THE SEXES EXHIBITED SIMILAR PATTERNS OF UPPER TRAPEZIUS EXCITATION DISTRIBUTION AT REST AND WITH FATIGUE DURING REPEATED ARM ELEVATION

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Females have a higher prevalence of neck/shoulder complaints compared to males, even when workloads are equal. Researchers theorize females may present with higher excitation amplitude in neck/shoulder muscles. We determined if excitation distribution of the upper trapezius (UT) differed between the sexes at baseline and fatigue in three tertiles of the raising phase of shoulder flexion. Twenty-eight individuals (females *n*=14) completed maximum voluntary contractions and a repeated arm elevation task to volitional fatigue while high density electromyography was collected. Statistical parametric mapping t-tests were performed between males and females withing each tertiles and at baseline and fatigue. UT excitation distribution between the sexes changed in tertile 2 across ~43% of the topographical map. No differences were found in tertiles 1 or 3 at baseline or fatigue.

KEYWORDS: high-density electromyography, sex, statistical parametric mapping, volitional fatigue

INTRODUCTION: The shoulder relies primarily on dynamic stability provided by soft tissues, including ligaments, tendons, and muscles for joint stability. The scapular stabilizers, namely the trapezius and serratus anterior muscles, act synergistically to produce smooth, coordinated motion of the scapula (Kibler et al., 1998). The coordination of muscle forces is critical, as asymmetrical muscle excitation and modified kinematics have been associated with an elevated risk of shoulder pathology (Ludewig et al., 2006). The upper trapezius (UT) plays a key role as it elevates and upwardly rotates the scapula and is more active in those with shoulder pathology (Cools et al., 2003). As such, defining UT excitation has been the focus of numerous investigations aimed at identifying risk factors, preventive and rehabilitative strategies to reduce the incidence and duration of shoulder pathology (Camargo et al., 2019; Cools et al., 2003).

Work-related neck/shoulder musculoskeletal pathology is associated with muscle fatigue, repetitive work, and prolonged static loads on the neck/shoulder (van der Windt et al., 2000). Interestingly, females have more neck/shoulder pathology than males (Norander et al., 2016). One proposed mechanism for females increased neck/shoulder pathology in sex-differences is muscle excitation, with females presenting higher excitation amplitude during identical working conditions (Meyland et al., 2014; Norlander et al., 2008). When submaximal effort is exerted and muscle fatigue develops, muscle excitation increases (Srinivasan et al. 2016), suggesting that increased muscle excitation may be a mechanism the body uses to mitigate fatigue (Côte, 2014). Increasing excitation to maintain task performance can lead to an increased risk of injury as more physiological stress is placed on those muscle fibres (Cools et al., 2003). Additionally, higher muscle excitation in one portion of the trapezius- serratus anterior force couple may lead to altered kinematics, increasing the risk of injury (Ludewig et al., 2006). This increased risk of injury in females has led researchers to investigate how differing task demands effects muscle excitation between the sexes.

Females exhibit lower fatigability than males during sustained and intermittent isometric contractions in the upper limb at comparable intensities (Hunter 2016). During slow (~60°/second) dynamic contractions, females exhibit lower fatiguability than males; however, these differences diminish at high velocities (Hunter, 2016). There is a scarcity of research on sex differences during dynamic tasks due to the introduction of numerous variables (e.g. contraction velocity and movement of muscle fibres; Hunter et al., 2016; Yoon et al., 2015). Yoon et al. (2021) investigated sex-specific muscle excitation, action patterns, hemodynamic and swelling responses to a repetitive pointing task to fatigue, revealing no disparities in time to fatigue or EMG amplitude, but identifying greater UT thickness and median power frequency in males compared to females (Yoon et al., 2021). Given that most studies on sex-differences in excitation have used bipolar EMG, the use of high-density electromyography (HD-sEMG) may offer a more compressive understanding of excitation across and within a given muscle (Holtermann et al., 2005).

