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Review

Are there sex differences in muscle coordination of the upper girdle during a sustained motor task?

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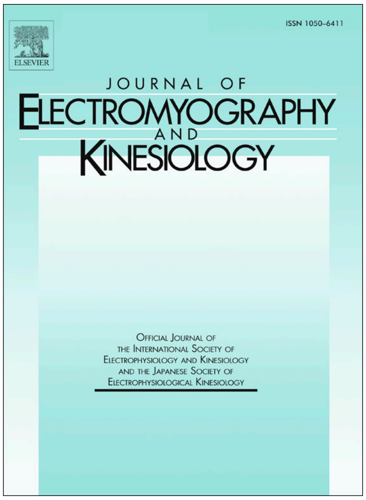

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Title Page

Title: Are there sex differences in muscle coordination of the upper girdle during a sustained motor task?

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Keywords: surface electromyography, neck/shoulder, gender differences, fatigue, repetitive task.

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Abstract

Purpose: The higher prevalence of work-related musculoskeletal disorders among women compared with men could be explained by sex-gender differences related to biological and physiological processes. The aim of this study was to evaluate sex differences in motor coordination during a sustained and repetitive motor task. Methods: Seventeen healthy females and 21 healthy males participated. The surface electromyography (sEMG) of the trapezius portions and serratus anterior were recorded. Root mean square (RMS) values were computed to assess the level of muscle activity. The standard deviation (SD) and coefficient of variation (CV) were computed as metrics of size of variability. The normalized mutual information (NMI) values were calculated as index of functional connectivity between muscles pairs. Results: Females had higher normalized RMS values for the upper trapezius (acromial fibers) and serratus anterior muscles compared with males. RMS decreased, SD and CV increased while NMI decreased for almost all muscle pairs over time. Conclusion: The present work showed some signs of sex differences in muscle coordination of the shoulder girdle during a sustained motor task, performed with the upper limb positioned above of the shoulder.

Key-words: surface electromyography; neck/shoulder; gender differences; fatigue; repetitive task.

Introduction

Studies on how biological differences between men and women affect motor behavior have largely focused on anthropometrical and hormonal differences. Sex differences also have been reported at several occasions in terms of level and pattern of surface electromyography (sEMG) activity. The influence of hormonal changes during the menstrual cycle on sEMG are not clearly understood (Tenan et al., 2013, 2016). Placing sex differences in an occupational context is of interest considering the higher prevalence of work-related musculoskeletal disorders (WMSD) in the neck-shoulder region reported by women compared with men (Côté, 2012). Sex differences have been shown in terms of motor strategies, i.e., sEMG activation level, size of motor variability and functional connectivity in response to fatigue of neck/shoulder muscles during repetitive tasks (Emery and Côté 2012; Johansen et al. 2013; Fedorowich et al. 2013; Srinivasan et al. 2016).

For tasks of comparable intensities, females have been shown to use higher normalized sEMG activation levels compared to their maximal activation levels (Johansen et al., 2013; Meyland et al., 2014; Nordander et al., 2008) during dynamic and repetitive tasks. This is interpreted as a higher muscular load for females compared with males when executing the task at hand (Ge et al., 2005).

Motor variability expresses motor control strategies, i.e. the degrees of freedom used in a standardized motor task (Latash et al., 2002). Variability may change in response to muscle fatigue (Fuller et al., 2011). Further, a lack of variability in muscle activity has been suggested to play a role in the development of WMSD (Madeleine, 2010; Srinivasan and Mathiassen, 2012). Sex-specific patterns of motor variability have been reported (Fedorowich et al., 2013). However, sex-specific changes in motor variability during a sustained repetitive motor task are not completely elucidated.

Beside the activation level and the variability of sEMG, another important aspect of motor control resides in synergistic action of muscles. Approaches based on non-negative matrix factorization, principal component analysis and coherence have been applied to study muscles coordination (Farina et al., 2014; Muceli et al., 2014; Steele et al., 2015). Another method, i.e. mutual information detecting both linear and non-linear dependencies (Jeong et al., 2001) has been applied to sEMG signals (Madeleine et al., 2011). Normalized mutual information (NMI) can be used as an index of functional connectivity between muscle pairs (Madeleine et al., 2011). NMI has been used e.g. to assess sex-differences in a repetitive task (Farias Zuniga and Côté, 2017; Fedorowich et al., 2013; Johansen et al., 2013) and development of muscle fatigue (Bingham et al., 2017; Fedorowich et al., 2013; Kawczyński et al., 2015). Changes in NMI are interpreted as altered muscles interplay (Madeleine et al., 2016). However, no clear findings exist in terms of NMI sex-differences. All in all, it is conceivable that males and females do not exploit their motor repertoires exemplified by differences in activation level and variability of sEMG, as well as in NMI during a sustained repetitive motor task to the same extent.

It is well established that females are less fatigable than males considering sustained contractions performed with upper limbs (Hunter et al., 2009), which may reflect sex differences in muscle coordination. However, the picture is not as clear during dynamic contractions (Hunter, 2016) since the specificities of the task (type, velocity, and intensity of the contractions) affect the development of muscle fatigue. The aim of this study was to evaluate sex differences in muscle coordination of the upper girdle during a sustained repetitive motor task. Higher levels of muscle activation (Meyland et al., 2014) as well as lower motor variability (Lomond and Côté, 2011, 2010; Madeleine et al., 2008) are suggested to be associated with WMSD and considering the high prevalence of WMSD among women, we hypothesized that females would have higher muscle activation and lower motor variability than males.

Methods

Subjects

Seventeen females (mean age 22.6±2.6 years, body mass 59.2±10.6 kg and size 164.8±7.1 cm) and 21 males (mean age 24.4±3.8 years, body mass 76.8±11.7 kg and size 178.2±7.0 cm) were included in the study. The Nordic Musculoskeletal Questionnaire (NMQ) and a Visual Analogue Scale (VAS) were applied in order to assess the possible presence of musculoskeletal symptoms in the neck/shoulder region and the pain intensity. The inclusion criteria for the study were: age between 18 and 35 years; body mass index (BMI) between 18.5 and 24.9 kg/m²; absence of musculoskeletal symptoms in the neck/shoulder region according to the NMQ and absence of neck/shoulder pain within the last seven days using the VAS. Moreover, volunteers who self-reported circulatory, rheumatic or inflammatory diseases, performed throwing sports or had experience in repetitive manual work, were excluded. This study was approved by the local ethics committee (Protocol #49259215.9.0000.5504) and conducted according to the Helsinki declaration.

sEMG recording and processing

All portions of the trapezius muscle: upper - clavicular fibers (CUT) and acromial fibers (AUT); middle (MT) and lower (LT) trapezius as well as, the serratus anterior muscle (SA) were evaluated through sEMG. A portable device was used (Myomonitor IV, Delsys, Boston, USA). Active differential electrodes (DE-2.3, Delsys, Boston, USA) were fixed to the skin with double-sided adhesive tape. Before applying the electrodes, the skin was shaved and cleaned with 70% ethyl alcohol to decrease skin-electrode impedance. The electrodes for all portions of the trapezius and SA muscles were placed in agreement with Januario et al. (2017). The reference electrode (5x5cm adhesive) was fixed on the manubrium sternae. The signals were amplified 2000 times for all portions of the trapezius muscle and 6000 for the SA and sampled at 2000 Hz using an A/D converter (16 bits A/D converter, Myomonitor IV, Delsys, Boston, USA).

