Gender differences in the muscular fatigue response and proprioception during a manual dexterity task at shoulder height

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CONTRIBUTION OF AUTHORS

Sunghoon Minn, the candidate, was responsible for the research, design, setup, recruitment, data collection, analysis, writing and any other steps related to the completion of the research study and submission of the thesis as per McGill University requirements.

Julie N. Côté, PhD, Associate Professor, Department of Kinesiology and Physical Education, McGill University, the candidate's supervisor, was actively involved in every step and decision made regarding the research study and the completion of this thesis.

Kim Emery, MSc, and Shaheen Ghayourmanesh, MSc, assisted in the training of the candidate and provided guidance during the data collection and analysis.

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ABSTRACT

Aim of this Master's study was to investigate gender differences in the response to a fatiguing task and to explore the potential link between the neck/shoulder region and the forearm while performing a manual dexterity (screwing) task at shoulder height. Purdue pegboard and shoulder joint position sense measurements were recorded both before and after the fatiguing task while electromyography (EMG) of eight muscle sites and screwing task performance were recorded during the fatiguing task. Results revealed no change in shoulder proprioception, and improvements in screws/min and in Purdue pegboard performance with time. However, No significant correlations were found between changes in Purdue pegboard scores and shoulder joint position sense errors from pre- to post-fatiguing task. Despite no gender differences in any of these measures, there were significant gender differences in EMG parameters, with females displaying overall higher amplitude and inter-muscle functional connectivity. Results can be interpreted as a possible explanation for why women experience more work-related musculoskeletal disorders compared to men.

RÉSUMÉ

Le but de cette étude de maîtrise était d'investiguer les différences entre les sexes en leurs réponses à une tâche fatigante, et d'explorer le lien potentiel entre la région du cou/épaule et l'avant-bras en performant une tâche de dextérité manuelle (vissage) à la hauteur de l'épaule. Les mesures au test Purdue pegboard et de proprioception de l'épaule ont été enregistrées avant et après la tâche fatigante, et l'électromyographie (EMG) de huit sites musculaires et la performance de vissage ont été enregistrées au cours de la tâche. Les résultats n'ont démontré aucun changement à la proprioception de l'épaule, ainsi qu'une amélioration avec le temps au taux de vissage par minute et à la performance au test Purdue. Cependant, aucune corrélation significative n'a été démontrée entre les changements aux résultats du test Purdue et les erreurs de proprioception avec le temps. Malgré le manque de différences à ces mesures entre les sexes, les femmes ont démontré différents patrons d'EMG, avec une plus grande amplitude et plus de connectivité intermusculaire. Les résultats peuvent offrir une explication potentielle pour les taux de troubles musculosquelettiques liés au travail plus élevés chez les femmes que chez les hommes.

TABLE OF CONTENTS

INTRODUCTION

Musculoskeletal disorders (MSDs) have become more prevalent throughout the past decade to a point where they can now be considered a global epidemic. Amongst different conditions that can trigger MSDs, occupational work takes a significant role. MSDs caused by occupational workload are often referred to as work-related musculoskeletal disorders (WMSDs). This term has been used in the last decades interchangeably with other terms such as occupational overuse syndrome, repetitive stress injury, and cumulative trauma disorders (Madeleine, 2010). According to Bongers, Ijmker, Heuvel, & Blatter (2006), prevalence of work-related neck and upper body MSD is a global concern, where it has been estimated that MSDs yearly costs 2.1 billion euro in Netherlands and $45 to $54 billion annually in the United States.

Manual dexterity is well documented as an important skill for daily tasks, including occupational tasks. Fine-motor tasks usually incorporate repetitive motions, which induce fatigue and contribute to risk of injury (Swaen, van Amelsvoot, Bültmann, & Kant, 2003). Prevalence of work-related complaints of neck, shoulder, and arm among computer office worker populations—representing a typical population with heavy reliance on manual dexterity tasks—was reported to be 56.9% over a year, where the most common region included the neck (36.7%) and the shoulder/arm regions (32.0%) (Ranasinghe et al., 2011). It has also been identified that workers in the manufacturing industries (another sector largely based on manual dexterity tasks) are at a great risk of developing work-related MSD (WMSD) (Zakaria, Robertson, MacDermid, Hartford, & Koval, 2002). In Québec, one in five workers experiences a non-traumatic MSD and a higher prevalence of WMSDs in manual occupations has been evident compared to other occupations (Vézina et al., 2011). However, statistical values of WMSD prevalence and occupational accidents may be underrepresented due to underreporting of the workers and healthcare providers (Zakaria et al., 2002).

According to the literature, it has been suggested that WMSDs in the neck and upper extremities are more prevalent in females than males. According to Hooftman, van der Beek, Bongers, & van Mechelen (2009) women are at a higher risk of developing neck-shoulder disorders while men are more exposed to lower back injuries. Additionally, in studies consisting of computer workers, higher prevalence of MSD was reported in women (Larsson, Søgaard, &

Rosendal, 2007; Juul, Søgaard, Stroyer, & Jensen, 2004). In fact, WMSDs in the neck and upper extremities are more regularly reported in females than males (Côté, 2012) such that in Quebec, significantly higher prevalence of MSDs are reported by females compared to males—25% by females and 16% by males (Vézina et al. 2011). Thus, the epidemiological literature does point to an important occupational health problem linked to WMSDs related to manual dexterity tasks, as well as potential sex differences therein. However, the exact mechanisms underlying this sex difference are poorly understood.

LITERATURE REVIEW

Fatigue

Fatigue has been well documented as a significant risk factor contributing to the development of occupational injuries (Sawen et al., 2003). Muscle fatigue is typically identified when there is a decrease in muscular performance, resulting in increased perceived task difficulty (Proske, 2005) and eventual inability to generate sufficient desired force (Enoka & Stuart, 1992). However, in the context of occupational work consisting of repetitive submaximal workload, fatigue is an on-going mechanism initiated with the onset of a sustained activity (Barry & Enoka, 2007). It is also widely accepted that various factors can influence the risk of developing a fatigue condition. It has been reported that development of fatigue is often influenced by changes in peripheral muscular properties or changes in the neural signaling and is dependent of the task performed, load type and limb posture (Barry & Enoka, 2007).

Various different pathways to detecting the presence of fatigue are readily available, such as through the usage of electromyography (EMG). Additional data that is commonly computed through the EMG signal to detect fatigue is known as root mean-square (RMS). RMS is defined as the mean power of the signal (Konrad, 2005). It has been regularly reported that EMG RMS amplitudes of the muscle significantly increase with the development of fatigue (Fedorowich, Emery, Gervasi, & Côté, 2013; Fuller, Fung, & Côté, 2011). Characteristics of EMG also display a general decrease in the frequency with the development of fatigue and a shift in the power spectrum towards lower frequency (Madeleine, Jørgensen, Søgaard, Arendt-Nielsen, & Sjøgaard, 2002).

Fatigue is also shown to have negative influences on the sensorimotor system function and acuity (Voight, Hardin, Blackburn, Tippett, & Canner, 1996; Carpenter, Blasier, & Pellizzon, 1998; Vafadar, Côté, & Archambault, 2016), where proprioception deficits in the shoulder joint can cause instability, ultimately leading to injuries. In a study of position reproduction acuity of overhead-throwing athletes, it had been documented that functional fatigue decreased joint position sense over multiple joints (Tripp, Boswell, Gansneder, & Shultz, 2004). In another study of repetitive low-intensity task, development of fatigue had decreased position sense acuity (Bjorklund et al. 2000). According to a repetitive arm motion-induced fatigue study by Emery and Côté (2012), fatigue had an effect on the proprioceptive ability of the subjects post-fatigue, where larger shoulder position errors were found. On the other hand, studies comparing the effects of fatigue on proprioceptive ability between males and females demonstrate conflicting results. According to Björklund, Crenshaw, Djupsjöbacka, & Johansson (2000), although influence of fatigue on position sense was similar for both genders, females demonstrated poorer overall acuity. Conversely, a new analysis of the original data reported no gender difference (Björklund, Crenshaw, Djupsjöbacka, & Johansson, 2003). Conclusively, Allen, Leung and Proske (2006) claimed that all forms of movement producing muscular fatigue should lead to position-matching errors and hence, confusion in the literature justifies for the need for more evidence.

An additional factor which can potentially be affected by fatigue is motor variability. While the human musculoskeletal system consists of multiple joints, it is not surprising that the human body is a mechanically redundant system. Such system allows an individual to perform any task with different variations of movements. Thus, motor variability is defined as the variation of movement outcomes over time (Latash, Scholz & Shoner, 2002). The concept of variability is often quantified as the Coefficient of Variability (CoV) measurement, representing the amount of deviation of values from the average. Such a concept in association to fatigue is significant, as the development of fatigue has been documented to alter movement variability in individuals. For instance, when fatigue was induced with a repetitive pointing task, subjects displayed changes in movement kinematics which can be depicted as task-specific movement strategies to prolong task performance (Fuller, Fung, & Côté, 2011). As indicated by Srinivasan and Mathiassen (2012), study of motor variability has the potential to allow prediction in the development of MSDs.

Although muscular responses of individual muscles alone are often sufficient enough to precisely identify the presence of fatigue, interactions between muscles are also an essential part of the underlying mechanism of fatigue, and might be indicative either of central fatigue per se, or of fatigue adaptation mechanisms. One particular statistical approach to study the relationship between EMG time series, that quantifies intermuscle sharing—also known as mutual information (MI)—can be defined as the quantity of functional connectivity that is dependent of or shared between two muscles, accounting for both linear and non-linear connections between

EMG time series (Jeong, Gore, & Peterson, 2001; Kojadinovic, 2005). Normalized mutual information (NMI) varies between a value of 0 to 1—0 indicating no functional connectivity and 1 indicating a full connectivity (Fedorowich, Emery, Gervasi, & Côté, 2013). For instance, in a study of the trapezius muscle, it was demonstrated that NMI increased with fatigue in the upper-middle and middle-lower subdivisions of the trapezius (Madeleine, Samani, Binderup, & Stensdotter, 2011). Collectively, the literature suggests that MI is highly associated with fatigue.

Sex Differences in the Fatigue Response

It is generally well known that there are physical differences between men and women, and these differences could affect men and women's likelihood of experiencing fatigue and WMSDs. One of the very discrete sex differences comes from the strength of the individuals. Men are generally stronger than women, with the largest differences in the upper body musculature. Moreover, it is also well known that women have a generally greater proportion of type 1 muscles, and that muscles containing higher portion of type 1 fibers have greater potential for oxidative phosphorylation (Gonzales & Scheuermann, 2007). Due to this difference in muscle composition, women are assumed to exhibit a greater fatigue resistance than men (Gonzales & Scheuermann, 2007). For example, in the vastus lateralis, higher proportions of more fatigable type II fibers have been found in men than women (Miller, MacDougall, Tarnopolsky, & Sale, 1993). The difference in fatigability between men and women has been documented by many researchers (Barry & Enoka. 2007; Hunter & Enoka, 2001; Hunter, Critchlow, Shin, & Enoka, 2004; Hunter, Butler, Todd, Gandevia, & Taylor, 2006).

There is no single mechanism responsible for sex differences in the fatiguing contraction performance (Hunter, 2009). For example, sex differences in fatigue response can be explained through differences in physiological mechanisms such as changes in peripheral muscular properties or changes in neural signalling and are often dependent of the task performed, load type and limb posture (Barry & Enoka, 2007). Other possible explanations include differences in muscle composition, difference in substrate utilization for ATP production and difference in neuromuscular activation including central motor drive (Hanjabam & Kailashiya, 2015).