Statistical parametric mapping (SPM) identifies regional differences in high-density electromyography data by analysing spatial changes in excitation with a remarkable level of sensitivity and precision (Pincheira et al., 2020). Notably, SPM analyses have demonstrated unique excitation patterns in the medial gastrocnemius with varying contraction intensities (20%, 40%, and 60% of participants' maximum voluntary isometric contraction; MVIC), which were not discernible through more traditional barycentre analyses (Pincheira et al., 2020).

Thus, we determined whether UT excitation differed between the sexes during three different sections of arm elevation before and after performing fatiguing arm elevation using SPM. Based on previous research (Hunter et al., 2016; Yoon et al., 2021), we hypothesized that sex would not impact RMS amplitude in any tertile of arm elevation raising at rest or fatigue.

METHODS: Twenty-eight individuals (females n=14) with asymptomatic shoulders (26 +/-5 years) performed arm elevation through their full range of motion while holding a load relative to 30% of their maximum isometric shoulder flexion (MISF) force at a rate of one movement (raising or lowering) per second. A 32-electrode high-density surface electromyography (HD-sEMG) grid collected EMG from the UT during three repetitions of five second MVIC with two minutes of rest between repetitions. After MVICs, three repetitions of five second MISFs were performed while force was collected using a load cell (PY6-1000, BERTEC Corporation, 126 Columbus, OH) with two minutes of rest between repetitions. A wireless motion sensor (DataRX-W, Tactile Robotics, Winnipeg, MB) was affixed to the anterior arm, just superior of the elbow crease. Participants then performed repeated arm elevation to volitional fatigue, until they reported 8/10 or greater on the Modified Borg Scale or if they could no longer keep cadence with the metronome. Motion sensor and EMG data were collected via an amplifier (Quattrocento, 400-channel EMG amplifier, OT Biolelettronica, Torino, Italy). EMG data were collected at a sampling rate of 2048 Hz in monopolar mode.

The raising phase of each repetition was defined as the onset of movement (the time point when angular acceleration exceeded 0.25 rad/s^2 to the peak pitch value. Each repetition was separated into three tertiles based on the time domain of the motion sensor data to create early, mid- and late-movement tertiles. The corresponding timestamps were used to export EMG for each tertile/repetition. EMG data were exported in 0.01-second epochs and high-pass filtered at 50Hz. Data were visually inspected for poor electrode channels and if they could not be replaced, they were removed from further analysis. The root mean square (RMS) was taken from 24 differential signals. The first and last three repetitions served as rested and fatigued states, respectively. RMS of each electrode of a grid within a tertile were averaged to yield 24 mean-grid RMS values, averaged across the 3 repetitions, and expressed relative to MVIC RMS (i.e., %MVIC). Topographical excitation maps were created for each tertile and condition for each participant after 2D interpolation by a factor of 4, creating 12 x 32-pixel maps. Maps were then transformed into Neuroimaging Informatics Technology Initiative (NIfTI) format and smoothed with a full width at half maximum kernel of 6 x 6 mm^2 in MATLAB software (Pincheira et al., 2020).

To determine if UT excitation distribution in each tertile of arm elevation differed between the sexes at rest or with fatigue, six t-tests were performed using SPM12 (Functional Imagine Laboratory, London, UK). Multiple t-tests were performed in SPM instead of a multivariant test, as the current multivariant approach assigns a weight to each voxel, rendering the weights essentially scale-free and with unclear statistical significance (Yourganov et al., 2020). In all statistical maps and tables, SPM inference is reported at a threshold of p<0.05, with family-wise error correction for multiple comparisons.

RESULTS: On average the female participants completed 29 repetitions in 59 seconds, while males completed 39 repetitions in 80 seconds.

Rested. There were no differences in UT excitation distribution at rest in tertile 1 or 3 between females and males. There were 168 pixels (~43% of the map) that were significantly different between females and males in tertile 2 at rest **(Figure 1; Table 1).**

Fatigue. There were no significant differences in excitation distribution between females and males in any tertile.

Table 1: SPM statistics when comparing topographical excitation maps between females (*n=12*) and males (*n=10*) in tertile 2 at rest.