The sEMG signals obtained during the sustained motor task were normalized with respect to sEMG amplitude obtained during maximal voluntary contractions (MVC) performed in isometric conditions. For this purpose, each muscle was individually assessed through three MVCs lasting 5-sec trials, with 1-min interval to minimize eventual fatigue development. During the MVCs, resistance was applied against a belt connected to a force plate fixed to the floor. The force produced was measured using a digital dynamometer (DDK, Kratos, São Paulo, Brazil). Participants received verbal encouragement during the MVC trials. The order of assessment of all muscles was randomized and counter-balanced between the two groups. The normalization positions are also shown in Table 1.

Sustained Motor Task

A sustained motor task requiring the apprehension and manipulation of light pieces was performed (Januario et al., 2018, 2017). During the task, the participants were seated in front of an adjustable table. The dominant arm was positioned with 60° of abduction and a string was adjusted below the elbow in order to ensure the maintenance of the upper limb in this position during the sustained motor task (Figure 1a).

A horizontal wooden board with six different holes for fitting the pieces, a recipient with corresponding pieces to be placed on the wooden board and another recipient used to place the discarded non-fitting pieces were positioned on the table (Figure 1b). Each piece had a different color, according to its shape. Each piece weighed approximately 2g and had a size of approximately 2 cm^2. The non-fitting pieces corresponded to 30% of the total amount of pieces and they were slightly larger than the board holes. The task involved to choose and fit the pieces on wooden board (in a vertical order) and discard the non-fitting pieces. The pace was set at 21 fittings per minute, which can be considered as a highly repetitive task according to Ohlsson et al. (1989). All participants performed a familiarization session prior to data collection to ensure that they were able to maintain the predetermined pace.

The sustained motor task was performed continuously for one hour. The work task was interrupted if the participant was unable to maintain the predetermined pace or to maintain the dominant upper limb in 60° of abduction or reported a score ≥ 8 on the Borg CR-10 Scale (Cote et al., 2008; Fedorowich et al., 2013).

Data Analysis

sEMG Processing

All sEMG signals were processed using Matlab (version 8.0, The Mathworks Inc., Natick, MA, USA), corrected for offset and band-pass filtered using a fourth order zero-lag Butterworth filter in the 30-450 Hz band. Signals obtained from MVCs were converted into RMS using 100-ms moving windows without overlap (Attebrant et al., 1995; Mathiassen et al., 1995). The maximum values were extracted for normalization purpose. Furthermore, the RMS using 1-sec windows of the sEMG signals recorded during the sustained motor task were computed and normalized with respect to maximum RMS values from the MVC tests. Figure 2 shows the absolute (mV) and normalized (%MVC) signal of one male and one female obtained during the simulated work task. For this analysis, 30 -sec sEMG signals recorded during the first (14 to 43-sec) and the last ($time_{end}$ (second) minus 46 to $time_{end}$ (second) minus 14) minute of the task were considered as starting and ending task periods, respectively (Fedorowich et al., 2013).

The absolute and relative size of sEMG variability was expressed computing the standard deviation (SD) and coefficient of variation (CV) of the RMS values obtained during the epochs corresponding the starting and ending task periods in line with Fedorowich et al. (2013).

The normalized mutual information (NMI) was calculated to evaluate the functional connectivity between the four portions of the trapezius and serratus anterior muscle. The mean values of the NMI were calculated over 500-ms windows of normalized sEMG signals. The NMI is unitless and varies between 0, indicating no functional connectivity and 1, indicating complete connectivity within the muscle pair (Madeleine et al., 2011). See supplementary material for further information.

Statistical analysis

The Shapiro-Wilk test was used to test the normality for all data. The data were normally distributed. Thus, a repeated-measures analysis of variance (RM-ANOVA) was applied for the absolute and normalized RMS, SD and CV values, as well as, NMI values. *Time* (pre/post-task periods) and *Group* (males/females) were considered as within and between-subjects factors, respectively. A post-hoc test using the Bonferroni correction was performed in case of significant interactions. The estimated effect size was reported using the partial eta squared (η2), and the follow classification was considered: small effect corresponds to η2 = 0.0099, medium effect to η2= 0.0588, and large effect to η2= 0.1379 (Cohen 1969). All tests were performed in SPSS (Statistical Package for Social Science, v. 17) and the level of significance was set at 0.05.

Results

Considering the task time, only two participants (both were males) performed the task for one hour while most of the participants stopped the sustained motor task when reaching a score ≥ 8 on the Borg CR-10 Scale. Three subjects (one female and two males) were stopped because they were unable to maintain the predetermined pace. Finally, two males were stopped because they were unable to maintain the dominant upper limb in 60° of abduction. There was no difference in time of task interruption between males and females (P=0.44). Moreover, males showed more motor output during the MVCs than females for all muscles evaluated (P<0.01).

The bar graphs with mean and standard deviation of RMS, SD and CV values are shown in Figures 3 and 4 and the statistical analyses are reported in Tables 1 and 2, respectively. Females showed higher normalized RMS values for AUT and SA, when compared to males. The absolute and normalized RMS values of LT and SA decreased at ending compared with starting task period, regardless of the group. Moreover, a similar decrease was observed for the normalized RMS of AUT. The SD and CV values of MT, LT and SA increased at ending compared with starting task period, regardless of the group.

Furthermore, the bar graphs with mean and standard deviation of NMI values are shown in Figure 5. The statistical analyses showed that NMI values were lower for almost all muscle pairs at ending compared with starting task period, except for the AUT-LT and AUT-SA pairs (Table 3), regardless of the group. No significant interaction *Group × Time* were observed for any the extracted outcomes.

Discussion

In contrast to our hypothesis, we found few sex differences in motor strategies during the designed sustained motor task requiring apprehension and manipulation of light pieces below shoulder level. Except for normalized RMS values of the AUT and SA muscles, muscle activation (absolute and normalized RMS), size of motor variability (SD and CV) and functional connectivity (NMI) were not different for females compared with males. However, changes were observed over time, the level of muscle activation decreased, and the size of motor variability (SD and CV values) increased. Furthermore, the NMI values decreased for almost all muscle pairs at the ending compared with the starting task period.

Martinez-Valdes and co-workers (2018) have recently shown that the amplitude of sEMG does not enable to extract precise information on neural drive to synergistic muscles. We found very few sex differences in EMG amplitude. In that sense, our findings are for the most contrary to previous studies (Anders et al., 2004; Ge et al., 2005) but in agreement with others (Fedorowich et al., 2013; Srinivasan et al., 2016). Still, we found higher normalized RMS values for the AUT and SA muscles for females than for males. This is in line with a study performed by Johansen and coworkers (2013). Actually the levels of activation were 3-5% of the MVCs higher for females than for males, representing a higher risk of developing WMSD (Madeleine et al., 2003; Veiersted et al., 1993).