Sex differences in strength seem to play an important role in the observed sex difference in fatigability. When men and women perform fatiguing contractions under normal conditions and are not strength-matched, there is a tendency for women to take longer time to task failure (Barry & Enoka. 2007, Hunter & Enoka, 2001, Hunter et al., 2004, Hunter et al., 2006). Hunter et al. (2004) suggest that there is an exponential relationship between strength of the individuals and time to task failure, for both sexes. The significance of lower absolute force in females could indicate lower muscle oxygen demand and less mechanical compression of the local vasculature (Hicks, Kent-Braun, & Ditor, 2001). Another study by Barry & Enoka (2007) supports that higher strength in men causes greater occlusion of blood flow and altered metabolic activity even when the task is performed at a similar relative intensity. Other possible reasons why strength is a significant predictor of a lower fatigue resistance in males is because of a more rapid accumulation of metabolites and impairment of oxygen delivery, ultimately leading to a higher rate of fatigue development (Hicks et al., 2001). Evidence by Hunter et al. (2004) suggests that when subjects are strength matched, time to task failure was similar in the elbow flexor muscles for a sustained submaximal contraction tasks. Additionally, a study by Gonzales & Scheuermann (2007) indicates that the time to task failure and the rate of fatigue development in the forearm muscle were similar between genders, even when the data was matched for strength. Such evidence demonstrates that sex difference in the development of fatigue cannot be explained by a simple investigation. It seems likely that stronger individuals have shorter endurance time (Hunter & Enoka, 2001). However, such a relationship is not definitive, as other physiological mechanisms responsible for such sex difference in the fatigue response have not been studied as much, and are therefore not as precisely understood. Also, there is evidence which contradicts such assumption.

Type of fatiguing task performed may also have an impact on the way that fatigue impacts function, and could possibly do so differently for men and women. In a study of isometric contraction of the elbow flexor muscles at 20% MVC force, it was discovered that women had significantly better endurance than men (Hunter & Enoka, 2001). However, when the sex difference was normalized to target force, it was found that there was no difference in the endurance time between women and men (Hunter & Enoka, 2001). During low-intensity contraction tasks of the knee extensor muscles, women had longer time to task failure (Maughn, Harmon, Leiper, Sale, & Delman, 1986). According to a study by (Fulco et al., 1999), even when subjects were matched for strength, it was reported that women had longer endurance time for adductor pollicis during an intermittent isometric contraction. Such previous studies support the assumption that females tend to be more fight resistant than males in general. In a study by Hanjabam & Kailashiya (2015) consisting of sprinting protocols, male hockey players were found to be more fatigable than female players. As indicated by Hunter (2009), contraction type and intensity are responsible for sex difference in the muscular fatigue difference in males and females. During lower relative contraction intensities, the sex difference in the fatigue response tends to be larger (Hunter, 2009). It has been reported that when contraction was to be maintained at 20% of maximum strength, women had longer time to task failure. It was also noted by Hicks et al. (2001) that females have advantage over males in fatigue protocols involving submaximal contractions.

On the contrary, when the contraction was to be sustained at 80% of maximum strength, time to task failure was similar between men and women (Hunter, 2009). Additionally, Hunter (2009) illustrates that sex difference is greater during voluntary intermittent contractions than sustained contractions because mechanisms responsible for the sex difference in fatigue response between sustained contraction tasks and voluntary intermittent contraction tasks are distinct. For instance, in an intermittent isometric contraction task at 50% of MVC with the elbow flexor muscles, women sustained the contraction longer with lower rate of decline in the MVC force (Enoka & Duchateau, 2008). Consequently, magnitude of females' fatigue resistance decreased as intensity of the contraction tasks increased and during 80% of MVC or maximal contraction tasks, sex difference was not found (Hicks et al., 2001). A possible explanation for such difference is that females and males undergo similar physiological changes during close to maximal contraction, such as blood occlusion in the working muscles (Hunter, 2009). Finally, Hunter (2009) also proposed that the muscular fatigue response is also dependent on the muscle group. Elbow flexor muscles at low- and high forces are the most commonly used group for determining a significant sex difference during fatiguing tasks (Hunter, 2009). Other muscles commonly tested to reveal a significant sex difference includes knee extensors, handgrip muscles and adductor pollicis muscle (Hick et al., 2001).

Sex difference in fatigability can also be approached through the EMG data analysis, providing more insight into the neuromuscular mechanisms underlying the fatigue response, and potential sex differences therein. According to a study by Hunter & Enoka (2001), during isometric contractions, women had lower rate of increase in the average EMG. In another study by Hunter et al. (2004), women displayed less average EMG of the elbow flexor muscles, expressed in % MVC, throughout the experiment. Barry & Enoka (2007) also reported that EMG activity increased more rapidly for men and they reached task failure sooner than did women. Increase in EMG amplitude had been well documented as being linked to an increased number of activated motor neurons and/or increased discharge rate of the motor neurons (Missenard, Mottet, & Perry, 2009; Hunter & Enoka, 2001). This increased activation of the muscle aims at compensating the contractile failure of muscle fibers to changes in its physiological properties (Missenard et al., 2009). Eventually both sexes will activated similar relative amounts of motor neuron pools in a fatiguing contraction task, but greater increase in average EMG for men demonstrates that more motor units are recruited at a faster rate to achieve or sustain the desired force (Hunter & Enoka, 2001), conclusively resulting in a higher rate of fatigue. However, how women were capable of sustaining the equal force for a comparable duration with lesser average EMG is not fully defined (Hunter et al., 2004). Anders, Bretschneider, Bernsdorf, Erler, & Schneider (2004) also noted that women utilize activation of synergist muscles with lesser activation of the agonist muscles during an isometric shoulder task to failure than men. Reliance on synergist muscles may be seen through the co-activation of muscles and such mechanism could explain alternative movement pathing in females to compensate for the fatigued agonist muscles in an attempt to endure the given fatiguing task.

Recent studies from our lab have investigated EMG patterns and the associated fatigue responses in men and women. As such, we recently investigated how EMG RMS, as well as EMG variability and MI could differ between men and women during a neck/shoulder fatigue protocol, also investigating whether different initial EMG patterns could predict endurance time of men vs women (Fedorowich et al., 2013). Results showed that initially low NMI was indicated to be a predictor of higher endurance in men. In addition, results of the correlations between pre-fatigue data and endurance time showed that variability is a significant predictor of endurance in women, whereas modulation of inter-muscle load sharing is a predictor of endurance in men (Fedorowich et al., 2013), suggesting differing fatigue adaptation pathways. With fatigue achieved by the same experimental task (repetitive pointing), men moved quicker whereas women moved slower (Emery & Côté, 2012), suggesting differences not only in the control of muscles but also of movement speed when facing fatigue in men vs women.

Taken together, literature on the fatigue response of men vs women shows that sex differences do exist. However, most of the previously cited studies investigated tasks mostly utilizing large muscle groups, in tasks requiring little dexterous control. Although the literature shows that the effects of fatigue vary depending on task, as we have previously suggested (Fuller, Lomond, Fung, & Côté, 2009), range of tasks previously studied does not encompass many fine-motor tasks, even though work-related tasks that fatigue the neck/shoulder very often involve such kinds manual dexterity component.

Dexterous work and associated sex differences

While the neck/shoulder is assumed to be one of the most predominant regions associated with WMSDs, the forearm is another region to be considered (Berglund, Persson, & Denison, 2008; Samani, Fernández-Carnero, Arendt-Nielsen, & Madeleine, 2011). Some studies have even speculated a shared injury mechanism between the two regions; however, mechanisms for such a relationship have yet to be clearly identified. In a study of forearm muscles during computer work by Samani et al., (2011), a decrease in muscle activity of wrist extensor was demonstrated following an acute experimental muscle pain triggered in the trapezius. During a computer task, Strøm, Knardahl, Stanghelle, & Røe (2009) has also observed a parallel increase in the forearm extensor EMG and the trapezius EMG. Such results suggest a connection between shoulder and forearm muscles. Therefore, an investigation of the forearm in association to the neck region would allow a better understanding of the nature of occupational work and development of WMSDs, especially in the contexts of tasks that both show a high prevalence of neck/shoulder symptoms and that involve dexterous upper limb distal (e.g.) movements. Indeed, dexterous work with a high precision context requires precise movements and control of distal muscles to accomplish the tasks successfully, as well as precise control of muscles of the neck/shoulder region in order to maintain a stable shoulder posture and stable visual platform. However, very few studies have investigated the coordination between neck/shoulder and forearm muscles, how fatigue may affect this coordination, and how men and women may deal with this dexterous work-related fatigue.

Reasons behind why the aforementioned s/g difference in the fatigue response exists are complicated and not yet fully defined. There are several assumptions and evidence in what produce such s/g difference. One of the theories in an attempt to explain the origin of such sex difference is Kimura's (2000) hunter-gatherer hypothesis. In his theory, it is assumed that the progression of sex difference in the motor performance is heavily influenced by the evolution. As given societal roles of men and women were strictly defined throughout the history, gender-specific motor and cognitive skills became distinct, where it is claimed that females became more proficient at fine-motor skill tasks (Kimura, 2000). The fact that the muscles responsible to control manual dexterity usually contain more type 1 (fatigue-resistant fibers), and that in general, women have a higher proportion of those type 1 fibers, suggest that they should display better fatigue resistance than men during a manual dexterity task. However, this has never been tested in experimental studies.

Different tests are available to study the actual performance difference in manual dexterity: Annett pegboard task, O'Connor tweezer dexterity task, Grooved pegboard task, Finger-tapping task, and Kimura-type sequencing task (Kimura, 1977; Peters & Durding, 1979; Annett, 1992). However, there is a disagreement amongst studies on whether females really outperform males in fine-motor skill tasks (Peters & Campagnaro, 1996). According to a normative study of a Box and Block test, it had been reported that females scored better than males (Mathiowetz, Volland, Kashman, & Weber, 1985). In another normative study by Grice et al. (2003), average women had better performance on the nine-hole peg test compared to men. In fact, the standard deviation score for female subjects was lower than that of men, illustrating that the score amongst female participants had lower variability (Grice et al., 2003). However, according to Peters and Campagnaro (1996), men were faster on the Annett pegboard task, finger-tapping task, and Kimura-type sequencing task. A possible explanation for such contradictions has been studied by Peters, Servos & Day (1990), where it was reported that when an index of finger and thumb size is used as a covariate of pegboard test, the sex difference was not present. It had been noted that with thicker pegs that are more easily grasped, men had a speed advantage over women (Kilshawt & Annett, 1983). In a study of computer-point task by Rohr (2006), no sex difference was found in the performance unless subjects were pressured to be fast and accurate. The study further revealed that men spent less time in deceleration and had more movement errors compared to women, who compensated movement deceleration time to maintain consistent accuracy (Rhor, 2006). In general, this study discovered that movement pathing is different between genders where men sacrificed movement accuracy to enhance their movement speed while women focused on movement accuracy at a cost of performance speed. In a study of position sense error by Vafadar, Côté, & Archambault (2015), it was demonstrated that men tends to both overestimate and underestimate the their position sense—indicating higher variability in performance—whereas women mostly overestimate their position sense—displaying a higher accuracy in movement. Thus, such relationship between fine-motor performance and gender is a complicated one and causal information cannot be specified by a single variable. Further testing is required to determine a more conclusive sex difference in manual dexterity and whether fine-motor skill is affected by fatigue or not.

Summary

In summary, the evidence provided by previous literatures highlights what we know and what we don't know regarding sex differences in the fatigue development. It appears likely that stronger individuals are more fatigable and that females are generally more fatigue resistant than men, especially during isometric contractions. We also know that men and women may incorporate different movement strategies to compensate for the effect of fatigue. However, the aforementioned research studies do conflict in some senses and hence, further testing is required to draw more conclusive agreements.

