The effects of repetitive motion-induced shoulder fatigue on proprioception

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CONTRIBUTIONS OF AUTHORS

Bridget Gervasi, the candidate, participated in every step of this research, including the design, setup, data collection, data analysis, subject recruitment, and writing, as per McGill University requirements.

Julie N. Côté, PhD., Associate Professor, Department of Kinesiology and Physical Education, the candidate's supervisor, was actively involved in all steps and decisions made concerning the research protocol, data analysis, and revision.

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ABSTRACT

The objective of this Master's thesis was to quantify the effects of repetitive arm motion-induced shoulder fatigue on perceptual characteristics related to shoulder proprioception in a healthy group of male and female adults. Through three simple perceptual tasks, our protocol aimed to assess healthy adults' senses of force, rhythm, and posture in a non-fatigued condition, and in a fatigued condition following an upper-extremity repetitive pointing task (RPT). Repetitive motion-induced fatigue revealed an increase in anterior-posterior center of pressure (CoP) range of motion and displacement, but no change in force matching accuracy, nor in the ability to maintain a particular rhythm during a repetitive arm task. Since our study involved relatively low efforts, compensations from unfatigued muscles possibly explain subjects' ability to preserve certain task characteristics. We do not fully understand the mechanisms by which repetitive arm motion-induced fatigue may impair postural stability, but it is possible that these mechanisms could involve changes in other systems, occurring with global fatigue. More studies are needed to shed light into that question.

RÉSUMÉ

Le but de ce projet de maîtrise était de mesurer les effets de la fatigue musculaire sur les caractéristiques perceptives liées à la proprioception dans un groupe de femmes et d'hommes en bonne santé. Par trois simples tâches perceptives, notre protocole visait à évaluer la perception de la force, du rythme, et de la posture dans un état non-fatigué, et dans un état fatigué suite à un mouvement répétitif. La fatigue, provoquée par des mouvements répétitifs, à révélé une augmentation antéro-postérieur de l'amplitude de mouvement et du déplacement du centre de pression, mais aucun changement dans la capacité d'égaler une force, ni dans la capacité de maintenir un rythme particulier au cours d'une tâche répétitive. Puisque notre étude a nécessité des efforts relativement faibles, la préservation de certaines caractéristiques de ces tâches peut être expliquée par l'assistance d'autres muscles non fatigués. Nous ne comprenons pas entièrement les mécanismes par lesquels la fatigue, causée par les mouvements répétitifs du membre supérieur, peut nuire à la stabilité posturale, mais il est possible que ces mécanismes pourraient impliquer des changements dans d'autres systèmes. D'autres études seront nécessaires pour répondre à cette question.

TABLE OF CONTENTS

TABLE OF CONTENTS *CONTINUED*

INTRODUCTION

The neck and shoulder joints are complex structures, required to sustain constant and sometimes heavy loads throughout the course of a day. For example, simply maintaining the head in an upright position requires continuous support of the neck extensor muscles (Kendall et al. 2005). Although both are considered separate joints, several muscles span both joints; for instance, the trapezius muscle's origin is from the occipital bone of the skull and the spinous process of the twelfth thoracic vertebrae and it inserts at the shoulder, touching both the clavicle and scapula. Therefore, several studies focus on the region spanning both joints and suggest that proper functioning of the neck/shoulder area is essential for many everyday activities.

Since we are so dependent on the posture and movements of the neck and shoulder joints to go about our daily lives, we often take the proper functioning of the muscles of that area for granted until pain or injury occurs. Injuries and disorders of the neck/shoulder area are increasingly common and can lead to decreases in performance in the workplace, and during activities of daily living (Bigland-Ritchie and Woods 1984; Lomond and Côté 2011). Studies suggest that muscle fatigue is one of the major precursors to injuries and disorders of the neck/shoulder and that these disorders are often linked to fatigue from repetitive arm motions that occur during various daily activities (Luopajarvi et al. 1979; Silverstein et al. 1998; Nordander et al. 1999; Herberts et al. 1981). Moreover, many common disorders of the neck/shoulder region are more prevalent among people regularly required to conduct fatigue-inducing repetitive motions compared with those who are not (Luopajarvi et al. 1979). In addition to the movements required by daily tasks and hobbies, it is common for many people to perform repetitive arm motions that induce excessive loads on the neck and shoulder region in the workplace on a daily basis.