Considering the size of variability of the sEMG, we found no sex differences in either SD and CV. These results are partly in disagreement with a recent study by Srinivasan et al. (2016). Similar to the present findings, no sex differences in motor variability has been reported at the beginning of the task. However, Srinivasan et al. (2016) have reported a higher increase in the size of motor variability of the upper trapezius at the end of the repetitive task. These sex differences in motor variability are usually interpreted as detrimental considering the higher prevalence of WMSD among females (Côté, 2012). The disagreement between our results and those presented by Srinivasan et al. (2016), may be attributed to methodological differences (repetitive task, pace and duration of the task).

No sex difference in the NMI of the evaluated muscle pairs. Fedorowich and co-workers (2013) have reported lower NMI values for middle deltoid and lower trapezius muscle pair for females compared with males. Opposite to that study, Johansen and co-workers (2013) have reported higher NMI values for upper-middle trapezius muscle pair for females compared with males during a repetitive task. The disagreement between our results and those reported previously regarding sex differences may also be attributed to methodological differences related to task characteristics. Those studies evaluated a repetitive task requiring the sustentation of the upper limb elevated at the shoulder level and a different pace (Fedorowich et al., 2013; Srinivasan et al., 2016). On the contrary, the present sustained motor task did not impose such constraint. It is most likely that differences in the motor task attributes, i.e. the temporal and spatial constraints affecting the muscular load were too low to produce significant difference among sexes in terms of motor variability or muscle pairs coordination.

Regardless of the group, the sEMG RMS values decreased toward the end compared with the start of the sustained motor task. These decreases were significant for both absolute and normalized RMS of the LT and SA and normalized RMS of the AUT. Such findings are in line with previous studies, reporting decreased muscle activation during sustained dynamic activities (Bennie et al., 2002; Hostens and Ramon, 2005) but also contrary to several studies reporting increased muscle activation during sustained repetitive tasks (Fedorowich et al., 2013; Samani et al., 2016; Srinivasan et al., 2016). The mode of testing to evaluate fatigue after sustained repetitive task has been reported to yield in varying results for males and females (Senefeld et al., 2013). Increased RMS values during sustained static contractions are attributed to neuro-muscular mechanisms including additional motor units' recruitment, changes in motor units discharge rates, motor unit substitution, decreased muscle fiber conduction velocity as well as increased duration and decreased amplitude of the extra-cellular action potential (Farina et al., 2008). Even if similar increases in RMS have been reported during dynamic sustained contractions, there are also studies reporting opposite findings. Decreased muscle activation during sustained dynamic contraction has been attributed to a protective mechanism in response to muscle fatigue (Bennie et al., 2002; Hostens and Ramon, 2005). This decrease in muscle activation has been explained by potentiation mechanisms of the active muscle fibers (Garner et al., 1989) and decreased neural drive (Vernillo et al. 2018). Still, the interpretation of changes in sEMG RMS needs to be made with caution (Farina et al., 2014; Martinez-Valdes et al., 2018). Here too, discrepancies in experimental protocols can explain the differences of RMS changes during sustained contractions.

Concerning the size of variability of the sEMG, the SD and CV values of MT, LT and SA increased toward the end compared with the start of the sustained motor task, regardless of the group. Our results are in agreement with Srinivasan et al. (2016). Motor variability has been suggested to play an important role in the development of WMSD (Madeleine, 2010). In a review performed by Srinivasan and Mathiassen (2012), it was pointed out that the increase of motor variability during the development of muscle fatigue, may represent an adaptive mechanism to maintain the task performance even in the presence of musculoskeletal overload (Srinivasan and Mathiassen, 2012).

Our results also showed that NMI values decreased over time regardless of sex for almost all muscle pairs evaluated, except for AUT-LT and AUT-SA. These findings are in agreement with Fedorowich and coworkers (2013) but contrary to Kawczyński and coworkers (2015) and Bingham and co-workers (2016) who reported increases in NMI values during a repetitive and static task performed until task failure. Lower NMI values may represent a motor strategy to reduce risks imposed during a sustained motor task (Farias Zuniga and Côté, 2017; Fedorowich et al., 2013) while higher NMI values may indicate increased stability of the shoulder girdle (Kawczyński et al., 2015).

Further studies are needed to evaluate the advantages and drawbacks of computing NMI with respect to e.g. coherence analysis.

Finally, we evaluated healthy and young adults. Thus, the interpretation of the results must be made with caution when considering other groups, such as patients with WMSD. Moreover, although we have controlled for the BMI of subjects, fat skinfolds were not evaluated leading to some inter-individual variance in sEMG signal (Nordander, 2003). Furthermore, it is possible that the pattern of muscular load imposed by the sustained motor task proposed in this study did not trigger the biological threshold that may be sufficient to show significant sex differences during sustained dynamic contractions. Other studies, with different protocols controlling hormones changes during menstrual cycle must be performed to provide better insight of sex differences and muscle activity pattern during dynamic and repetitive tasks. It is possible that a sustained motor task, which requires the upper limb positioned above of the shoulder level may result in sex differences in the motor strategies adopted during the task, due the higher demand imposed to the shoulder girdle muscles.

Conclusion

To the best of our knowledge, no previous study had investigated sex differences in muscle activation pattern and motor strategies adopted in response to a sustained repetitive motor task, quite representative of the industrial context. The present work showed few sex differences in muscle activation level, and no difference in motor variability and functional connectivity of the trapezius and serratus anterior muscles during the performance of a sustained motor task. We found decreases in RMS values, increases in the size of motor variability, as well as decreases in NMI values for almost all muscles pairs evaluated towards the end of the sustained motor task. Further studies assessing sex differences and muscle activity pattern during dynamic and repetitive tasks are warranted.

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References

Anders, C., Bretschneider, S., Bernsdorf, A., Erler, K., Schneider, W., 2004. Activation of shoulder muscles in healthy men and women under isometric conditions. J. Electromyogr. Kinesiol. 14, 699–707. doi:10.1016/j.jelekin.2004.04.003

Attebrant, M., Mathiassen, S.E., Winkel, J., 1995. Normalizing upper trapezius EMG amplitude: Comparison of ramp and constant force procedures. J. Electromyogr. Kinesiol. 5, 245–250. doi:10.1016/1050-6411(95)00005-4

Bennie, K.J., Ciriello, V.M., Johnson, P.W., Dennerlein, J.T., 2002. Electromyographic activity of the human extensor carpi ulnaris muscle changes with exposure to repetitive ulnar deviation. Eur. J. Appl. Physiol. 88, 5–12. doi:10.1007/s00421-002-0666-5

Bingham, A., Arjunan, S.P., Kumar, D.K., 2017. Measuring the interactions between different locations in a muscle to monitor localized muscle fatigue. Conf. Proc. ... Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. IEEE Eng. Med. Biol. Soc. Annu. Conf. 2017, 3461–3464. doi:10.1109/EMBC.2017.8037601

Bingham, A., Arjunan, S.P., Kumar, D.K., 2016. Estimating the progression of muscle fatigue based on dependence between motor units using high density surface electromyogram. 2016 38th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. 3654–3657. doi:10.1109/EMBC.2016.7591520

Cohen, J., 1969. Statistical power analysis for the behavioural sciences. New York: Academic Press.

Côté, J.N., 2012. A critical review on physical factors and functional characteristics that may explain a sex/gender difference in work-related neck/shoulder disorders. Ergonomics 55, 173–182. doi:10.1080/00140139.2011.586061

Cote, J.N., Feldman, A.G., Mathieu, P. a, Levin, M.F., 2008. Effects of fatigue on intermuscular coordination during repetitive hammering. Motor Control 12, 79–92.