Above all, most studies have been performed using gross motor tasks involving large muscle masses and little is known about the sex differences in the fatigue response associated with fine motor tasks. This is important, since such fine motor tasks are more often performed by women in the workplace, and this could be part of the explanation for why women report more work-related MSDs, although in the absence of empirical data, this is pure speculation. This study will be one of the first to investigate the sex differences in fatigue response while incorporating a manual dexterity task in an attempt to discover how males and females responds to fatigue induced by a fine-motor task, especially in the neck/shoulder region and how fatigue will affect their performance therein.

RESEARCH ARTICLE

Gender differences in the muscular fatigue response and proprioception during a manual dexterity task at shoulder height

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ABSTRACT

The objective of this study was to investigate the gender differences in muscular fatigue response while performing a manual dexterity task at shoulder height, and to assess if performing a neck/shoulder fatiguing task would affect fine-motor performance in healthy young adult males and females. Twenty-nine volunteers (15 men, 14 women) performed a manual dexterity task involving screwing and unscrewing bolts at shoulder height until scoring 8 on a Borg CR-10 scale. Electromyography (EMG) was recorded at eight muscle sites. Root Mean Square (RMS), variability and normalized mutual information (NMI) were computed. Purdue pegboard and joint position sense were measured both before and after the fatiguing task and screwing task performance (bolts/min) was recorded during the fatiguing task. Shoulder proprioception was not affected by the fatiguing task, and, surprisingly, screwing and Purdue pegboard performance actually improved ($p < 0.001$). Gender differences were evident in RMS and NMI measures, with females displaying overall higher RMS and NMI values; for instance, UT RMS was 80% higher and AD RMS was 42% higher in females. Although task performance and proprioception did not change, gender differences in EMG measures may help understand the sex-specific muscle fatigue mechanisms and help explain the higher rates of neck/shoulder injuries in women.

1. Introduction

Manual dexterity is well documented as an important skill for daily tasks, including occupational tasks. Fine-motor tasks usually incorporate repetitive motions, which induce fatigue and contribute to risk of injury (Swaen, van Amelsvoot, Bültmann, & Kant, 2003). While the risk of developing work-related musculoskeletal disorders (WMSDs) is common amongst various occupations, it is not surprising that workers largely reliant on manual dexterity tasks, such as manufacturing industries, are at a great risk of developing WMSD (Zakaria, Robertson, MacDermid, Hartford, & Koval, 2002). The prevalence of work-related complaints of neck, shoulder, and arm among computer office worker populations—representing a typical population with heavy reliance on manual dexterity tasks—was reported to be 56.9% over a year, where the most common region included the neck (36.7%) and the shoulder/arm regions (32.0%) (Ranasinghe et al., 2011).

Fatigue is a well-known factor leading to the development of WMSDs, and it is well documented as a risk factor contributing to the development of occupational injuries (Sawen et al., 2003). Muscle fatigue is typically identified when there is a decrease in performance, resulting in increased perceived task difficulty (Proske, 2005) and eventual inability to generate sufficient desired force (Enoka & Stuart, 1992). It has been reported that the development of fatigue is often influenced by changes in peripheral muscular properties or changes in the neural signaling and is dependent of the task performed, load type and limb posture (Barry & Enoka, 2007). It has been regularly reported that EMG RMS, defined as the mean power of the signal (Konrad, 2005), significantly increases with the development of fatigue (Fedorowich, Emery, Gervasi, & Côté, 2013; Fuller, Fung, & Côté, 2011).

Motor variability, defined as the variation of movement outcomes over time (Latash, Scholz & Shoner, 2002), is another pathway linked to presence of fatigue. It is often quantified as the Coefficient of Variability (CoV) measurement, representing the amount of deviation of values from the average. Such a concept in association to fatigue is significant, as the development of fatigue has been documented to alter movement variability in individuals. For instance, when fatigue was induced with a repetitive pointing task, subjects displayed changes in movement kinematics which can be depicted as task-specific movement strategies to prolong task performance (Fuller, Fung, & Côté, 2011). As indicated by Srinivasan and Mathiassen

(2012), the study of motor variability has the potential to allow prediction in the development of MSDs.

Although muscular responses of individual muscles alone are often sufficient enough to precisely identify the presence of fatigue, the interactions between muscles are also an essential part of the underlying mechanism of fatigue, and might be indicative either of central fatigue per se, or of fatigue adaptation mechanisms. One particular statistical approach to study the relationship between EMG time series, that quantifies intermuscle sharing—also known as mutual information (MI)—can be defined as the quantity of functional connectivity that is dependent of or shared between two muscles, accounting for both linear and non-linear connections between EMG time series (Jeong, Gore, & Peterson, 2001; Kojadinovic, 2005). Normalized mutual information (NMI) varies between a value of 0 to 1—0 indicating no functional connectivity and 1 indicating a full connectivity (Fedorowich et al., 2013). For instance, in a study of the trapezius muscle, it was demonstrated that NMI increased with fatigue in the upper-middle and middle-lower subdivisions of the trapezius (Madeleine, Samani, Binderup, & Stensdotter, 2011). Collectively, the literature suggests that MI is highly associated with fatigue.

The previous literature points to gender differences in the prevalence of WMSDs, where WMSDs in the neck and upper extremities are more regularly reported in females than males (J. N. Côté, 2012). In studies consisting of computer workers, higher prevalence of MSD was reported in women (Larsson, Søgaard, & Rosendal, 2007; Juul, Søgaard, Stroyer, & Jensen, 2004). According to Hooftman, van der Beek, Bongers, & van Mechelen (2009), women are at a higher risk of developing neck-shoulder disorders while men are more exposed to lower back injuries. Moreover, it has been regularly reported that men are more fatigable then women (Hicks et al., 2001). Barry and Enoka (2007) reported that EMG activity increased more rapidly for men and they reached task failure sooner than did women. Such increased activation of the muscle aims at compensating the contractile failure of muscle fibers to changes in its physiological properties (Missenard et al., 2009). Additionally, Anders, Bretschneider, Bernsdorf, Erler, & Schneider (2004) also noted that women utilize activation of synergist muscles with lesser activation of the agonist muscles during an isometric shoulder task to failure than men. In a study of box-folding task by Johansen et al. (2012), higher NMI was observed in the upper-middle and upper-lower trapezius in women compared to men. Reliance on synergist muscles may be seen through the co-activation of muscles and such mechanism could explain alternative movement pathing in females to compensate for the fatigued agonist muscles in an attempt to endure the given fatiguing task.

While the neck/shoulder is assumed to be one of the most predominant regions associated with WMSDs, the forearm is another region to be considered (Berglund, Persson, & Denison, 2008; Samani, Fernández-Carnero, Arendt-Nielsen, & Madeleine, 2011).). Some studies have even speculated a shared injury mechanism between the two regions; however, the mechanisms for such a relationship have yet to be clearly identified. In a study of forearm muscles during computer work by Samani et al., (2011), a decrease in muscle activity of wrist extensor was demonstrated following an acute experimental muscle pain triggered in the trapezius. During a computer task, Strøm, Knardahl, Stanghelle, & Røe (2009) has also observed a parallel increase in the forearm extensor EMG and the trapezius EMG. Such results suggest a connection between shoulder and forearm muscles. Indeed, dexterous work with a high precision context requires precise movements and control of distal muscles to accomplish the tasks successfully, as well as precise control of muscles of the neck/shoulder region in order to maintain a stable shoulder posture and stable visual platform. However, very few studies have investigated the coordination between neck/shoulder and forearm muscles, how fatigue may affect this coordination, and how men and women may deal with this dexterous work-related fatigue.

In summary, the epidemiological literature does point to an important occupational health problem linked to WMSDs related to manual dexterity tasks, as well as potential sex differences therein. However, the exact mechanisms underlying this sex difference are poorly understood. Furthermore, most of the previously cited studies investigated tasks mostly utilizing large muscle groups, in tasks requiring little dexterous control. Although the literature shows that the effects of fatigue vary depending on task, as we have previously suggested (Fuller, Lomond, Fung, & Côté, 2009), the range of tasks previously studied does not encompass many fine-motor tasks, even though work-related tasks that fatigue the neck/shoulder very often involve such kinds manual dexterity component.

2. Methods

2.1 Participants

Using convenience-sampling, healthy young adults were recruited through institutional networks, personal contacts and advertisements. Volunteers were excluded if they had a history of or current musculoskeletal, or neurological disorders that would significantly affect the outcome of the experiment. Subjects who had significant exposure to manual dexterity tasks through their occupation or daily activities were also excluded. For example, subjects were asked on the type of occupation and daily activities such as playing instruments or certain sports, and the amount of hours spent daily on such task to ensure that they were not exposed to excessive fine-motor task on daily basis. All volunteers were right-hand dominant, aged between 20 and 40 years old, and generally healthy as determined by Par-Q Health Questionnaire. Final sample consisted of 29 healthy young adults (15 males (age: 22.8 (SD 1.8) years, height: 178.9 (SD 4.0) cm, weight: 76.2 (SD 10) kg) and 14 females (age: 23.4 (SD 2.7) years, height: 169.0 (SD 6.0) cm, weight: 57.0 (SD 11) kg)). Study took place at Occupational Biomechanics and Ergonomics Laboratory (OBEL) of the Jewish Rehabilitation Hospital in Laval, Quebec. Prior to participating in the study, all subjects provided informed consent using a form approved by the Research Ethics Board of the Center for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal.

2.2 Data Acquisition

For electromyography (EMG) collection, bipolar Ag/AgCl surface electrodes were used (TeleMyo, Noraxon, USA, 10-350 Hz operating bandwidth). Electrodes were placed over 8 muscle sites: right upper trapezius (UT: midpoint between the acromion and C7 spinous process), right middle trapezius (MT: midpoint between the medial border of scapula and spine at level of T3), right lower trapezius (LT: approximately 2/3 on the line from the trigonum spinea to T8), right anterior deltoid (AD: below the lateral end of the clavicle), right bicep brachii (BIC: approximately 1/3 of the distance between fossa cubit and medial acromion), right long head of the triceps (TRI: midpoint and 2 cm medial between the posterior crista of acromion and olecranon), right extensor carpi ulnarius (EXT: a finger width above 1/3 of the distance between olecranon process and styloid process of the ulna), and right flexor carpi radialis (FLEX: ½ of the distance between the lateral point of bicep tendon and pisiform bone). A small area of approximately 3 cm at each muscle site was shaved and cleaned with alcohol to remove any hair and dead skin that may interfere with conductivity. Electrodes were placed in a consistent manner—3 centimeter distance between the centers, parallel to the direction of the muscle fibers and directly over the muscle belly—over each of the muscle sites (Basmajian & Blumenstein, 1980; Hermens et al., 1999).

Seven high-resolution cameras were used to record kinematics during the joint position sense task, through the Vicon MX3 motion-capture system (VICON Peak, Oxford Metrics ltd., Oxford, UK), operating at a sampling frequency of 100 Hz. A total of ten passive light reflective markers were fixed to the skin using double-sided adhesive tape on the following anatomical landmarks: both anterior and posterior sides of the left and right sides of the forehead, spinous process of C7, left and right acromioclavicular joints, right lateral epicondyle and right medial and lateral wrist.

Volunteers performed maximum voluntary isometric contractions (MVICs) against a manual or isometric resistance using a stationary machine (BTE Simulator II™ (Sim-II), BTE Technologies©, Baltimore, MD, USA, serial number: 1113ST). Kendall's (1993) and Konrad's (2005) methods were used to measure MVICs and trials were recorded to be used as baseline reference measurements for EMG analysis. Subjects were instructed to sit in a chair while having their upper body fixed against the back rest with a Velcro™ strap. Two MVIC trials were recorded for each of the 8 muscle sites. For UT trials, subjects were to perform a unilateral shoulder elevation with arms hanging on the sides. For MT trials, shoulders were horizontally abducted with arms fixated straight throughout the downward scapula movement against the stationary resistance. For LT trials, scapular was adducted and depressed with shoulder flexed at 90° on the stationary resistance. For AD trials, subjects were to perform upward shoulder flexion at 90 ° against a stationary resistance. For BIC trials, bicep curl with elbow flexion at 90 ° against the stationary resistance was performed. For TRI trials, subjects were to extend their elbow against the stationary resistance at 90 °. For EXT and FLEX trials, wrist extension and flexion was performed against a stationary resistance at elbow flexion of 90° by the side of the trunk.