Work involving repetitive motions can be found among several different types of occupations. Assembly-line workers, production workers, and office workers are a few common examples, which illustrates how a large variety of people can be affected (Jensen et al. 1993; Luopajarvi et al. 1979). Many of these occupations involve the use of the upper extremity in positions at or above shoulder height, which is considered an ergonomic risk factor for injury (Armstrong et al. 1993; Luttmann et al. 2010; Mehta and Agnew 2010). Performing repetitive motions for long periods of time has been known to cause muscle fatigue, which in turn, may lead to the development of musculoskeletal disorders (Sjogaard and Sogaard 1998). As a result, 55% of all upper extremity injuries such as rotator cuff tendinitis, tenosynovitis, and epicondylitis have previously been shown to occur in the workplace, and about 25% of injuries from repetitive motions affect the neck and shoulder region (Tjepkema 2003).

Fatigue can be defined as “an acute impairment in performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (Enoka and

Stuart 1992). Studies have shown that fatigue leads to a decrease in maximal voluntary isometric force output (Albert et al. 2006), as well as decreases in speed of task execution and accuracy (Bosch et al. 2011; Bottas et al. 2009). In addition, muscle fatigue has been shown to be associated with posture and movement changes that are not limited to the directly fatigued muscle, but that span across the entire body (Cote et al. 2002; Cote et al. 2008). Recent research suggests that these adaptations occur as an attempt to lessen the work of the fatigued muscles and prolong task performance while avoiding further fatigue (Fuller et al. 2011; Fuller et al. 2009; Gates and Dingwell 2011; Cote et al. 2005). However, the mechanisms controlling these whole-body adaptations remain poorly understood. In particular, it is still unclear to what extent these changes are voluntary, feedforward strategies to avoid further fatigue, or if they are involuntary, reactive, mechanical in nature. Gaining insight on how fatigue affects other elements of the neuromuscular control chain involved in coordinating multijoint actions would help elucidate this question.

As such, the use of sensory information is an important element of the control loop. Proprioceptive abilities play an important role in the control of various aspects of movement such as limb position, joint angle, speed, and strength (Kerr and Worringham 2002). Myers and Lephart (2000) describe proprioception as a set of sensory information that provides movement control and stability. Sensory information is detected by mechanoreceptors and sent to the central nervous system, where it is integrated with other afferent input in order to generate an appropriate motor response (Myers and Lephart 2000). Proprioception encompasses three main submodalities, including the sensations of kinaesthesia, or joint movement, joint position sense (Warner et al. 1996), and sense of force (Proske 2005). If our ability to convey proprioceptive information to various parts of the body is affected by fatigue, the risk of injury may increase. Moreover, it has been shown that deafferented subjects exhibit impairments in movement control and coordination (Tunik et al. 2003; Sainburg et al. 1995), suggesting that proprioceptive deficits occurring with fatigue may also affect coordination. It has been well demonstrated that position sense accuracy decreases when fatigue is locally induced (Carpenter et al. 1998; Bjorklund et al. 2000; Myers et al. 1999; Emery and Cote 2012). However, we have recently shown that accuracy in the upper limb's endpoint is not affected when the shoulder is fatigued, suggesting that mulitjoint compensations occurring with fatigue also involve proprioceptive adaptations (Emery and Cote 2012). The effects of fatigue on the sense of force have been studied but findings are equivocal (Jones and Hunter 1983a, b; Carson et al. 2002) and may be related to the choice of load used in the fatiguing and force matching protocols. Fatigue has also been shown to affect postural stability (Fuller et al. 2009; Gates and Dingwell 2011; Gribble and Hertel 2004; Corbeil et al. 2003; Pinsault and Vuillerme 2010; Vuillerme et al. 2005; Naussbaum 2003). Despite these advances, the effects of fatigue on various perceptual characteristics related to proprioception such as the senses of rhythm and of postural alignment are not well understood. Moreover, studies investigating gender differences in proprioceptive and perceptual characteristics are equivocal.