Emery, K., Côté, J.N., 2012. Repetitive arm motion-induced fatigue affects shoulder but not endpoint position sense. Exp. Brain Res. 216, 553–564. doi:10.1007/s00221-011-2959-6

Farias Zuniga, A.M., Côté, J.N., 2017. Effects of Dual Monitor Computer Work Versus Laptop Work on Cervical Muscular and Proprioceptive Characteristics of Males and Females. Hum. Factors 59, 546–563. doi:10.1177/0018720816684690

Farina, D., Leclerc, F., Arendt-Nielsen, L., Buttelli, O., Madeleine, P., 2008. The change in spatial distribution of upper trapezius muscle activity is correlated to contraction duration. J. Electromyogr. Kinesiol. 18, 16–25. doi:10.1016/j.jelekin.2006.08.005

Farina, D., Merletti, R., Enoka, R.M., 2014. The extraction of neural strategies from the surface EMG: an update. J. Appl. Physiol. 117, 1215–30. doi:10.1152/japplphysiol.00162.2014

Fedorowich, L., Emery, K., Gervasi, B., Côté, J.N., 2013. Gender differences in neck/shoulder muscular patterns in response to repetitive motion induced fatigue. J. Electromyogr. Kinesiol. 23, 1183–1189. doi:10.1016/j.jelekin.2013.06.005

Fuller, J.R., Fung, J., Côté, J.N., 2011. Time-dependent adaptations to posture and movement characteristics during the development of repetitive reaching induced fatigue. Exp. Brain Res. 211, 133–143. doi:10.1007/s00221-011-2661-8

Garner, S.H., Hicks, A.L., McComas, A.J., 1989. Prolongation of twitch potentiating mechanism throughout muscle fatigue and recovery. Exp. Neurol. 103, 277–281. doi:10.1016/0014-4886(89)90051-4

Ge, H.Y., Arendt-Nielsen, L., Farina, D., Madeleine, P., 2005. Gender-specific differences in electromyographic changes and perceived pain induced by experimental muscle pain during sustained contractions of the upper trapezius muscle. Muscle and Nerve 32, 726–733. doi:10.1002/mus.20410

Hostens, I., Ramon, H., 2005. Assessment of muscle fatigue in low level monotonous task performance during car driving. J. Electromyogr. Kinesiol. 15, 266–274. doi:10.1016/j.jelekin.2004.08.002

Hunter, S.K., 2016. The relevance of sex differences in performance fatigability. Med. Sci. Sports Exerc. 48, 2247–2256. doi:10.1249/MSS.0000000000000928

Hunter, S.K., Butler, J.E., Todd, G., Gandevia, S.C., Taylor, L., Gruet, M., Temesi, J., Rupp, T., Levy, P., Verges, S., Guillaume, Y., Gruet, M., Temesi, J., Rupp, T., Levy, P., Verges, S., Guillaume, Y., Keller-ross, M.L., Pereira, H.M., Pruse, J., Yoon, T., Schlinder-delap, B., Nielson, K.A., Hunter, S.K., Physiol, J.A., Hunter, S.K., Butler, J.E., Todd, G., Gandevia, S.C., Taylor, J.L., Sandra, K., Butler, J.E., Todd, G., Simon, C., Taylor, J.L., 2006. Supraspinal fatigue does not explain the sex difference in muscle fatigue of maximal contractions Supraspinal fatigue does not explain the sex difference in muscle fatigue of maximal contractions 1036–1044. doi:10.1152/japplphysiol.00103.2006

Hunter, S.K., Griffith, E.E., Schlachter, K.M., Kufahl, T.D., 2009. Sex differences in time to task failure and blood flow for an intermittent isometric fatiguing contraction. Muscle Nerve 39, 42–53. doi:10.1002/mus.21203

Januario, L.B., Madeleine, P., Cid, M.M., Samani, A., Oliveira, A.B., 2018. Can exposure variation be promoted in the shoulder girdle muscles by modifying work pace and inserting pauses during simulated assembly work? Appl. Ergon. 66, 151–160. doi:10.1016/j.apergo.2017.08.011

Januario, L.B., Oliveira, A.B., Cid, M.M., Madeleine, P., Samani, A., 2017. The coordination of shoulder girdle muscles during repetitive arm movements at either slow or fast pace among women with or without neck-shoulder pain. Hum. Mov. Sci. 55, 287–295. doi:10.1016/j.humov.2017.09.002

Jeong, J., Gore, J.C., Peterson, B.S., 2001. Mutual information analysis of the EEG in patients with Alzheimer's disease. Clin. Neurophysiol. 112, 827–35. doi:10.1016/S1388-2457(01)00513-2

Johansen, T.I., Samani, A., Antle, D.M., Côté, J.N., Madeleine, P., 2013. Gender effects on the coordination of subdivisions of the trapezius muscle during a repetitive box-folding task. Eur. J. Appl. Physiol. 113, 175–182. doi:10.1007/s00421-012-2425-6

Kawczyński, A., Samani, A., Mroczek, D., Chmura, P., Błach, W., Migasiewicz, J., Klich, S., Chmura, J., Madeleine, P., 2015. Functional connectivity between core and shoulder muscles increases during isometric endurance contractions in judo competitors. Eur. J. Appl. Physiol. 115, 1351–1358. doi:10.1007/s00421-015-3114-z

Latash, M.L., Scholz, J.P., Schöner, G., 2002. Motor control strategies revealed in the structure of motor variability. Exerc. Sport Sci. Rev. 30, 26–31.

Lomond, K. V., Côté, J.N., 2011. Differences in posture-movement changes induced by repetitive arm motion in healthy and shoulder-injured individuals. Clin. Biomech. (Bristol, Avon) 26, 123–9. doi:10.1016/j.clinbiomech.2010.09.012

Lomond, K. V., Côté, J.N., 2010. Movement timing and reach to reach variability during a repetitive reaching task in persons with chronic neck/shoulder pain and healthy subjects. Exp. brain Res. 206, 271–82. doi:10.1007/s00221-010-2405-1

Madeleine, P., 2010. On functional motor adaptations: From the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. Acta Physiol. 199, 1–46. doi:10.1111/j.1748-1716.2010.02145.x

Madeleine, P., Lundager, B., Voigt, M., Arendt-Nielsen, L., 2003. The effects of neck-shoulder pain development on sensory-motor interactions among female workers in the poultry and fish industries. A prospective study. Int. Arch. Occup. Environ. Health 76, 39–49. doi:10.1007/s00420-002-0375-8

Madeleine, P., Madeleine, P., Xie, Y., Szeto, G.P.Y., Samani, A., 2016. Effects of chronic neck-shoulder pain on normalized mutual information analysis of surface electromyography during functional tasks Clinical Neurophysiology Effects of chronic neck – shoulder pain on normalized mutual information analysis of surface electromyography during functional tasks. Clin. Neurophysiol. 127, 3110–3117. doi:10.1016/j.clinph.2016.06.015

Madeleine, P., Mathiassen, S.E., Arendt-Nielsen, L., 2008. Changes in the degree of motor variability associated with experimental and chronic neck-shoulder pain during a standardised repetitive arm movement. Exp. Brain Res. 185, 689–698. doi:10.1007/s00221-007-1199-2