Standard administration process of Purdue Pegboard Test User Instructions by Lafayette Instrument (2002) was used to measure Purdue Pegboard performance (Lafayette Instrument, model 32020), where the test was directed in consecutive order for right-handed subjects. Test trials were repeated three times for each subject. Subjects were instructed to sit at fixed distance from the table 76.2 cm in height. Thorough instructions were provided with 30 seconds rest between each trial and subjects were provided with opportunities to practice before the actual test began. Key task to this study was the Right Hand task where subjects were to pick up pins one at a time from the right-handed cup and placing them into the holes starting from the top hole, as fast as possible and accurately as possible. For instance, if a subject dropped a pin or failed to fully place it in the hole, they were instructed to grab another pin to continue the task.

For joint position sense (JPS) testing, three trials—for each no-fatigue (NF) and fatigue state (FS)—were taken at the shoulder-flexion angle of 90±10 degrees. Subjects were instructed to stand still with their eyes closed while holding a cylindrical touch-sensitive target on their left hand. With a verbal cue, subjects were instructed to slowly raise their right arm while keeping their elbow fully extended and wrist in a neutral position. Once subjects reached the aforementioned pre-determined range, they were verbally instructed to stop, hold the position touch the touch-sensitive target, and bring back their arm to the starting position. Then subjects were asked to immediately reproduce the same movement and stop at the previous position as they remember, without the verbal cue of the experimenter. Five seconds of rest were provided between the trials.

A manual dexterity task at shoulder height was used to induce shoulder fatigue. The workstation consisted of a vertical board with two rows of screws, which was adjusted to each subject's specific anthropometrics (shoulder height of the subjects at a distance of full arm extension). All subjects used only middle 6 bolts of the workstation. The fatiguing task consisted of fastening bolts into the first row from the second row and unfastening bolts from the first row to the second row. Subjects were to screw each nut for a depth of 2 cm—width of the nut. A Styrofoam barrier was placed to prevent the nuts from going beyond the 2cm depth. Figure 1a displays the basic set-up of the workstation. Instructions provided to subjects regarding performance objectives were to "firstly unscrew the nut from the bolt, align the nut to the bolt of the second row, and screw each nut into the bolt until encountering resistance, and move as quickly as possible to the next one". No additional instructions were provided regarding the components of the posture except trying to keep their arm as straight while keeping their back straight. Figure 1b demonstrates the typical starting position of the task with the view of marker sets. Subjects were to report their self-perceived neck/shoulder exertion at the end of each minute using Borg CR-10 scale (Borg, 1982). This sequence was repeated until the subject met the stoppage criteria: reporting a score of 8 or higher on the modified Borg CR-10 scale; performing over 30 minutes. Once subjects met the stoppage criteria, EMG data was collected for 30 seconds and the subjects were asked to stop. Time to fatigue was measured in minutes and seconds through how long each subjects can perform the fatiguing task until termination. Immediately following the fatiguing task, subjects were instructed to complete 3 trials of JPS task, followed by 3 trials of Purdue pegboard test.

Fig. 1a Image of the basic workstation set-up for the experiment.

Fig. 1b Illustration of the start-up position of the fatiguing task

2.3 Data analysis.

For the purpose of data collection, the fatiguing protocol was split into cycles of 1 minute, where EMG data was collected during the last 30 seconds of each cycle. The first block of 30 seconds recorded was considered as no-fatigue (NF) and the final 30 seconds recorded after reaching the stoppage criteria was considered as fatigue state (FS). Recorded EMG data were filtered (Butterworth band-pass, 20-500Hz) and heartbeats were removed by identifying a reference heartbeat and cross-correlating it to other signals. The EMG signals were then full-wave rectified. The root mean square (RMS) values were calculated and then smoothed using the moving average technique with a 100 ms window. These values were then normalized to the filtered MVIC values, which were also filtered with heartbeats removed and rectified. The statistics for EMG data analysis were then calculated over each 30 seconds of recording. Additionally, motor variability was analyzed by the use of Coefficient of Variation (CoV), where the mean of 30 second RMS values were divided by the standard deviation, for each EMG series to evaluate the variability of each muscle activation patterns. Furthermore, normalized mutual information (NMI) data were calculated between pairs of EMG series over 30 second lengths to determine the levels of shared activation between muscle pairs (Johansen, Samani, Antle, & Côté, 2013). Using this technique, a value of 0 meant no connectivity, and a value of 1 meant complete connectivity between the two time series. All EMG data were computed using MatLab software (Mathworks, Massachusetts, USA).

Shoulder flexion angles for JPS data were computed using MatLab software. The instantaneous Shoulder Flexion angle was calculated by projecting the right arm vector (built by connecting the markers RSHO and RELB) into the Sagittal Plane. The sagittal plane was built by first creating the CLAVICLES vector (attaching RSHO to LSHO markers), then passing a plane perpendicular to this vector (i.e. CLAVICLES) and containing the C7 point. Position of the right lateral epicondyle marker (RELB) used for calculations of the angular differences were quantified at the time identified by the cylindrical touch-sensitive target. Hence, final outcome measurement of the task was the angular difference between the non-fatigue state and the fatigue state. Moreover, three trials—for both NF trials and FS trials—were averaged to calculate the overall absolute angular difference of each subject in degrees. Figure 1c displays a basic stick figure example of JPS task.

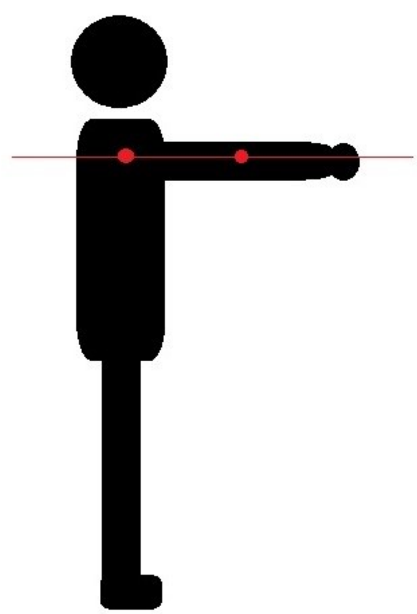

Fig. 1c JPS task illustrating the right arm vector created by markers RSHO and RELB.

For performance analysis, number of bolts screwed in for the first block of 30 seconds recorded and the last block of 30 seconds were used. Pegboard scores used for analysis were scores of right-hand task. Three trials—for both NF trials and FS trials—were first averaged then the differences in the values pre-fatigue and post-fatigue were calculated.

2.4 Statistical analysis.

Repeated measure ANOVA was used to analyze the effect of time and gender on fatiguing task performance, EMG characteristics—RMS, NMI, and CoV, JPS, and Purdue Pegboard scores. Time was set as a within-subject factor with 2 levels (NF, FS) and Gender as a covariate (male, female). To this aim, general linear model (GLM) Repeated Measures of SPSS software was used, modeling Time as the within-subject factor, Gender as covariate and interaction of Time x Gender as part of the model. An independent T-test was conducted on time-to-fatigue data to determine the difference between men and women's time to fatigue. To determine the relationship between shoulder proprioception and manual dexterity, Spearman Correlation Coefficients were computed for the difference between the JPS errors and the Purdue Pegboard scores, for both genders separately and together. Significance was set as $p < 0.05$ for all analyses and SPSS statistical software was used to compute all analysis.

3. Results

3.1 Fatigability.

All subjects performed the fatiguing task until participants reached a self-perceived exertion Borg score of 8 or higher. Male subjects performed the fatiguing task for an average of 4.01±1.63 minutes and female subjects for an average of 4.81±2.62 minutes. There were no gender effects on time to fatigue (t (26) = 0.986, p=0.333).

3.2 Performance and proprioception.

Average performance scores for the Screwing Task of male subjects for the first minute of the fatiguing task was 2.07±0.59 bolts per minute and for the last minute 3.8±1.15 bolts per minute. Average scores of female subjects for the first minute were 2.27±0.6 bolts per minute and for the last minute 3.85±1.14 bolts per minute. Statistical analysis revealed a significant Time effect for the Screwing Task performance [$F(1,26) = 51.063$, $p < 0.001$], where performance improved with time for both genders (See Fig. 2a). Purdue pegboard performance also displayed a significant Time effect where both genders significantly improved their performance after the fatiguing task [$F(1,26) = 38.907$, $p < 0.001$]. Before fatigue, average scores of the right-hand task was 16.21 pins, and after fatigue, it changed to 17.50 pins (See Fig. 2b).

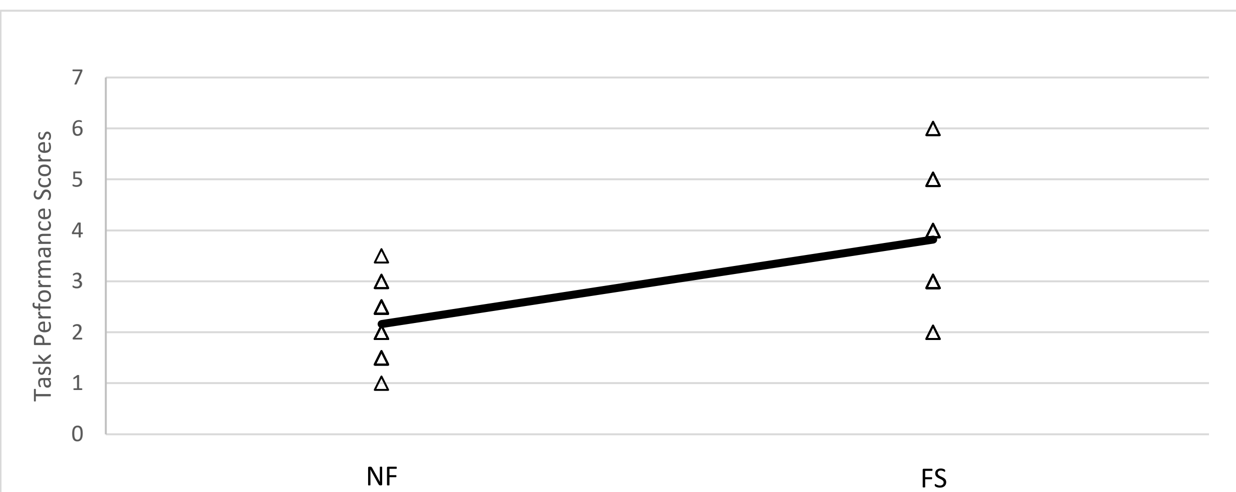

Fig. 2a Fatiguing task performance scores in the non-fatigue condition (NF) and the fatigue state (FS) with 28 subjects' scores on each condition—NF & FS (overlaps exist in scores).