The relevance of this Master's thesis can be linked to the fact that the perceptual characteristics studied in this project are closely linked to everyday functioning and to work-related capabilities, as can affect one's ability to be effective and productive at work. Deficits in these perceptual characteristics could also play parts in the development of injuries, for instance through an impaired ability to perceive changes in neck/shoulder postural alignment with fatigue. From a fundamental perspective, it is important to have a more complete understanding of how proprioception is affected by fatigue in order to better predict the body's reactions. Practically, this could contribute to more effective training and rehabilitation methods, such as learning what preventative measures would be effective in the control of muscular fatigue and the delay, or reduction of musculoskeletal injuries and disorders. Finally, results of this study could provide a better understanding of the mechanisms underlying gender differences in the fatigue response, and could contribute to a better understanding for why women display higher prevalence and severity of neck/shoulder disorders (Hooftman et al. 2009; Larsson et al. 2007).

The objective of this Master's thesis was to measure the effects of fatigue on perceptual characteristics related to shoulder proprioception in a healthy group. Through three simple perceptual tasks, this protocol aimed to assess healthy adults' senses of force, rhythm, and posture in a non-fatigued condition, and in a fatigued condition following an upper-extremity repetitive pointing task. We hypothesized that fatigue would significantly affect the subject's ability to detect the amount of applied shoulder force, the ability to follow a certain arm movement rhythm, and the ability to maintain a standing posture as still and as symmetrical as that adopted before fatigue.

LITERATURE REVIEW

Fatigue

Fatigue is a common occurrence following repetitive motions, arising from several possible circumstances in addition to those at the workplace, such as during exercise and activities of daily living. For example, in office workers, paper work was shown to cause significant fatigue in the upper trapezius (Luttmann et al. 2010). Muscle fatigue, which can be defined as “an acute impairment in performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (Enoka and Stuart 1992), is most commonly characterized by a decrease in maximal isometric force production (Bigland-Ritchie and Woods 1984). It can also affect neuromuscular control and task performance at a submaximal level (Gribble and Hertel 2004), resulting in low force fatigue, which is a more common occurrence in everyday life and is the focus of this work. Fatigue develops gradually and originates both centrally and peripherally, by maximal, as well as submaximal efforts (Sogaard et al. 2006; Gandevia and McCloskey 1978). Central fatigue refers to a decrease in the ability of the motor command that is sent by the central nervous system to maintain the contraction; peripheral fatigue refers to the decreased propagation of efferent commands between the nerve ending and the muscle (Bigland-Ritchie and Woods 1984). In addition, to better understand the characteristics of fatigue, authors have studied muscle contractions at a physiological level.

This has revealed that a change in the excitation-contraction coupling sequence is another determinant of the presence of fatigue (Edwards et al. 1977). It can be quantified through changes at the neuromuscular junction, such as altered intra- and extracellular sodium and potassium ion concentrations, possibly affecting action potentials (Edwards et al. 1977).