Madeleine, P., Samani, A., Binderup, A.T., Stensdotter, A.K., 2011. Changes in the spatio-temporal organization of the trapezius muscle activity in response to eccentric contractions. Scand. J. Med. Sci. Sport. 21, 277–286. doi:10.1111/j.1600-0838.2009.01037.x

Martinez-Valdes, E., Negro, F., Falla, D., De Nunzio, A.M., Farina, D., 2018. Surface electromyographic amplitude does not identify differences in neural drive to synergistic muscles. J. Appl. Physiol. 124, 1071–1079. doi:10.1152/japplphysiol.01115.2017

Mathiassen, S.E., Winkel, J., Hägg, G.M., 1995. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies - A review. J. Electromyogr. Kinesiol. 5, 197–226. doi:10.1016/1050-6411(94)00014-X

Meyland, J., Heilskov-Hansen, T., Alkjær, T., Koblauch, H., Mikkelsen, S., Svendsen, S.W., Thomsen, J.F., Hansson, G.-Å., Simonsen, E.B., 2014. Sex differences in muscular load among house painters performing identical work tasks. Eur. J. Appl. Physiol. 114, 1901–1911. doi:10.1007/s00421-014-2918-6

Muceli, S., Falla, D., Farina, D., 2014. Reorganization of muscle synergies during multidirectional reaching in the horizontal plane with experimental muscle pain. J. Neurophysiol. 111, 1615–1630. doi:10.1152/jn.00147.2013

Nordander, C., Ohlsson, K., Balogh, I., Hansson, G.Å., Axmon, A., Persson, R., Skerfving, S., 2008. Gender differences in workers with identical repetitive industrial tasks: Exposure and musculoskeletal disorders. Int. Arch. Occup. Environ. Health 81, 939–947. doi:10.1007/s00420-007-0286-9

Nordander, H.C., 2003. Influence of the subcutaneous fat layer , as measured by ultrasound , skinfold calipers and BMI , on the EMG amplitude 514–519. doi:10.1007/s00421-003-0819-1

Ohlsson, K., Attewell, R., Skerfving, S., 1989. Self-reported symptoms in the neck and upper limbs of female assembly workers. Impact of length of employment, work pace, and selection. Scand. J. Work. Environ. Heal. 15, 75–80. doi:10.5271/sjweh.1879

Samani, A., Srinivasan, D., Mathiassen, S.E., Madeleine, P., 2016. Variability in spatio-temporal pattern of trapezius activity and coordination of hand-arm muscles during a sustained repetitive dynamic task. Exp. brain Res. doi:10.1007/s00221-016-4798-y

Senefeld, J., Yoon, T., Bement, M.H., Hunter, S.K., 2013. Fatigue and recovery from dynamic contractions in men and women differ for arm and leg muscles. Muscle Nerve 48, 436–439. doi:10.1002/mus.23836

Srinivasan, D., Mathiassen, S.E., 2012. Motor variability in occupational health and performance. Clin. Biomech. 27, 979–993. doi:10.1016/j.clinbiomech.2012.08.007

Srinivasan, D., Sinden, K.E., Mathiassen, S.E., Côté, J.N., 2016. Gender differences in fatigability and muscle activity responses to a short-cycle repetitive task. Eur. J. Appl. Physiol. 116, 2357–2365. doi:10.1007/s00421-016-3487-7

Steele, K.M., Tresch, M.C., Perreault, E.J., 2015. Consequences of biomechanically constrained tasks in the design and interpretation of synergy analyses. J. Neurophysiol. 113, 2102–2113. doi:10.1152/jn.00769.2013

Tenan, M.S., Hackney A.C., Griffin L., 2016. Entrainment of vastus medialis complex activity differs between genders. Muscle & nerve 53(4), 633-640.

Tenan, M.S., Peng, Y., Hackney, A.C., Griffin, L., 2013. Menstrual Cycle Mediates Vastus Medialis and Vastus Medialis Oblique Muscle Activity. doi:10.1249/MSS.0b013e318299a69d

Veiersted, K.B., Westgaard, R.H., Andersen, P., 1993. Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scand. J. Work. Environ. Heal. 19, 284–290. doi:10.5271/sjweh.1472

Vernillo, G., Temesi, J., Martin, M., Millet, G.Y., 2018. Mechanisms of Fatigue and

Recovery in Upper versus Lower Limbs in Men. Med. Sci. Sports Exerc. 50, 334–343. doi:10.1249/MSS.0000000000001445

Table 1. statistical analyses (F ratio, P value and effect size - η²) of the comparisons between *Time* (starting/ending task periods), *Group* (males/females) and interaction effects of *Time* and *Group* considering the absolute and normalized root mean square (RMS) values obtained during the simulated work task for all portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle, and

	Time			**Group**			**Time x Group**		
	F	**P**	**η²**	**F**	**P**	**η²**	**F**	**P**	**η²**
Absolute RMS (mV)									
CUT	3.29	0.08	0.08	1.00	0.32	0.03	<0.01	0.99	<0.01
AUT	2.29	0.14	0.06	0.02	0.89	<0.01	0.34	0.56	0.01
MT	0.13	0.72	<0.01	1.39	0.25	0.04	0.86	0.36	0.02
LT	11.23	**<0.01**	0.24	0.32	0.57	0.01	1.84	0.18	0.05
SA	26.71	**<0.01**	0.43	1.53	0.22	0.04	0.70	0.41	0.02
Normalized RMS (%MVC)									
CUT	3.24	0.08	0.08	3.42	0.07	0.09	0.15	0.70	<0.01
AUT	4.21	**0.05**	0.10	5.64	**0.02**	0.14	0.33	0.57	0.01
MT	0.06	0.80	<0.01	0.51	0.48	0.01	1.17	0.29	0.03
LT	10.30	**<0.01**	0.22	1.25	0.27	0.03	0.02	0.88	<0.01
SA	23.50	**<0.01**	0.39	6.69	**0.01**	0.16	0.12	0.73	<0.01

Table 2. Statistical analyses (F ratio, P value and effect size - η^2) of the comparisons between *Time* (starting/ending task periods), *Group* (males/females) and interaction effects of *Time* and *Group* considering the standard deviation and coefficient of variation of RMS values obtained during the simulated work task, considering the absolute electromyographic signal, for all portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle.

	Time			**Group**			**Time x Group**		
	F	**P**	**η^2**	**F**	**P**	**η^2**	**F**	**P**	**η^2**
Standard Deviation of RMS									
CUT	0.15	0.70	<0.01	0.02	0.90	<0.01	<0.01	0.99	<0.01
AUT	0.01	0.93	<0.01	0.09	0.77	<0.01	0.55	0.46	0.01
MT	15.36	**<0.01**	0.30	0.18	0.68	<0.01	0.30	0.59	0.01
LT	14.50	**<0.01**	0.29	0.14	0.71	<0.01	0.39	0.54	0.01
SA	13.04	**<0.01**	0.27	1.18	0.28	0.03	2.45	0.13	0.06
Coefficient of Variation of RMS									
CUT	<0.01	0.99	<0.01	1.06	0.31	0.03	0.05	0.83	<0.01
AUT	0.16	0.69	<0.01	0.21	0.65	0.01	0.34	0.56	0.01
MT	14.84	**<0.01**	0.29	1.25	0.27	0.03	0.07	0.79	<0.01
LT	20.56	**<0.01**	0.36	0.69	0.41	0.02	0.35	0.56	0.01
SA	17.24	**<0.01**	0.32	<0.01	0.95	<0.01	0.52	0.48	0.01

Table 3. Statistical analyses (F ratio, P value and effect size - η^2) of the comparisons between *Time* (pre/post-task periods), *Group* (males/females) and interaction effects of *Time* and *Group* considering the normalized mutual information (NMI) data, obtained during the simulated work task, for all muscle pairs considering the four portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle.