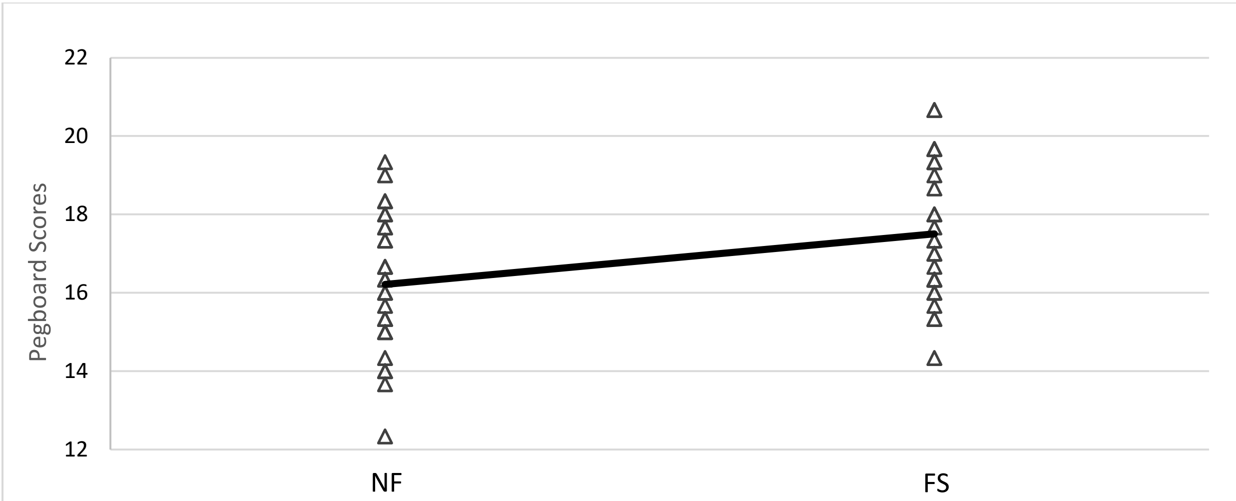

Fig. 2b Purdue pegboard scores in the non-fatigue condition (NF) and in the fatigued state (FS).

Statistical analysis revealed no significant Time effects [$F(1,26) = 1.732$, $p = 0.200$] or gender effects [$F(1,26) = 0.392$, $p = 0.537$] for joint position sense errors. Before fatigue, the average shoulder joint error of males was 3.14° while for females, it was 3.42°. After the fatiguing task, they were 3.19° and 3.22° respectively. Correlations between the difference in the non-fatigue to fatigue state pegboard scores and the difference in the joint position sense errors revealed no significant effects, for both genders individually and assessed together ($r = -0.032$, $p = 0.874$). No significant gender effects were found for Purdue Pegboard test; [$F(1,26) = 1.069$, $p = 0.311$] or for shoulder proprioception performance; [$F(1,26) = 0.234$, $p = 0.632$].

3.3 Muscle activity patterns.

Significant Time main effects were found in the EMG RMS average values of the TRI [$F(1,26) = 4.771$, $p = 0.038$] , EXT [$F(1,25) = 12.287$, $p = 0.002$], and FLEX [$F(1,26) = 12.507$, $p = 0.002$]. For TRI, statistical analysis revealed a significant increase in the RMS value by 14.54%±32.39. However, for EXT and FLEX, significant decrease in the RMS average value was observed. For FLEX, there was a 17.85%±24.33 decrease and for EXT, there was a 10.04%±17.88 decrease. There were significant Gender effects in the RMS in UT [$F(1,27) = 6.812$, $p = 0.015$], AD [$F(1,27) = 12.145$, $p = 0.002$], LT [$F(1,24) = 4.394$, $p = 0.047$], BIC [$F(1,27) = 7.165$, $p = 0.12$], TRI [$F(1,26) = 45.814$, $p < 0.001$], EXT [$F(1,25) = 7.099$, $p = 0.013$], and FLEX [$F(1,26) = 9.813$, $p = 0.004$]. For all of the 7 muscle sites, females displayed greater RMS values compared to males. Coefficient of variation (CoV) showed significant Time main effects on AD [F(1,27) = 7.082, p = 0.013], LT [F(1,24) = 6.988, p = 0.014], and EXT [F(1,25) = 9.199, p = 0.006], displaying increased variability at the end of the fatiguing task. For AD, there was a 14.35%±27.61 increase in the CoV value. For LT, there was a 24.57%±40.05 increase, and lastly for EXT, there was a 9.087%±16.17 increase (see Table. 1). Normalized Mutual Information (NMI) revealed no significant Time main effect or Time × Gender interaction effects for any of the muscle pairs. However, significant Gender effects were found for NMI between 3 muscle pairs: AD-BIC [F(1,27) = 824.565, p < 0.001], EXT-FLEX [F(1,24) = 2068.201, p < 0.001], and MT-UT [F(1,25) = 630.819, p < 0.001]. For all of the three pairs, females displayed higher NMI (See Fig. 3).

Muscles	Average Normalized RMS (SD)		Average CoV (SD)	
	Pre	Post	Pre	Post
UT	0.127 (0.099)	0.154 (0.104)	0.329 (0.089)	0.355 (0.158)
AD	0.152 (0.052)	0.16 (0.059)	0.304 (0.052)*	0.341 (0.065)*
MT	0.139 (0.130)	0.120 (0.087)	0.491 (0.164)	0.531 (0.183)
LT	0.128 (0.089)	0.123 (0.075)	0.483 (0.171)*	0.580 (0.213)*
BIC	0.086 (0.068)	0.095 (0.07)	0.470 (0.200)	0.474 (0.162)
TRI	0.029 (0.02)*	0.032 (0.02)*	0.276 (0.055)	0.301 (0.058)
EXT	0.358 (0.104)*	0.319 (0.101)*	0.453 (0.085)**	0.489 (0.094)**
FLEX	0.073 (0.049)*	0.057 (0.032)*	0.568 (0.116)	0.582 (0.147)

Table 1. Time main effects for muscles' average normalized RMS and coefficient of variation (CoV). Refer to the text for full muscle names.

* p <0.05.
**p<0.01.
***p<0.001.

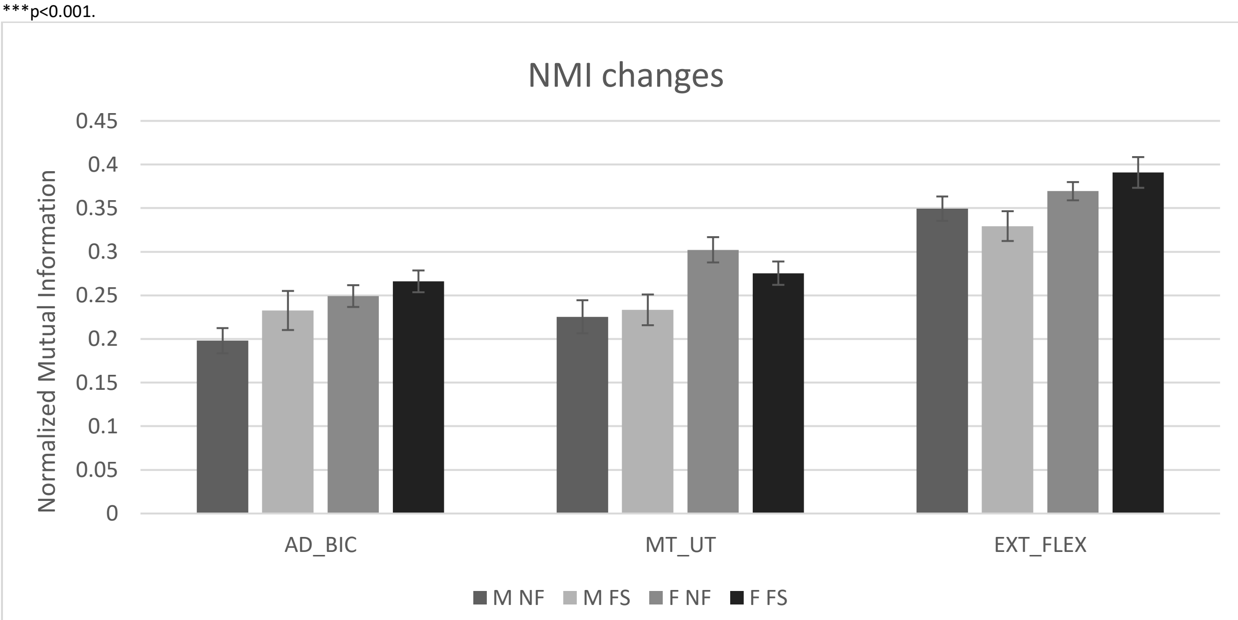

Fig. 3 Normalized Mutual Information (NMI) between AD_BIC, MT_UT, and EXT_FLEX pairs in the non-fatigue (NF) condition and at the end of the fatiguing task (FS), for each gender.

4. Discussion

4.1 Signs of fatigue.

The purpose of this study was to quantify the gender difference during a manual dexterity task performed at shoulder level and designed to induce neck/shoulder fatigue, and also to identify whether there is a connection between the fatigue development at the neck/shoulder and manual dexterity performance. Signs of fatigue development were weak in this study where only increase in the EMG RMS value of TRI was shown to be significant. Although not statistically significant, EMG RMS values of UT, AD, and BIC displayed near significant increases in RMS values. Interestingly, there was a significant decrease in both of the forearm muscles tested—FLEX and EXT. In addition, AD, LT and EXT had significant increase in their variability. Increase in variability has been shown to be an indicator of fatigue development (Srinivasan & Mathiassen, 2012), suggesting that some muscle fatigue was present at the end of the fatiguing task at shoulder height.

4.2 Performance and proprioception.

In contrast to the hypothesis, overall manual dexterity performance—measured by both Purdue Pegboard scores and screwing performance (screws/min) the fatiguing task itself—improved with time. One feasible interpretation for such result is the learning effect. Because subjects were to repeatedly perform the same task, a significant learning effect may have occurred where subjects became more accustomed to the movement. Another possible interpretation of the result could be made from the EMG RMS decrease in the FLEX and EXT. These results could reflect an alternative movement pattern to overcome fatigue experienced in the neck-shoulder region and the arm. By utilizing less of the forearm muscles, subjects may have decreased use of wrist rotation to perform the manual dexterity task and instead, used rotation of the entire arm to execute the task. This could have masked the expected increase in EMG RMS of the shoulder muscles by changing the type of contractions from isometric to dynamic, which may represent inherently less fatiguing types of muscle contractions. In this study, such assumption is supported through the increased variability in AD and LT.

Our study also revealed that shoulder proprioception did not significantly change with fatigue. It was observed in a study by Carpenter et al. (1998) that fatigue developed from isokinetic movement significantly decreased proprioceptive sense in the shoulder external and internal rotations. Differently to other studies, we used a manual dexterity task where the arm was maintained at shoulder height in a quasi-isometric posture as our fatigue-inducing protocol. Due to the nature of task-specific characteristic of fatigue, such isometric shoulder efforts may not have been adequate to induce fatigue that effected proprioceptive ability of the shoulder, especially considering that the performance of the shoulder proprioception task involved dynamic muscle contractions (flex the shoulder). Despite this absence of shoulder proprioception change, other measures such as screwing performance (screws/min) and scores on the Perdue pegboard test changed, but contrary to expectations, improved after the fatiguing task. As suggested by Hunter et al. (2006), different types of fatigue may have different impact on the underlying mechanisms to fatigue response. As aforementioned, the type of fatiguing task we used for the experiment may not have significantly enough impacted on the mechanism underlying fatigue response.

Moreover, the literature had previously shown that there may be a possible connection between fatigue of shoulder and forearm muscles (Samani et al., (2011); Strøm et al (2009)), and hence, it was expected that there may be a correlational decrease in the fatiguing task performance, Pegboard test performance and shoulder proprioception with the development of neck/shoulder fatigue. However, this was not observed. This suggests that the shoulder and forearm muscles did not work together during the fatiguing task, or that subjects were able to dissociate the function of both muscle groups as fatigue develops. This interpretation would be in line with other studies showing changes in association and dissociation of different muscle groups with fatigue (Fuller, Fung, & Côté, 2009; Fuller, Fung, & Côté, 2011). However, it should be noted that these results may be largely impacted by the limited evidence that there was actual neck/shoulder muscle fatigue induced in our protocol.