	Height Threshold[1]	K_E[2]	$P_{FWEcorr}$[3]	Test Statistic[4]	Peak Coordinates[5]	
Two sample t-test	2.06	168	0.047			
Cluster 1			0.027	2.41	1	1
Cluster 2			0.033	2.30	32	11

[1] Height threshold: calculated for $p<0.05$, corrected for family-wise error rate; [2] KE: number of pixels that exceeded the significance threshold; [3] $P_{FWEcorr}$: p-values corrected for family-wise error rate; [4] test statistic: the maximum T value obtained by the local maxima; [5] peak coordinates: position on the map (12 x 32 mm) in millimetres of the maximum value (x = lateral; y=cranial).

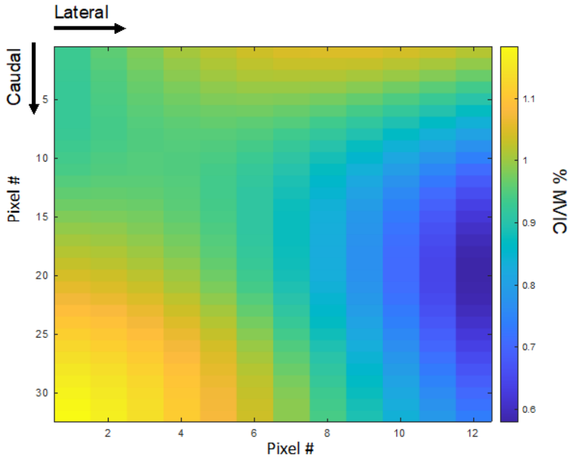

Figure 1: Average topographical map comparing sex. *Topographical difference map of the average of all participant's % maximum voluntary isometric contraction (MVIC) data, calculated by subtraction of female participant's data by male participant's data.*

DISCUSSION: The main findings of the current study are that UT excitation distribution differed between the sexes in the middle phase (tertile 2) of arm raising at rest. No other differences were present between tertiles at rest or fatigue between the sexes. Collectively, our data suggest that UT excitation distribution is similar between the sexes at rest and with fatigue during repeated arm elevation.

While most of our findings suggest an absence of sex-differences, UT excitation distribution did differ in ~34% (168 pixels) of the grid during the middle phase of arm elevation. While muscle excitation of the UT has been shown to increase between 90-120° abduction in males (approximately the middle phase) (Bagg et al., 1986; Ludwig et al., 2000), our observation that muscle excitation differed in a third of the grid suggests females may use a different UT excitation pattern to stabilize the scapular at the onset of movement. Future research should examine kinematics and EMG of more shoulder muscles to gain a better understanding of what occurs during fatigue, both generally and between the sexes.

Our hypothesis that sex-differences would not be present was confirmed by the remainder of our data. Differences in UT excitation distribution between the sexes may be more apparent in mean power frequency, as it is more sensitive to muscle fatigue than RMS amplitude (Arendt-Nielsen, 1985). Given that females exhibit less fatigue than males at slow but not high-velocity contractions (Hunter et al., 2016), it is also plausible that sex-differences in UT excitation distribution may be present at slower tasks than the one used in the current study (1 arm raising/second). Future work should aim to define excitation distribution of the trapezius in response to different task speeds to determine if sex-differences are present.

There are limitations to the current study that should be considered when interpreting our results. RMS was used to create the topographical thresholding maps, which is not as sensitive as mean power frequency to changes in fatigue (Arendt-Nielsen, 1985). Additionally, barycentre analyses were not completed, thus changes in excitation distribution can only be described as a result of visual inspection of topographical maps.

CONCLUSION: The sexes exhibit similar patterns of UT excitation distribution at rest and with fatigue during repeated arm elevation. Additional research is needed to better understand the motor strategies employed by the upper trapezius to maintain task performance during fatigue and between the sexes. This research will assist practitioners with training and understanding fatigue between the sexes. Specifically, future research should investigate the mean power frequency and RMS of a variety of different shoulder muscles at different speeds of movement in conjunction with kinematics between the sexes.

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