	Time			**Group**			**Time x Group**		
	F	**P**	**η^2**	**F**	**P**	**η^2**	**F**	**P**	**η^2**
CUT_AUT	26.54	**<0.01**	0.42	<0.01	0.95	<0.01	3.79	0.06	0.10
CUT_MT	31.79	**<0.01**	0.47	0.61	0.44	0.02	0.58	0.45	0.02
CUT_LT	21.02	**<0.01**	0.37	0.16	0.69	<0.01	1.60	0.21	0.04
CUT_SA	4.12	**0.05**	0.10	1.06	0.31	0.03	0.27	0.60	0.01
AUT_MT	15.52	**<0.01**	0.30	0.01	0.92	<0.01	0.02	0.89	<0.01
AUT_LT	3.32	0.08	0.08	0.04	0.84	<0.01	1.25	0.27	0.03
AUT_SA	2.93	0.10	0.08	1.27	0.27	0.03	1.29	0.26	0.03
MT_LT	13.09	**<0.01**	0.27	0.33	0.57	0.01	0.62	0.44	0.02
MT_SA	9.71	**<0.01**	0.21	0.09	0.76	<0.01	0.31	0.58	0.01
LT_SA	16.44	**<0.01**	0.31	0.78	0.38	0.02	0.01	0.94	<0.01

Figure 1. Volunteer's positioning during the sustained motor task (a); wooden board and recipients with pieces used for the sustained motor task (b).

Figure 2. Absolute (mV) and normalized (%MVC) signal of one male and one female obtained during the simulated work task for all portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT, and serratus anterior (SA) muscle.

Figure 3. Bar graphs showing mean and standard deviation of the absolute (mV) and normalized (%MVC) root mean square (RMS) values obtained during the simulated work task for all portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle at the starting and ending task periods.

Figure 4. Bar graphs showing mean and standard deviation of the standard deviation and coefficient of variation of RMS values obtained during the simulated work task, considering the absolute electromyographic signal, for all portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle at the starting and ending task periods.

Figure 5. Bar graphs showing mean and standard deviation of the normalized mutual information (NMI) data, obtained during the simulated work task, for all muscle pairs considering the four portions of the trapezius (clavicular upper trapezius – CUT, acromial upper trapezius – AUT, middle trapezius – MT, lower trapezius – LT), and serratus anterior (SA) muscle at the starting and ending task periods.

Figure 1.

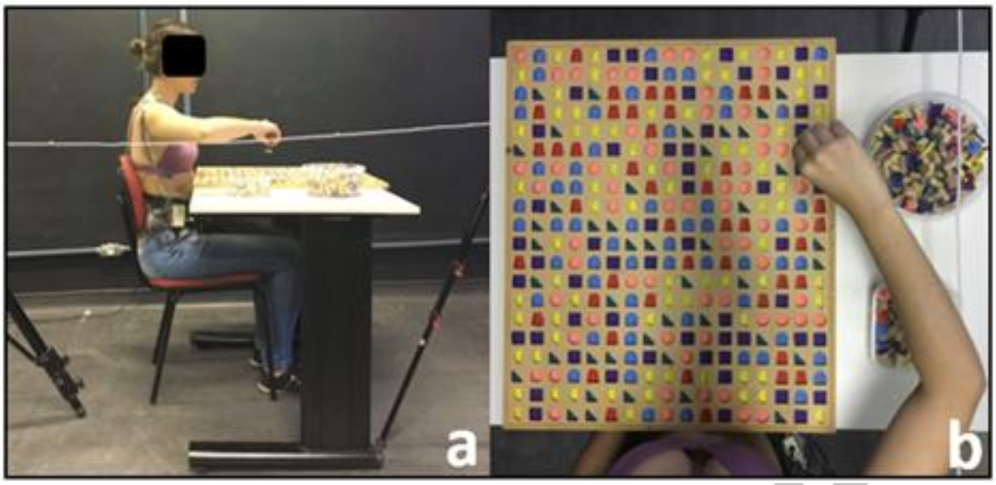


Figure 2.

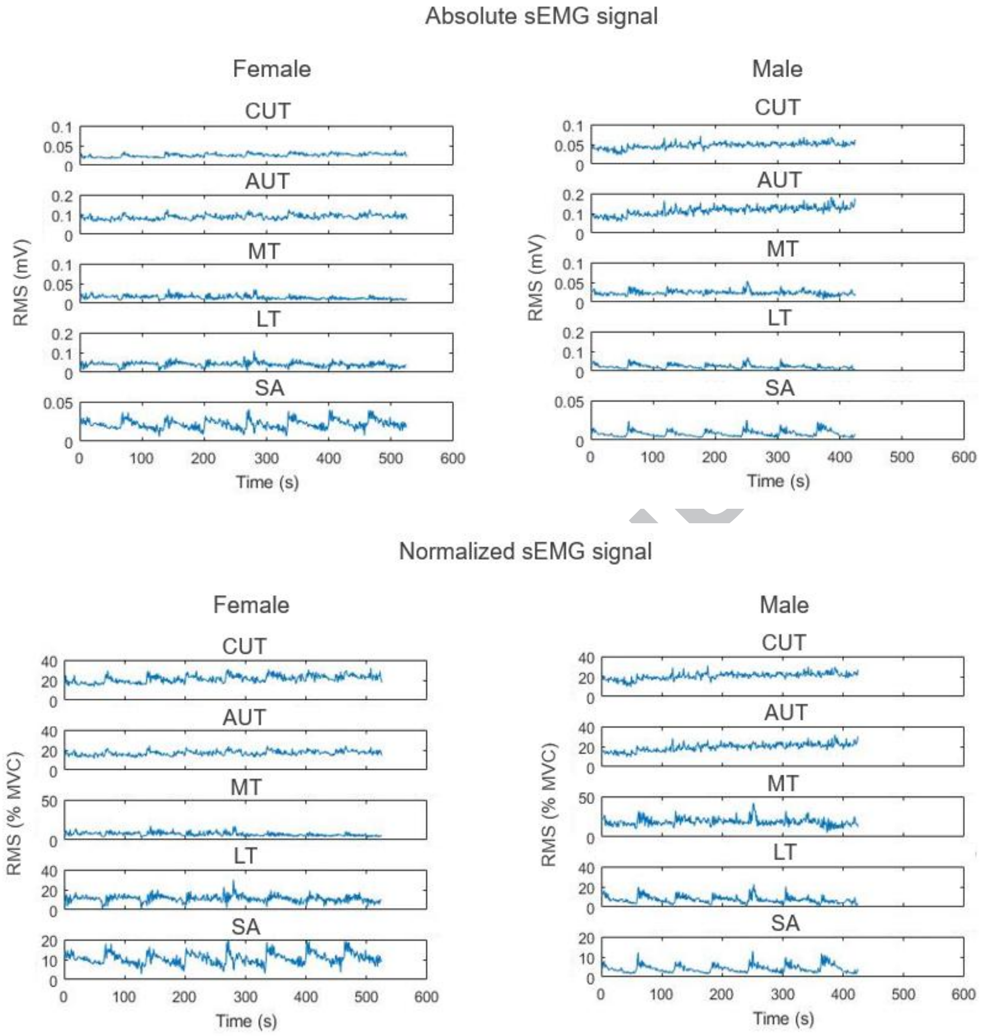

Absolute sEMG signal
Female
Male
CUT
AUT
MT
LT
SA
RMS (mV)
0.1
0.05
0.2
0
100
200
300
400
500
600
Time (s)
Normalized sEMG signal
RMS (% MVC)
40
20
50
10

Figure 3.