4.3 Gender differences.

In agreement to literature, our overall results show no difference in time to fatigue between genders. Comprehensively, there were no other gender differences found in both performance and proprioception measures. For both genders, performance increased with fatigue while there were no proprioceptive disruptions with fatigue. However, gender differences were observed in EMG RMS values with fatigue, but not in the variability values. According to the literature, it has been suggested that gender differences in the fatigue response do exist, but they may be task-specific (Hunter, 2009; Martin & Rattey, 2007). A previous study by Ferodowich et al. (2013) found no gender differences in the RMS and variability measures, but found several gender differences in the NMI parameters during their repetitive-pointing fatiguing task. Interestingly, gender differences in the RMS values were observed in UT, AD, LT, BIC, TRI, EXT, and FLEX in our study. For all of these 7 muscle sites, RMS values were higher for women. Hence, even though males and females respond to the fatiguing task similarly in terms of time to fatigue, proprioceptive and motor outcomes, the way that they use their muscles to reach these outcomes is different. Previous research indicates in the neck/shoulder region, elevated activation of a muscle has been indicated as a predictor of pain development (Veiersted, Westgaard, & Anderson, 1993). Punnet and Wegman (2004) also indicates upper part of trapezius as the most prone region of WMSD development in the neck/shoulder region. Hence, the higher RMS values of UT seen in females may have influence on the gender differences seen in the occurrence rate of neck/shoulder related WMSD. However, it should be noted that the EMG data was not amplitude normalized to MVICs in the Fedorowich et al. (2013) paper, such that this normalization procedure may in itself induce a gender difference.

Analysis of inter-muscle connectivity revealed that although there were no statistically significant changes in the NMI with fatigue, 3 pairs of muscles displayed significant gender effects (AD-BIC, EXT-FLEX, and MT-UT). Functional connectivity within each pair was higher in females. This result is in line with those in another study by Johansen et al. (2012) who also observed higher connectivity in the UT-MT pair in women. Females showing higher NMI may be a possible explanation to their elevated occurrence of work-related MSDs. A study by Fedorowich et al. (2013) suggested that lower NMI may be interpreted as a beneficial alternate movement strategy to avoid fatigue from dispersing to neighbouring muscles. Svendsen, Samani, Mayntzhusen, and Madeleine (2010) also demonstrated in their study of forearm muscle that lower NMI is a beneficial strategy during active work. In a study utilizing a sustained shoulder abduction task to fatigue by Falla, Arendt-Nielson, and Farina (2008), it was observed that females exhibit less shoulder reorganization patterns in addition to higher pain felt during the task. It is highly likely that such result seen from the elevated NMI in females suggests that gender differences in such muscle activation strategies is the reason why women are at a higher risk of developing work-related MSDs. Johansen et al. (2012) also implicated that higher shoulder functional connectivity seen in women may be responsible for the elevated risk of developing MSDs. Taken together, lower NMI could mean more efficient movement strategies of utilizing the neck-shoulder musculature to minimize the risk of developing an injury from fatigue.

Lastly, limitations of the study should be considered in interpreting our results. For one, muscles in the forearm are very close to one another. Although both EXT and FLEX EMG measures displayed a significant parallel increase, EMG readings still may contain crosstalk from the other nearby muscles. In addition, Purdue Pegboard and JPS test are not considered fatiguing compared to the actual fatiguing task itself. Purdue pegboard procedure was administered in the same way before and after the fatigue in same sequence—right hand, left hand, both hands, and assembly—totaling to approximately 12 minutes for the entire 3 trials of Pegboard testing. Therefore, towards the end of the post-fatigue procedure, it is possible that the participants could have recovered. However, we re-analyzed the data using only the results of the first trial of the post-fatigue Pegboard sequence and we were able to obtain nearly identical statistical results, suggesting a negligible effect of this methodological limitation on these results. Additionally, the fatiguing task somewhat allowed freedom of movement which could have added additional variability to the findings. Present findings should also be interpreted only for the general healthy young adult population due to the specificity of the inclusion criteria. Implications of our results are limited to standing work requiring no lower body movement and the specific task used in our study. It may not be representative of the real-life work tasks since it is rare to find an occupation requiring to stand still with no lower body movement.

5. Conclusion

The aim of this study was to investigate gender differences in upper limb performance and muscle activity characteristics and explore the potential link between the neck-shoulder and the forearm regions while performing a manual dexterity task at shoulder height. Previous studies utilized gross motor tasks to study neck-shoulder fatigue, while little was known about the gender difference that may be present during a fine-motor task, and whether working at shoulder height had any effect on dexterity. Results show no change in shoulder proprioception but time-related changes in both the screwing task performance and the Purdue pegboard performance in both genders, although, surprisingly, these were improved. Moreover, there was a lack of association between time-related changes in task performance, shoulder proprioception and dexterity measures. Finally, although none of these performance or proprioception measures were different between genders, gender differences were observed through the parameters of muscle activity amplitudes, and inter-muscle patterns. For both, females displayed higher values. Since the human body is a mechanically redundant system, the results suggest different muscle activation strategies between genders such that the way men and women utilize their muscles to reach the same motor outcome may be different. This could support the hypothesis that injury mechanisms may differ between genders, and provide a possible explanation to the elevated risk of work-related musculoskeletal disorders in women.

Acknowledgements

In addition to the participants of the study, the authors would like to thank Kim Emery, Shaheen Ghayourmanesh, and Annamaria Otto.

CONCLUSION

The goal of this thesis was to study the performance and task characteristics of men and women performing a manual dexterity task at shoulder height. Previous studies of shoulder height work investigated gross motor tasks (with little precision work requirement); therefore, we developed this study in an attempt to reach a better understanding of the underlying mechanisms of shoulder height work injuries and the relationship between the fatigue developed in the neck-shoulder region, forearm muscles and manual dexterity performance. We hypothesized that a screwing task performed at shoulder height would induce measurable fatigue of the neck-shoulder region, which would have a negative effect on the forearm muscles, ultimately leading to a decreased manual dexterity performance. Based on previous studies, we also hypothesized that gender differences in the fatigue response would be demonstrated through differences in task performance as well as in associated muscle activity characteristics.

Overall, although all participants finished the shoulder height task by scoring 8 out of 10 on the Borg CR10 scale, indicating significant subjective fatigue of the neck-shoulder region, there were very few parameters showing evidence that the screwing task performed at shoulder height induced significant muscle fatigue. Additionally, correlations between the Purdue pegboard scores and joint position sense errors revealed no significant relationship, suggesting little connection between the effects of the task on gross (shoulder) and fine (manual dexterity) characteristics. Despite this, there were clear signs of sex differences in how muscles were used to accomplish the shoulder height task, in terms of muscle activity amplitude and inter-muscle functional connectivity. These results suggest that different muscle activation strategies are utilized between genders and that the pathway to reaching a certain motor outcome may be different between men and women. Ultimately, findings suggest that injury mechanisms between men and women may be different and provide implications towards developing a guideline to help explain the gender specific prevalence of fatigue-induced injuries in occupational settings.

The work injury literature suggests that working at shoulder height is contra-indicated and can lead to injury risk and work errors. Future research should aim to utilize different, more fatiguing protocols to determine the relationship between neck-shoulder region fatigue and the forearm muscles, and to develop more sensitive measures of work performance.

References

Allen, T. J., Leung, M., & Proske, U. (2010). The effect of fatigue from exercise on human limb position sense. *J Physiol, 588*(8), 1369-1377.

Anders, C., Bretschneider, S., Bernsdorf, A., Erler, K., & Schneider, W. (2004). Activation of shoulder muscles in healthy men and women under isometric conditions. *Journal of Electromyography and Kinesiology, 14*, 699-707.

Annett, M. (1992). Five tests of hand skill. *Cortex*, 583-600.

Barry, B. K., & Enoka, R. M. (2007). The neurobiology of muscle fatigue: 15 years later. *Integrative and Comparative Biology, 47*(4), 465-473.

Basmajian, J.V., & Blumenstein, R. (1980). *Electrode Placement in Electromyographic Biofeedback*. Baltimore: Williams & Wilkins.

Berglund, K. M., Persson, B. H., & Denison, E. (2008). Prevalence of pain and dysfunction in the cervical and thoracic spine in persons with and without lateral elbow pain. *Manual Therapy, 13*, 295-299.

Björklund, M., Crenshaw, A. G., Djupsjöbacka, M., & Johansson, H. (2000). Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. Eur J Appl Physiol, 81, 361-367.

Björklund, M., Crenshaw, A. G., Djupsjöbacka, M., & Johansson, H. (2003). Position sense acuity is diminished following repetitive low-intensity work to faigue in a simulated occupational setting. A critical comment. Eur J Appl Physiol, 88, 485-486.

Bongers, P. M., Ijmker, S., van den Heuvel, S., & Blatter, B. M. (2006). Epidemiology of work related neck and upper limb problems: Psychosocial and personal risk factors (Part I) and effective interventions from a bio behavioural perspective (Part II). *Journal of Occupational Rehabilitation, 16*, 279-302.

Carpenter, J. E., Blaiser, R. B., & Pellizzon, G. G. (1998). The effects of muscle fatigue on shoulder joint position sense. *Am J Sports Med, 26*, 262-265.

Côté, J. (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*(2), 173-182.

Emery, K., & Côté, J. (2012). Repetitive arm motion-induced fatigue affects shoulder but not endpoint position sense. *Exp Brain Res, 216*, 553-564.

Enoka, R. M., & Duchateau, J. (2008). Muscle fatigue: what, why and how it influences muscle function. *J Physiol, 586*, 11-23.

Enoka, R. M., & Stuart, D. G. (1992). Neurobiology of muscle fatigue. *J. Appl. Physiol., 72*(5), 1634-1648.

Falla, D., Arendt-Nielsen, L., & Farina, D. (2008). Gender-specific adaptations of upper trapezius muscle activity to acute nociceptive stimulation. *Pain,* 138, 217-225.

Fedorowich, L., Emery, K., Gervasi, B., & Côté, J. (2013). Gender differences in neck/shoulder muscular patterns in response to repetitive motion induced fatigue. *Journal of Electromyography and Kinesiology, 23*, 1183-1189.

Fulco, C. S., Rock, P. B., Muza, S. R., Lammi, E., Cymerman, A., Butterfield, G., Moore, L. G., Braun, B., & Lewis, S. F. (1999). Slower fatigue and faster recovery of the adductor pollicis muscle in women matched for strength with men. *Acta Physiol, 167*, 233-239.

Fuller, J. R., Fung, J., & Côté, J. (2011). Time-dependent adaptations to posture and movement characteristics during the development of repetitive reaching induced fatigue. *Exp Brain Res, 211(1)*, 133-143.

Fuller, J. R., Lomond, K. V., Fung, J., & Côté, J. N. (2009). Posture-movement changes following repetitive motion-induced shoulder muscle fatigue. *Journal of Electromyography and Kinesiology, 19*, 1043-1052.

Gonzales, J. U., & Scheuermann, B. W. (2007). Absence of gender differences in the fatigability of the forearm muscles during intermittent isometric handgrip exercise. *Journal of Sports Science and Medicine, 6*, 98-105.

Grice, K. O., Vogel, K. A., Le, V., Mitchell, A., Muniz, S., & Vollmer, M. A. (2003). Adult Norms for a Commercially Available Nine Hole Peg Test for Finger Dexterity. *American Journal of Occupational Therapy, 57*(5), 570-573.

Hanjabam, B., & Kailashiya, J. (2015). Gender Difference in Fatigue Index and its Related Physiology. *Indian J Physiol Pharmacol, 59*(2), 170-174.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development,* 8(2), 13-54.

Hicks, A. L., Kent-Braun, J., & Ditor, D. S. (2001). Sex Differences in Human Skeletal Muscle Fatigue. *Exercise and Sports Science Reviews, 29*(3), 109-112.

Hooftman, W., van der Beek, A., Bongers, P., & van Mechelen, W. (2009). Is there a gender difference in the effect of work-related physical and psychosocial risk factors on musculoskeletal symptoms and related sickness absence? *Scand J Work Environ Health, 35*(2), 85-95.