Several methods exist to quantify muscle fatigue, both directly and indirectly. A common non-invasive measure of muscular fatigue is via surface electromyography (sEMG). Unlike intramuscular EMG, which involves the measurement of muscular activity via a needle inserted directly in the muscle, sEMG measures muscular activity through electrodes placed on the skin (Winter 1990). Fatigue from high-intensity muscle contractions has been shown to result in compression and shift of the sEMG frequency spectrum towards lower frequencies (Vollestad 1997); however, changes in the frequency spectrum occurring with low force fatigue are more equivocal. Conversely, several previous studies have shown that the amplitude of the sEMG signal, which represents the number and size of action potentials within the muscle, increases with low force fatigue (Vollestad 1997). Increases of the signal amplitude could be generated from either an increase in the number of muscle fibres recruited, or of the excitation rates (Vollestad 1997). Root-mean-square calculations are commonly used to quantify sEMG amplitude.

Other, non-invasive measures of fatigue include endurance time and ratings of perceived exertion. Endurance time is best used as an indicator of muscular fatigue when it is in combination with force or power output of the muscle (Vollestad 1997). Ratings of perceived exertion is a subjective measure of fatigue in which fatigue is rated on a 0-10 Category Ratio Scale (Borg 1982a). Although these methods provide a reliable indication of muscular fatigue (Enoka and Stuart 1992), they do not specify the mechanisms by which fatigue is developed. Therefore these scales would also be most effective in combination with other fatigue measures.

Muscle fatigue has consequences on the kinematics of the fatiguing task. For instance, fatigue from repetitive tasks such as hammering and sawing has been shown to decrease the range of motion (RoM) of the main joint involved in the movement (e.g. elbow) (Cote et al. 2002; Cote et al. 2005). However, these decreases in RoM have been associated with increased RoM at other joints that mechanically can compensate for the fatigued joint, for instance in these previous studies, the trunk. In addition, repetitive upper-limb fatigue has also been shown to lead to increases in EMG activity not only in fatigued muscles but also in others, such as the external obliques, suggesting that the system recruits trunk muscles in order to facilitate movement in additional planes and continue the task (Cote et al. 2008). Furthermore, kinematic analysis during a repetitive arm task revealed global postural adaptations as well. In this case, a lateral body shift towards the non-moving side was observed, accompanied by an increased anterior-posterior Center of Pressure (CoP) RoM (Fuller et al. 2009). These findings suggest that postural adaptations occur with shoulder fatigue as a mechanism to compensate for the decreases in RoM observed in the areas that are fatigued. However, if not well controlled, these global postural adaptations can become risk factors by compromising postural stability and increasing the chance of injury in fatigued individuals (Kang and Lipsitz 2010; Naussbaum 2003). In addition, the mechanisms behind these whole-body fatigue adaptations are still not well understood.

Proprioception

It has been suggested that fatigue can lead to injury through a degenerative effect on proprioception, consequently affecting a person's ability and accuracy in task performance (Myers et al. 1999). Proprioception is a term that encompasses several sensations involved in movement such as the senses of joint position, force, timing, orientation (Gandevia et al. 2002), and velocity (Cordo et al. 1994). Myers and Lephart (2000) describe proprioception as a set of sensory information that provides movement control and stability. The sensory information is detected by mechanoreceptors and sent to the central nervous system, where it is integrated with other afferent input in order to generate an appropriate motor response (Myers and Lephart 2000). It has also been suggested that proprioception plays an important role in movement coordination (Tunik et al. 2003). The integrity of the proprioceptive system allows for information about joint angles, muscle lengths, and degree of skin stretch to be transmitted to the central nervous system in order to be able to better plan complex movements and coordination patterns (Kerr & Worringham, 2002). Moreover, studies of deafferented patients suggest that proprioception is important in controlling movement variability (Sainburg et al. 1993) as well as the timing of movements, possibly due to long feedback delays (Sainburg et al. 1995; Forget and Lamarre 1987). When fatigue is present, the increase of the muscle spindle discharge threshold causes an overall decrease of afferent feedback (Balestra et al. 1992) and subsequently affects detection of limb orientation, possibly causing impaired proprioception (Macefield et al. 1990). It is important to understand the proprioceptive mechanisms involved in movement control and coordination, and how they are regulated in the presence of fatigue because proprioception plays a key role in controlling the coordination of movements; if movement coordination is compromised by fatigue, the risk of accidents or injuries can increase.