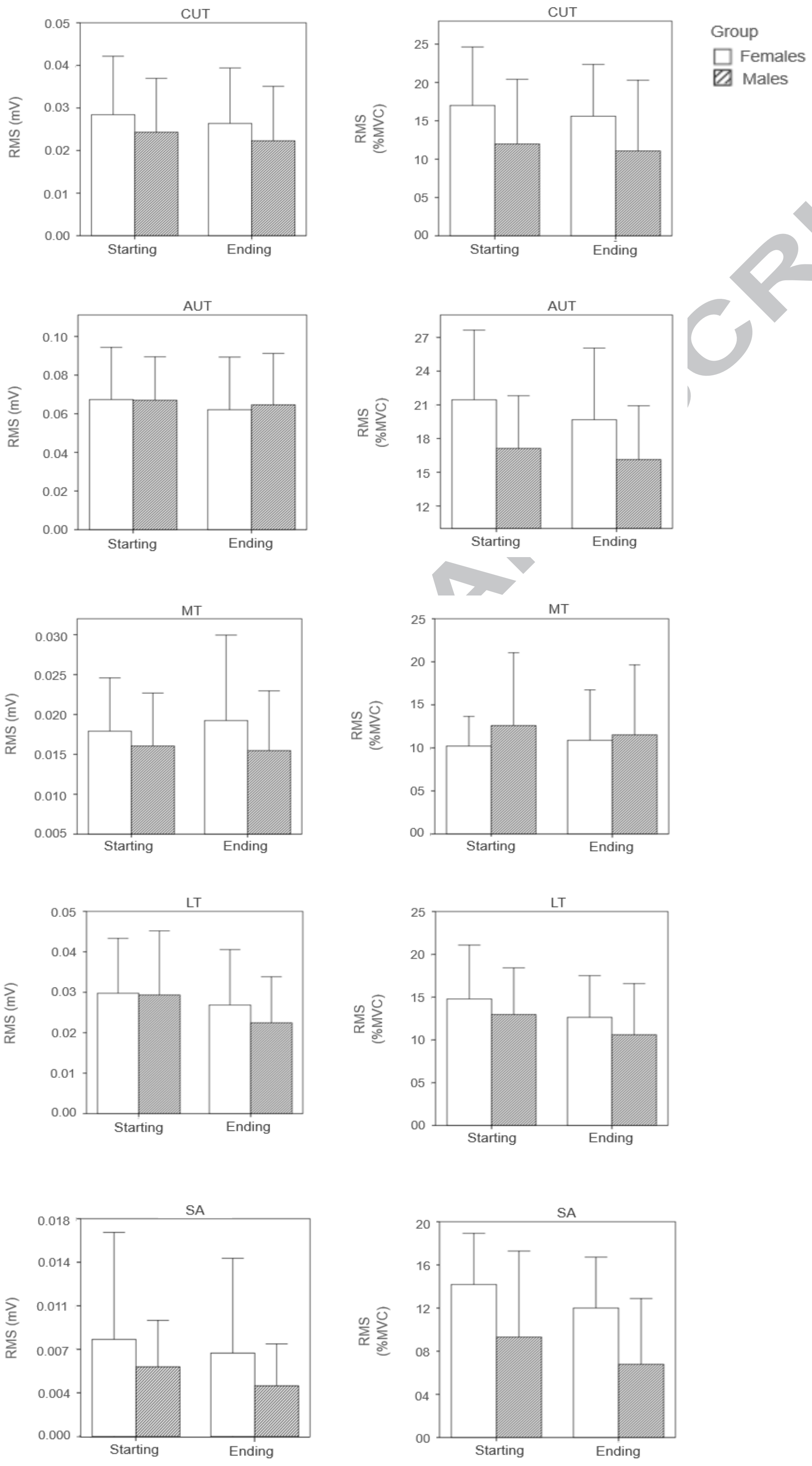

Group
▢ Females
▨ Males
CUT
RMS (mV)
0.05
0.04
0.03
0.02
0.01
0.00
RMS (%MVC)
25
20
15
10
05
00
AUT
0.10
0.08
0.06
0.04
0.02
0.00
27
24
21
18
15
12
MT
0.030
0.025
0.020
0.015
0.010
0.005
LT
SA
0.018
0.014
0.011
0.007
0.004
0.000
20
16
12
08
04
00
Starting
Ending

Figure 4.