Hunter, S. K. (2009). Sex Differences and Mechanisms of Task-Specific Muscle Fatigue. *Exerc Sport Sci Rev, 37*(3), 113-122.

Hunter, S. K., Butler, J. E., Todd, G., Simon, C. G., & Janet, L. T. (2006). Supraspinal fatigue does not explain the sex difference in muscle fatigue of maximal contractions. *Journal of Applied Physiology, 101*, 1036-1044.

Hunter, S. K., Critchlow, A., Shin, I., & Enoka, R. M. (2004). Fatigability of the elbow flexor muscles for a sustained submaximal contraction is similar in men and women matched for strength.*Journal of Applied Physiology, 96*, 195-202.

Hunter, S. K., & Enoka, R. M. (2001). Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. *Journal of Applied Physiology, 91*, 2686-2694.

Jeong, J., Gore, J. C., & Peterson, B. S. (2001). Mutual information analysis of the EEG in patients with Alzheimer's disease. *Clinical Neurophysiology, 112*, 827-835.

Johansen. T., Samani. A., Antle. D. M., Côté. J. N., & Madeleine, P. (2012). Gender effects on the coordination of subdivisions of the trapezius muscle during a repetitive box-folding task. *Eur J Appl Physiol,* 113(1), 175-182.

Juul Kristensen, B., Søgaard, K., Stroyer, J., & Jensen, C. (2004). Computer users' risk factors for developing shoulder, elbow and back symptoms. *Scand J Work Environ Health, 30*(5), 390-398.

Kendall, F.P., McCreary, E. K., & Kendall, H. O. (1993). *Muscles, testing and function*. Baltimore: Williams & Wilkins.

Kilshaw, D., & Annett, M. (1983). Right- and left-hand skill I: Effects of age, sex, and hand preference showing superior skill in left-handers. *British Journal of Psychology, 74*(2), 253-268.

Kimura, D. (1977). Acquisition of a motor skill after left-hemispheric damage. *Brain, 100*, 527-542.

Kimura, D. (2000). *Sex and cognition*. Cambridge, MA: MIT Press.

Kojadinovic, I. (2005). Relevance measures for subset variable selection in regression problems based on k-additive mutual information. *Computational Statistics & Data Analysis, 49*, 1205-1227.

Konrad, P. (2005). The ABC of EMG: A Practical Introduction to Kinesiological Electromyography. from Noraxon U.S.A

Larsson, B., Søgaard, K., & Rosendal, L. (2007). Work related neck-shoulder pain; a review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions.*Clinical Rheumatology, 21*(3), 447-463.

Latash, M. L., Scholz, J. P., & Schoner, G. (2002). Motor control strategies revealed in the structure of motor variability. *Exercise and Sport Science Reviews, 30*, 26-31.

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 Physiologica, 199*(Suppl. 679), 1-46.

Madeleine, P., Jørgensen, L. V., Søgaard, K., Arendt-Nielsen, L., & Sjøgaard, G. (2002). Development of muscle fatigue as assessed by electromyography and mechanomyography during continuous and intermittent low-force contractions: effects of the feedback mode. *Eur J Appl Physiol, 87*, 28-37.

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 Sports, 21*, 277-289.

Martin, P. G., & Pattey, J. (2007). Central fatigue explains sex differences in muscle fatigue and contralateral cross-over effects of maximal contractions. *Eur J Appl Physiol,* 454, 957-969.

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985). Adult Norms for the Box and Block Test for Manual Dexterity. *The American Journal of Occupational Therapy, 39*(6), 386-391.

Maughan, R., Harmon, M., Leiper, J., Sale, D., & Delman, A. (1986). Endurance capacity of untrained males and females in isometric and dynamic muscular contractions. *Eur J Appl Physiol, 55*, 395-400.

Miller, A. E. J., MacDougall, J. D., Tarnopolsky, M. A., & Sale, D. G. (1993). Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol, 66*, 254-262.

Missenard, O., Mottet, D., & Perry, S. (2009). Factors responsible for force steadiness impairment with fatigue. *Muscle & Nerve, 40*, 1019-1032.

Peters, M., & Campagnaro, P. (1996). Do Women Really Excel Over Men in Manual Dexterity? *Journal of Experimental Psychology, 22*(5), 1107-1112.

Peters, M., & Durding, B. (1979). Left-handers and right-handers compared on a motor task. *Journal of Motor Behavior, 11*, 103-111.

Peters, M., Servos, P., & Day, R. (1990). Marked Sex Differences on a Fine Motor Skill Task Disappear When Finger Size Is Used as Covariate. *American Psychological Association, 75*(1), 87-90.

Proske, U. (2005). What is the role of muscle receptors in proprioception? *Muscle & Nerve, 31*, 780-787.

Punnet, L., & Wegman, D. H. (2004). Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol, 14,* 13-23.

Ranansinghe, P., Perena, Y. S., Lamabadusuriya, D. A., Kulatunga, S., Jayawardana, N., Rajapakse, S., & Katulanda, P. (2011). Work related complaints of neck, shoulder and arm among computer office workers: a cross-sectional evaluation of prevalence and risk factors in a developing country. *Environmental Health, 10*(70), 1-9.

Rohr, L. E. (2006). Gender-Specific Movement Strategies Using a Computer-Pointing Task. *Journal of Motor Behavior, 38*(6), 431-437.

Sadamoto, T., Bonde-Petersen, F., & Suzuki, Y. (1983). Skeletal muscle tension, flow, pressure, and EMG during sustained isometric contractions in humans. *Eur J Appl Physiol, 51*, 395-408.

Samani, A., Fernández-Carnero, J., Arendt-Nielsen, L., & Madeleine, P. (2011). Interactive effects of acute experimental pain in trapezius and sored wrist extensor on the electromyography of the forearm muscles during computer work. *Applied Ergonomics, 42*, 735-740.

Srinivasan, D., & Mathiassen, S. E. (2012). Motor variability in occupational health and performance. *Clinical Biomechanics, 27*, 979-993.

Strøm, V., Knardahl, S., Stranghelle, J. K., Røe, C. (2009). Pain induced by a single simulated office-work session: Time course and association with muscle blood flux and muscle activity. *European Journal of Pain, 13*, 843-852.

Svendsen, J. H., & Madeleine, P. (2010). Amount and structure of force variability during short, ramp and sustained contractions in males and females. *Hum Mov Sci,* 29, 35-47.

Swaen, G. M. H., van Amelsvoort, L. G. P. M., Bültmann, U., & Kant, I. J. (2003). Fatigue as a Risk Factor for Being Injured in an Occupational Accident: Results from the Maastricht Cohort Study. *Occupational and Environmental Medicine, 60*(Supplement 1), i88-i92.

Tripp, B. L., Boswell, L., Gansneder, B. M., & Shultz, S. J. (2004). Functional Fatigue Dereases 3-Dimensional Multijoin Position Reproduction Acuity in the Overhead-Throwing Athlete.*Journal of Athletic Training, 39*(4), 316-320.

Vafadar, A. K., Côté, J. N., & Archambault, P. S. (2015). Sex differences in the shoulder joint position sense acuity: a cross-sectional study. *BMC Musculoskeletal Disorders, 16*(273), 1-7.

Vafadar, A. K., Côté, J. N., & Archambault, S. (2016). Interrater and Intrarater Reliability and Validity of 3 Measurement Methods for Shoulder-Position Sense. *Journal of Sport Rehabilitation*, 1-9.

Veiersted, K. B., Westgaard, R. H., & Anderson, P. (1993). Electromyographic evaluation of muscular pattern as a predictor of trapezius myalgia. *Scand J Work Environ Health*, *19*, 284-290.

Voight, M. L., Hardin, J. A., Blackburn, T. A., Tippett, S., & Canner, G. C. (1996). The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther, 23*, 348-352.

Vèzina, M., Cloutier, E., Stock, S., Lippel, K., Fortin, E., Delisle, A., St-Vincent, M., Funes, A., Duguay, P., Vèzina, S., Prud'homme, P. (2011). *Québec Survey on Working and Employment Conditions and Occupational Health and Safety (EQCOTESST)*. Retrieved from

Zakaria, D., Robertson, J., MacDermid, J., Hartford, K., & Koval, J. (2002). Work-related Cumulative Trauma Disorders of the Upper Extremity: Navigating the Epidemiologic Literature.*American Journal of Industrial Medicine, 42*, 258-269.

APPENDICES

A. Consent Form (English Version)

Consent form

1 - Title of project

Sex/Gender specific effects of repetitive motion-induced fatigue on arm and

2 - Researchers in charge of project

Julie Côté, Ph.D. Associate Professor, Department of Kinesiology and Physical Education, McGill University, (514) 398-4184 ext. 0539, (450) 688-9550, ext. 4813.

Annamaria Otto, B.Sc., Master's student, Department of Kinesiology and Physical Education, McGill University, 450-688-9550 ext. 4827

Sunghoon Minn, B.Sc., Master's student, Department of Kinesiology and Physical Education, McGill University, 450-688-9550 ext. 4827

3 - Introduction

Before agreeing to participate in this project, please take the time to read and carefully consider the following information.

This consent form explains the aim of this study, the procedures, advantages, risks and inconvenience as well as the persons to contact, if necessary.

This consent form may contain words that you do not understand. We invite you to ask any question that you deem useful to the researcher and the others members of the staff assigned to the research project and ask them to explain any word or information which is not clear to you.

4 - Project description and objectives

The objective of this research is to measure how fatigue affects perception, movement, exertion and pain response of men and women. Thirty healthy adults, 15 male and 15 female, will be recruited to complete this study. The long-term objectives of this research are to better understand how a person responds to muscular fatigue, which can lead to interventions or new guidelines that promote a safer working environment for tasks involving repetitive movements.

5 - Nature and duration of participation

The experimental procedure will be performed at the Jewish Rehabilitation Hospital in the Occupational Biomechanics and Ergonomics laboratory (OBEL) (3205 place Alton-Goldbloom, Laval, Qc, H7V 1R2). We ask that you participate in one experimental session lasting approximately 3 hours and consisting of four phases: a preparation phase, a pre-fatigue phase, an experimental phase and a post-fatigue phase. We will ask you to wear sport shoes and a tight fitting tank top. None of the procedures used in this study are invasive.

During the preparation phase, upon entering into the lab, surface electrodes and light reflective markers will be taped onto the skin over muscles of the arm, back and neck. These serve to measure muscle activity and body position, respectively. This phase should last about 20 minutes.

During the pre-fatigue phase, you will be asked to complete several muscle contractions. Then, you will perform an arm-repositioning test where you will be asked to lift your arm to about horizontal, bring it back next to your body, then move the arm back to that position with your eyes closed. You will then be asked to perform a test of fine finger control by quickly moving small objects with your fingers. Finally, pressure will be applied to your arm muscles, after which you will fill out some short questionnaires to rate your perceptions of the pain associated with this pressure. This phase will take approximately 1 hour.

During the experimental phase, you will be asked to repeatedly unscrew and screw nuts into a wood panel placed in front of you as fast as possible with as few mistakes (drops) as possible (Figure 1). You will be asked to rank your discomfort during the task after each minute. You will complete this task until you meet our stoppage criteria based on your performance. The research equipment will collect data every minute during the repetitive task. This phase should last about 1 hour.

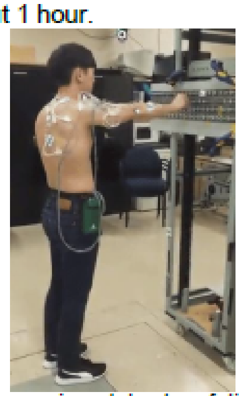

Figure 1: experimental setup, fatiguing task

During the post-fatigue phase, you will repeat the pre-fatigue tests except for the tests for muscle contraction. This phase should last about 30 minutes.