A few studies have focused on the effects of fatigue on proprioception, most of them focusing on position sense. It has been well demonstrated that position sense accuracy in the upper extremity decreases with fatigue (Carpenter et al. 1998; Bjorklund et al. 2000; Myers et al. 1999; Emery and Cote 2012). Fatigue from both eccentric and concentric exercise of the elbow flexors revealed that position sense accuracy decreased in a way that suggested that subjects believed the fatigued muscle to be longer that it actually was (Allen et al. 2007). However, position sense at one joint was not affected by fatigue in a more distant joint (Allen et al. 2010). In addition, position sense accuracy was improved when the entire limb was involved in the experimental task, rather than a task involving only the fatigued joint (Fuentes and Bastian 2010). This suggests that proprioception might benefit from assistance from areas not related to the site of fatigue during multi-joint tasks. While the effects of fatigue on position sense are beginning to be well understood, much less is known about the effects of fatigue on other perceptual characteristics.

Force Sense

As the second most studied proprioceptive characteristic in relation to fatigue, studies focusing on the upper extremities have shown that fatigue caused decreases in the accuracy in estimating a required level of force (Jones and Hunter 1983a, b; Proske et al. 2004; Carson et al. 2002). Authors have related this finding to an increased sense of effort with fatigue (McCloskey et al. 1974; Allen et al. 2010), with the sense of effort defined as a centrally generated sense which, for a given level of force, increases with fatigue and is thought to increase error, oftentimes in overestimating the level of force required. The sense of force has often been studied using a contralateral limb-matching procedure in which subjects are asked to estimate, with one limb, the force being produced by a fatigued muscle in the opposing limb, in relation to how accurately they predicted this force prior to fatigue. This method is used with the underlying assumption that one can accurately match a force with a contralateral limb, while not affected by fatigue. When subjects attempted to match a force exerted by the fatigued arm with the unfatigued arm, they tended to use more force than required with the unfatigued arm (Jones and Hunter 1983a, b; Proske et al. 2004). In contrast, in studies using the opposite paradigm, in which the fatigued limb attempted to match the force exerted by the unfatigued limb, subjects tended to use less force than required when asked to match the force of the unfatigued limb. This was true following fatigue from both concentric and eccentric exercise (Carson et al. 2002). Thus, findings from contralateral force matching tasks are equivocal, which can be related, at least in part, to differences in accuracy, force and/or fatigability between the non-dominant and dominant sides (Farina et al. 2003).

Several studies do point to possible differences in the fatigue response mechanisms depending on the level of force used. In protocols where the load to be matched was calculated relative to a person's strength, it has been shown that with greater strength comes lower time to fatigue (Hunter and Enoka 2001), as well as greater intramuscular pressure (Sadamoto et al. 1983), and consequently greater blood flow occlusion (Barnes 1980). This, in turn, could add to the impairment caused by fatigue. In fact, a rise in intramuscular pressure and consequence on blood supply has also been observed to occur at relatively low force levels of 10-20% maximal force (Wesche 1986). This is important because Bosch et al. (2011) measured the average trapezius activity level to be 10-15% maximal force during assembly line work. Thus, findings from studies on the effects of fatigue on the sense of force have been equivocal, likely due to the experimental methods used, especially in selecting the load used for the fatiguing and force-matching parts of the protocol.