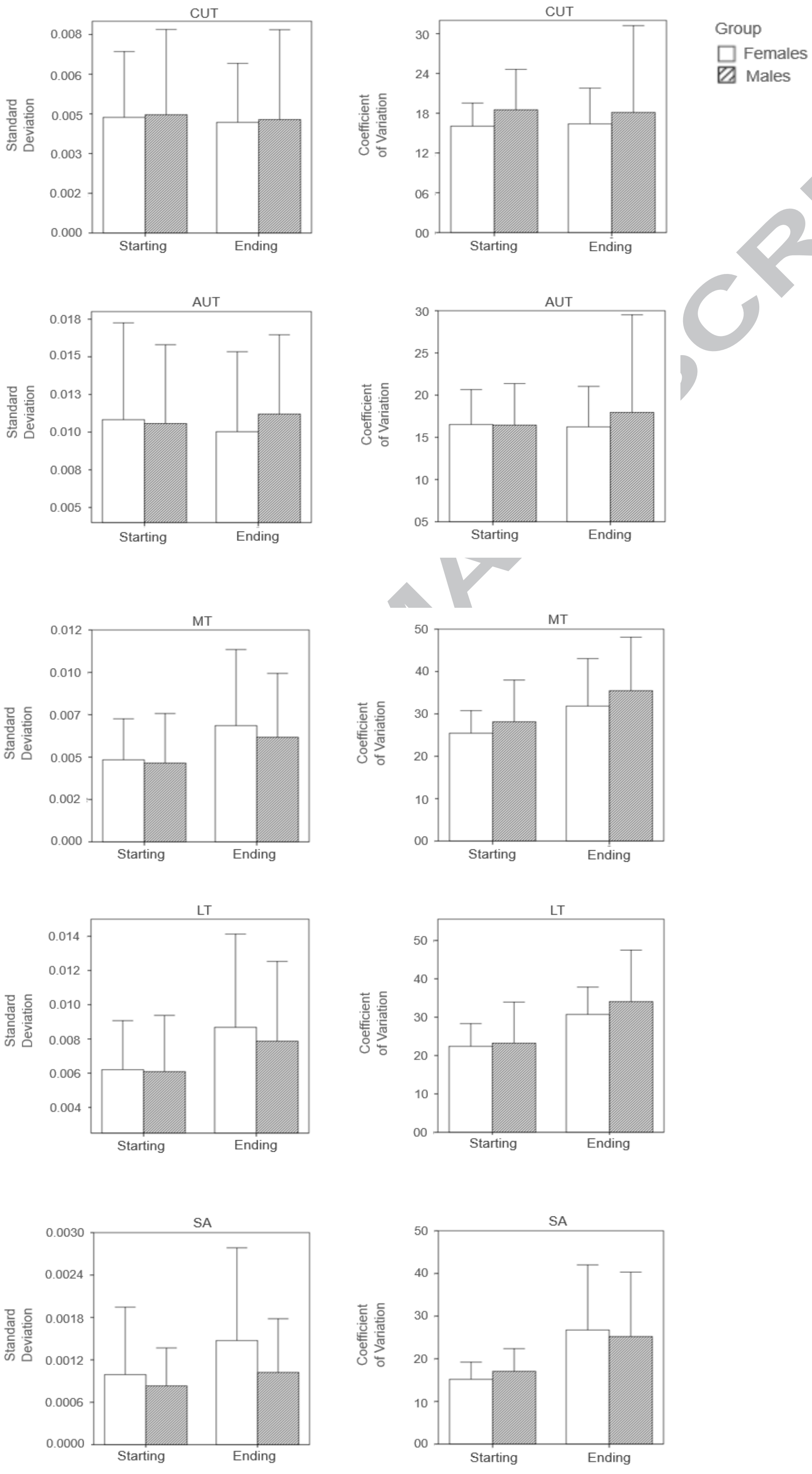
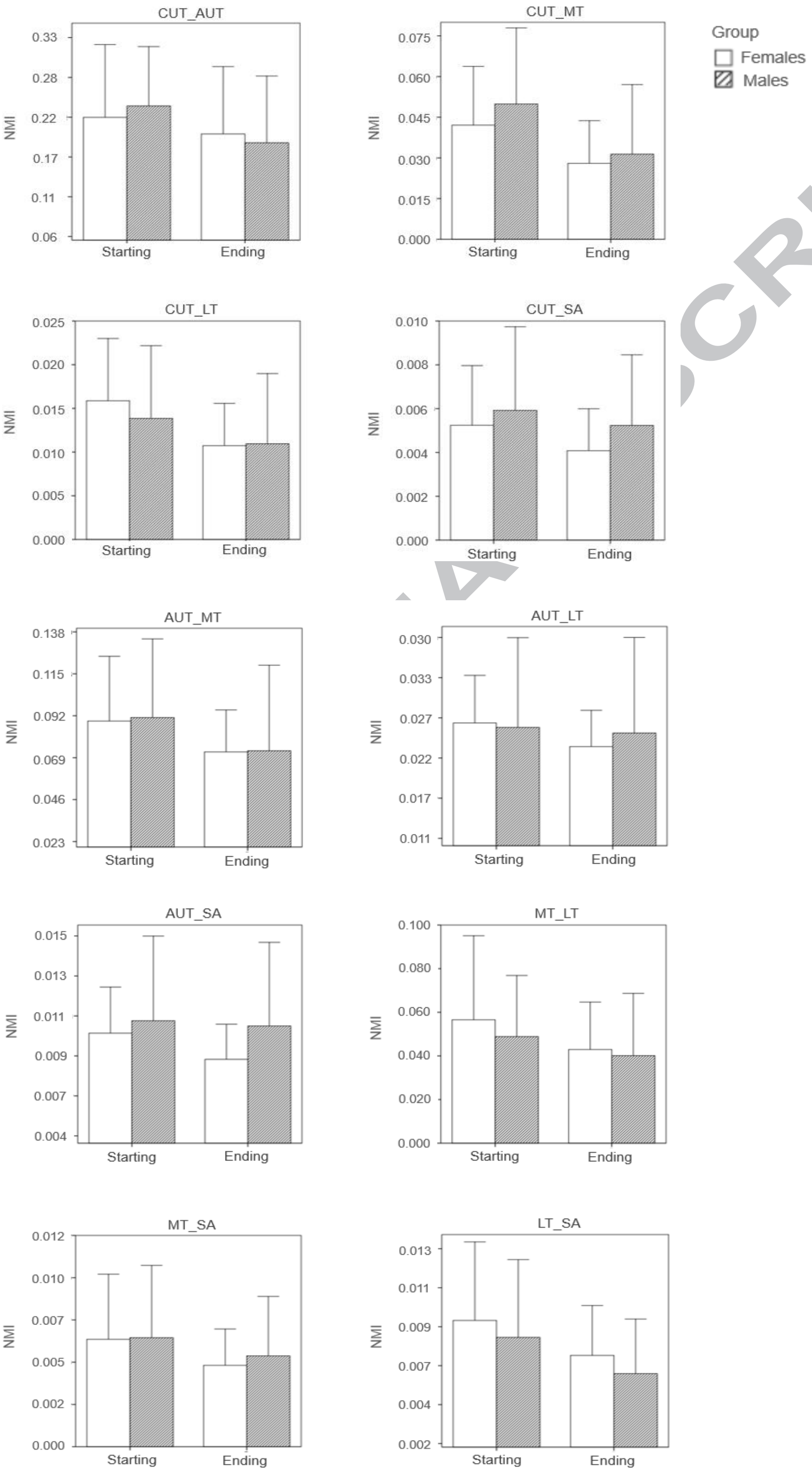

CUT
Standard Deviation
0.000
0.002
0.003
0.005
0.006
0.008
Coefficient of Variation
00
06
12
18
24
30
Group
☐ Females
▨ Males
AUT
0.005
0.008
0.010
0.013
0.015
0.018
05
10
15
20
25
30
MT
0.000
0.002
0.005
0.007
0.010
0.012
00
10
20
30
40
50
LT
0.004
0.006
0.008
0.010
0.012
0.014
00
10
20
30
40
50
SA
0.0000
0.0006
0.0012
0.0018
0.0024
0.0030
00
10
20
30
40
50
Starting
Ending

Figure 5.


Group
☐ Females
▨ Males
CUT_AUT
NMI
0.33
0.28
0.22
0.17
0.11
0.06
Starting
Ending
CUT_MT
NMI
0.075
0.060
0.045
0.030
0.015
0.000
Starting
Ending
CUT_LT
NMI
0.025
0.020
0.015
0.010
0.005
0.000
Starting
Ending
CUT_SA
NMI
0.010
0.008
0.006
0.004
0.002
0.000
Starting
Ending
AUT_MT
NMI
0.138
0.115
0.092
0.069
0.046
0.023
Starting
Ending
AUT_LT
NMI
0.030
0.033
0.027
0.022
0.017
0.011
Starting
Ending
AUT_SA
NMI
0.015
0.013
0.011
0.009
0.007
0.004
Starting
Ending
MT_LT
NMI
0.100
0.080
0.060
0.040
0.020
0.000
Starting
Ending
MT_SA
NMI
0.012
0.010
0.007
0.005
0.002
0.000
Starting
Ending
LT_SA
NMI
0.013
0.011
0.009
0.007
0.004
0.002
Starting
Ending