6 - Advantages associated with my participation

As a participant you will receive no direct benefit from your involvement in this study. However, you will contribute to the fundamental science of human physiology and biomechanics and to applied knowledge in ergonomics and occupational health.

7 - Personal inconvenience

The duration of the session (approximately 3 hours) may represent an inconvenience for you. The possibility that a few small areas (8, 3x3 cm each) of the skin over your arm, back and neck may have to be shaved before positioning the electrodes might also be an inconvenience to you. The material used respects the usual hygiene norms. Although it is hypo-allergenic, the adhesive tape used to fix the electrodes on your skin may occasionally produce some slight skin irritation. Should this happen, a hypo-allergic lotion will be applied on your skin to relieve skin irritation. You will experience some fatigue towards the end of the sessions, which may cause some arm muscle tenderness or stiffness. If this occurs, symptoms should dissipate within 48 hours following the completion of the protocol. A clinician will be present at all times during the protocol to ensure your safety.

8 - Confidentiality

All the personal information collected for this study will be codified to insure its confidentiality. Only the people involved in the project will have access to this information. However, for means of control of the research project, your research records could be consulted by a person mandated by the REB of the CRIR establishments or by the ethics unit of the Ministry of health and social services, which adheres to a strict confidentiality policy. All information will be kept under locking key at the research center of the Jewish Rehabilitation Hospital by the person responsible for the study for a period of five years following the end of the study, after which it will be destroyed. If the results of this research project are presented or published, nothing will allow your identification.

9 - Withdrawal of subject from study

Participation in the research project described above is completely voluntary. You have the right to withdraw from the study at any moment. If ever you withdraw from the study, all documents concerning yourself will be destroyed at your request.

10 - Responsibility

By accepting to participate in this study, you do not surrender your rights and do not free the researchers, sponsor or the institutions involved from their legal and professional obligations.

11 - Monetary compensation

No monetary compensation will be offered to you.

12 - Contact persons

If you need to ask questions about the project, signal an adverse effect and/or an incident, you can contact at any time Julie Côté at (514) 398-4184, ext. 0539 or Annamaria Otto at annamaria.otto@mail.mcgill.ca or Sunghoon (Eric) Minn at sunghoon.minn@mail.mcgill.ca or at (450) 688-9550 Ext. 4827.

Also, if you have any questions concerning your rights regarding your participation to this research project, you can contact Ms. Anik Nolet, Research ethics co-ordinator of CRIR at (514) 527-4527 ext. 2649 or by email at anolet.crir@ssss.gouv.qc.ca. The local ethics complaints commission at the Jewish Rehabilitation Hospital in Laval is also available to answer the same questions about your participation in the study.

CONSENT

I declare to have read and understood the project, the nature and the extent of the project as described in the present document. I had the opportunity to ask all my questions concerning the different aspects of the study and to receive explanations to my satisfaction.

I, undersigned, voluntarily accept to participate in this study. I can withdraw at any time without any prejudice. I certify that I have received enough time to take my decision.

A signed copy of this information and consent form will be given to me.

NAME OF PARTICIPANT (print): ________________________________

SIGNATURE OF PARTICIPANT: ________________________________

SIGNED IN ____________________, on ________________, 20_____.

COMMITMENT OF RESEARCHER

I, undersigned, ______________________________, certify

(a) having explained to the signatory the terms of the present form ;

(b) having answered all questions he/she asked concerning the study ;

(c) having clearly told him/her that he/she is at any moment free to withdraw from the research project described above; and

(d) that I will give him/her a signed and dated copy of the present document.

____
Signature of person in charge of the project or representative

SIGNED IN _________________, on ________________________ 20__.

B. Consent Form (French Version)

Effets spécifiques au sexe/genre de la fatigue induite par le mouvement répétitif sur le contrôle sensorimoteur du bras et de l'épaule, l'effort et la perception de la douleur.

CRIR Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Formulaire de consentement

Centre intégré de santé et de services sociaux de Laval Québec

1 - Titre du projet

Effets spécifiques au sexe/genre de la fatigue induite par le mouvement répétitif sur le contrôle sensorimoteur du bras et de l'épaule, l'effort et la perception de la douleur.

2 - Responsables du projet

Julie Côté, Ph.D. professeure agrégée, Département de kinésiologie et d'éducation physique, Université McGill, (514) 398-4184 poste 0539, (450) 688-9550, poste 4813.

Annamaria Otto, B.Sc., Master's student, Department of Kinesiology and Physical Education, McGill University, 450-688-9550 ext. 4827

Sunghoon Minn, B.Sc., Master's student, Department of Kinesiology and Physical Education, McGill University, 450-688-9550 ext. 4827

3 - Préambule

Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin.

Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

4 - Description du projet et de ses objectifs

L'objectif de cette recherche est de mesurer comment la fatigue affecte la perception, le mouvement, l'effort et la réponse à la douleur chez les hommes et les femmes. Trente adultes en bonne santé générale, 15 hommes et 15 femmes, seront recrutés pour participer à cette étude. Les objectifs à long terme de cette recherche sont de mieux comprendre comment une personne répond à la fatigue musculaire, ce qui pourrait mener à l'identification de normes de travail plus sécuritaires durant les tâches impliquant le mouvement répétitif.

5 - Nature et durée de la participation

Le protocole de recherche sera effectué à l'hôpital juif de réadaptation, au laboratoire de biomécanique du travail et d'ergonomie (OBEL) (3205 place Alton-Goldbloom, Laval, Qc, H7V 1R2). Nous vous demandons de participer à une séance expérimentale d'environ 3 heures et qui consistera en quatre phases : une phase de <u>préparation</u>, une phase <u>pré-fatigue</u>, une phase <u>expérimentale</u>, et une phase <u>post-fatigue</u>. On vous demandera de porter des souliers de sport et une camisole ajustée à la peau. Aucune des procédures utilisées dans cette étude n'est invasive.

Durant la phase de <u>préparation</u>, des électrodes de surface et des marqueurs réfléchissants seront fixés sur la peau de votre bras, de votre cou et de votre dos afin de mesurer l'activité des muscles et les positions de vos segments corporels. Ensuite, on vous demandera d'effectuer plusieurs efforts avec vos muscles. Cette phase durera environ 20 minutes.

Durant la phase <u>pré-fatigue</u>, on vous demandera d'effectuer plusieurs efforts musculaires. Ensuite, vous effectuerez une tâche de repositionnement du bras où vous lèverez le bras jusqu'à environ l'horizontale, vous le ramènerez contre vous, et vous le ramènerez à la position en gardant les yeux fermés. Ensuite vous effectuerez un test de contrôle des doigts où vous déplacerez rapidement des petits objets avec vos doigts. Finalement, nous appliquerons de la pression sur vos muscles du bras, après quoi vous remplirez de courts questionnaires pour évaluer votre perception de la douleur associée à la pression. Cette phase durera environ 1 heure.

Durant la phase <u>expérimentale</u>, on vous demandera de visser et dévisser des boulons dans un panneau placé devant vous le plus rapidement possible avec le moins d'erreurs (boulons échappés) possible (Figure 1). A chaque minute, on vous demandera d'évaluer votre inconfort/fatigue à l'épaule. On vous demandera de continuer cette tâche jusqu'à ce que vous rencontriez nos critères d'arrêt, qui seront basés sur votre performance. Des données seront collectées chaque minute pendant la tâche répétitive. Cette phase durera environ 1 heure.

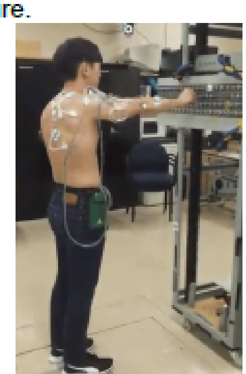

Figure 1 : montage expérimental, tâche de fatigue

Durant la phase post-fatigue, vous allez effectuer les même tests que ceux effectués durant la phase pré-fatigue excepté les tests d'effort musculaire. Cette phase durera environ 30 minutes.

6 - Avantages pouvant découler de votre participation

En tant que participant, vous ne retirerez personnellement pas d'avantages à participer à cette étude. Toutefois, vous aurez contribué à l'avancement de la science fondamentale de la physiologie humaine et de la biomécanique et aux connaissances appliquées de l'ergonomie et la santé au travail.

7 - Inconvénients personnels

La durée de la séance expérimentale (environ 3 heures) peut représenter un inconvénient pour certaines personnes. La possibilité que quelques régions (8, 3x3 cm chaque) de la peau de votre dos, votre cou et de votre bras doivent être rasées avant d'y apposer des électrodes peut également représenter un inconvénient pour vous. Le matériel utilisé respecte les règles d'hygiène usuelles. Toutefois, bien qu'il soit hypo-allergène, le ruban adhésif utilisé pour maintenir les électrodes sur la peau peut occasionnellement provoquer de légères irritations de la peau. Le cas échéant, une lotion hypo-allergène sera appliquée pour soulager l'irritation cutanée. Vous ressentirez de la fatigue vers la fin de la séance expérimentale, ce qui pourrait causer de la sensibilité ou de la raideur des muscles du bras. S'ils se manifestent, les symptômes devraient disparaître dans les 48 heures suivant la fin du protocole expérimental. Un clinicien sera présent en tout temps durant le protocole pour assurer votre sécurité.

8 - Confidentialité

Tous les renseignements personnels recueillis à votre sujet au cours de l'étude seront codifiés afin d'assurer leur confidentialité. Seuls les membres de l'équipe de recherche y auront accès. Cependant, à des fins de contrôle du projet de recherche, votre dossier de recherche pourrait être consulté par une personne mandatée par le CÉR des établissements du CRIR ou de l'Unité de l'éthique du ministère de la Santé et des Services sociaux, qui adhère à une politique de stricte confidentialité. Toutes les données seront conservées sous clé au centre de recherche de l'Hôpital juif de réadaptation par la responsable de l'étude pour une période de 5 ans suivant la fin du projet, après quoi, elles seront détruites. En cas de présentation de résultats de cette recherche ou de publication, rien ne pourra permettre de vous identifier.

9 - Retrait de la participation du sujet

Votre participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est entendu que vous pourrez, à tout moment, mettre un terme à votre participation. En cas de retrait de votre part, tous les documents vous concernant seront détruits à votre demande.

10 - Clause de responsabilité

En acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs, le commanditaire ou les institutions impliquées de leurs obligations légales et professionnelles.

11 - Indemnité compensatoire

Aucune indemnité compensatoire ne vous sera offerte pour votre participation.

12 - Personnes ressources

Si vous désirez poser des questions sur le projet ou signaler des effets secondaires, vous pouvez rejoindre en tout temps Julie Côté au (514) 398-4184 poste 0539 ou Annamaria Otto au annamaria.otto@mail.mcgill.ca, ou Sunghoon (Eric) Minn au sunghoon.minn@mail.mcgill.ca, ou au 450-688-9550 poste 4027.

De plus, si vous avez des questions sur vos droits et recours ou sur votre participation à ce projet de recherche, vous pouvez communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2649 ou par courriel à l'adresse suivante: anolet.crir@ssss.gouv.qc.ca. Pour ces mêmes questions, vous pouvez aussi communiquer avec le commissaire local aux plaintes de l'Hôpital juif de réadaptation du CISSS de Laval.

CONSENTEMENT

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice d'aucune sorte. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision.

Une copie signée de ce formulaire d'information et de consentement doit m'être remise.

NOM DU PARTICIPANT : ______________________________

SIGNATURE : ______________________________

Signé à ______________________, le __________, 20_____.

ENGAGEMENT DU CHERCHEUR

Je, soussigné (e), _______________________________ , certifie

(a) avoir expliqué au signataire les termes du présent formulaire;

(b) avoir répondu aux questions qu'il m'a posées à cet égard;

(c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus;

et (d) que je lui remettrai une copie signée et datée du présent formulaire.

____
Signature du responsable du projet
ou de son représentant

Signé à _________________, le _____________ 20__.