMS value for each of the 32 electrode grid locations for each participant and 2-Dimensional (2D) maps were developed for each participant. The HDsEMG maps represent the spatial distribution of intensities of active MUs over the surface of the muscle as follows [19]:

$$\mathrm{HM}_{ij} = RMS(sEMG_{ij}) \qquad (1)$$

where HM is an activation map and each pixel in a map (HM i,j) corresponds to an RMS value of a channel in an electrode array (position i,j).

In addition to the 2D maps for each individual participant, the mean RMS of each location was calculated for each age and gender group and mean 2D maps were developed to represent the distribution of activity of each group for comparison.

Intensity was defined similar to previous work [19,20] as the common logarithm of the mean intensity of the HDsEMG maps:

$$\mathrm{I} = \log_{10} \frac{1}{N} \sum_{i,j} \mathrm{HM}_{i,j} \qquad (2)$$

where I is an intensity feature calculated from the HDsEMG intensity map HM with a total number of N channels, and HMij is the intensity of a channel located at position i,j.

F. Statistical Analysis:

Data was summarized using mean and SD for each group. Prior to beginning analysis, Shapiro-Wilks test was used to ensure normal distribution of the data. Significant difference between sex and age for torque, RMS, and intensity were determined using a two-way ANOVA across all groups. Bonferroni post-hoc analysis was used when an ANOVA resulted in a p-value less than the alpha value, set at 0.05. All of the statistical tests were performed using RStudio 1.0. 136 (RStudio, Boston, MA).

III. Results

Mean and standard deviation for torque, RMS and intensity, in Table 2. MVC torque was significantly different between elderly men (193 ± 46.6 Nm) and younger men (311.9 ± 69.4 Nm) and also between older women (114.8 ± 31.8 Nm) and younger women (168.6 ± 33.7 Nm). There was a significant difference in MVC torque between age categories for both males and females (P <0.001), as well as between males and females for both younger and older groups (P <0.001) (Table 2).

Table 2: Measures for all participant categories (mean ± sd)
(*- indicates significant differences between age groups. $^{+}$-indicates significant difference between gender groups)

	Young Males	Older Males	Young Females	Older Females
Torque (Nm)	311.9 ± 69.4^{*+}	193 ± 46.6^{*+}	168.6 ± 33.7^{*+}	114.8 ± 31.8^{*+}
RMS (mV)	0.75 ± 0.42*	0.33 ± 0.20^{*+}	0.50 ± 0.23*	0.18 ± 0.11^{*+}
Intensity	-0.20 ± 0.28*	-0.52 ± 0.25^{*+}	-0.36 ± 0.24*	-0.81 ± 0.22^{*+}

Mean activation maps were generated and are shown in Figure 2. Significant gender-related differences in Mean RMS were found between older females and older males (p=0.014). Differences were also detected between older and younger males (p=0.0058) and between older and younger females (p<0.001). However, there were no significant differences in RMS between younger males and females (p=0.085). Similarly, the intensity differed between older females and males (p=0.005), between older and younger males (p=0.0059) and older and younger females (p<0.001). There were no differences in intensity between younger males and females (p=0.085).

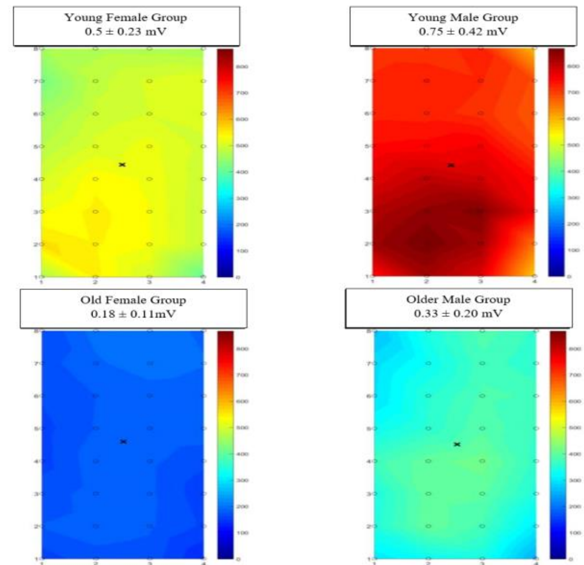

Figure 2: Mean activation maps : (clockwise from top left): Young females, young males, old males, old females (Mean ± Std Dev)

IV. Discussion

This study compared the spatial distribution of EMG activity in the vastus lateralis between young and older males and females during maximal voluntary contraction of the knee extensors. The findings of this research were (1) that there is a significant difference in torque output between younger and older populations for both sexes, (2) there are significant differences in muscle activation and intensity between individuals as well as across groups (Figure 2). Overall young males exhibited the greatest strength and highest amplitude and intensity.

The mean activation maps illustrate the spatial differences that occur due to age and gender and showed that generally older females had lower intensity and lower strength than young males. Older males and females appear to be less uniformly distributed than for young males and females, indicating age related differences. Previous research (Watanabe et al., 2012) used HDsEMG to investigate the change in activation pattern between young and old men when contracting the vastus lateralis through 20-65% of ramped MVC. Their results showed a significant difference in the spatial distribution at 65% between young and old men. They suggested that the difference in spatial distribution is expected as a result of the morphological changes to the muscle as a result of sarcopenia.

In this study there were differences detected in torque due to age and sex as well as mean RMS and intensity. It was found that older females exhibited the least strength as well as mean RMS amplitude and intensity. The EMG amplitude provides an overall estimation of muscle activation and is related to motor unit recruitment. Force and EMG have a monotonic relationship (as one increases, so does the other), and that relationship can be exploited to examine methods to improve overall lower limb function. Age and sex differences in strength production provide valuable information to develop appropriate training programs to improve lower limb function.

This work was limited to the observation of a maximal isometric knee extension. It is critical to observe muscle behaviour under a range of contraction levels as well as dynamically. Watanabe et al. (2012) examined a ramped contraction and only found significance at the highest intensity (65% MVC). Examining contractions of varying intensity could provide greater insight regarding age and sex-related strength changes. In the present study a 32-channel grid was placed over the quadricep. A larger grid with more electrode detection sites would cover a larger area of muscle providing a more accurate representation of the muscle fiber distribution over the entire muscle. It could provide information regarding muscle co-contraction and coordination changes. It is possible that the intervening tissue between the electrode and muscle is affected by age and sex. Further studies should take into account factors such as muscle thickness and subcutaneous tissue thickness. Future work should also include a range of contraction level, as well as dynamic contractions such as isokinetic contractions to examine muscle activation changes during force development. Furthermore, studying different speeds of contraction as well as different muscle groups may provide greater insight into motor unit behaviour.

V. Conclusions

HDsEMG is a non-invasive technique that can provide information regarding spatial distribution of muscle activity. This research examined spatial distribution of muscle activation in older and younger males and females to determine if there are age-related differences and if these differences can be detected using high density EMG. Further research including a larger range of submaximal contractions as well as dynamic contractions with varying speed may provide further information of the impact of muscle morphology on spatial distribution. Understanding these relationships will provide valuable information regarding age-related changes in muscle characteristics as well as force development and help to develop training programs to offset the impact of aging.

VI. Acknowledgment

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Conflict of Interest

The authors declare that they have no conflict of interest.

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