Posture Sense

Several aspects of the effects of fatigue on characteristics of the sense of posture are well known. Many studies have shown that fatigue of muscles responsible for maintaining the standing posture results in decreased postural stability. For example, studies have shown that localized fatigue of the soleus, gastrocnemius, and trunk extensors each affect postural stability such that the center of pressure surface area, velocity, and mean and median frequency increase during quiet standing (Corbeil et al. 2003; Pinsault and Vuillerme 2010). Even when asked to stand as still as possible, fatigue of the ankle, knee, and hip was shown to increase CoP RoM velocity in both the mediolateral and anteroposterior directions (Gribble and Hertel 2004). Authors have explained this finding as a consequence of decreased neural transmission speed occurring with fatigue (Gribble and Hertel 2004), which has also been shown to occur in deafferented patients (Sainburg et al. 1995). Under normal, unfatigued conditions, maintaining postural stability involves constant corrective contractions to counteract small postural disturbances. Therefore it is possible that slowed neuromuscular transmission decreases the ability to control muscles that are responsible for maintaining a stable posture (Gribble and Hertel 2004). Similarly, localized fatigue of the upper trapezius and levator scapulae muscles from repetitive shoulder shrugging exercise, or from repetitive overhead reaches has also been shown to result in impaired control of the center of pressure (Vuillerme et al. 2005; Naussbaum 2003), with authors suggesting that this can be attributed to decreased cervical area proprioception.

During upper limb movement tasks, similar postural effects have been observed as fatigue accumulated from arm movement repetition. In a study of repetitive hammering and sawing, results showed that while fatigued, subjects displayed increased trunk motion in the same direction as the motion of the hammer or saw, which was interpreted as a way to compensate for the decreased range of motion of the fatigued elbow (Cote et al. 2002; Cote et al. 2005). Increased CoP range of motion in the anterior-posterior direction was also shown to occur as people performed a fatiguing upper extremity repetitive forward reaching task (Fuller et al. 2009). In addition, as people moved, the center of pressure shifted laterally, towards the side of the unfatigued arm, possibly to lessen the work of the fatigued arm (Fuller et al. 2009). The same lateral shift was observed in another study using a similar unilateral arm task performed in a seated position (Gates and Dingwell 2011). In it, subjects also showed a more forward inclined body posture when performing the task (Bosch et al. 2011; Pigini et al. 2008). In summary, studies have shown that postural adaptations can occur not only in the presence of postural muscle fatigue but also in the presence of upper extremity fatigue. Despite this, the mechanism underlying the changes in postural stability following upper limb fatigue is still unclear. The same can be said about the mechanisms underlying the changes in postural symmetry with fatigue. For instance, whether these adaptations are voluntary in nature or as simple mechanical consequence of the repetitive arm task is not well known. In these previous studies, subjects were free to move their trunk and only the arm task component was constrained. One can argue that both increased postural movements and lateral postural shifts can theoretically facilitate the arm task; however this is not sufficient to prove whether the system has control over postural stability and symmetry in order to contribute to the repetitive arm task while in a state of fatigue. Knowledge could help understand and predict injuries or accidents that could occur as a result, for instance, of working in an unstable or asymmetrical posture.

Rhythm Sense

Rhythm sense is among the functional characteristics related to proprioception that may affect repetitive movement control, and is operationally defined here as an ability to follow a set movement rhythm. Although not a sense attached to one proprioceptive submodality per se, this characteristic may rather have an important practical impact on one's ability to accomplish work that is repetitive in nature. No known studies to date have assessed how fatigue affects the ability to accurately perceive movement rhythm. However, some aspects that may relate to this characteristic include the ability to maintain movement accuracy and timing, in that well coordinated and rhythmic movements require that the muscles involved contract and relax at specific moments and in a specific sequence (O'Boyle et al. 1996). In addition, decreased position sense accuracy caused by fatigue (Myers et al. 1999) may also play a part in the ability to keep movement rhythm constant. In a study where subjects were asked to point to a remembered target with their finger before and after fatigue, Emery and Cote (2012) observed no change in finger position accuracy to occur with fatigue. However, an increase in peak finger speed, which was not constrained in this case, was also found, as people pointed to the remembered target, suggesting changes in the strategies used to achieve the task. Additional studies have reported that there was no change in average movement velocity following eccentric elbow flexor fatigue (Bottas et al. 2009), but that peak movement velocity decreased, suggesting an impaired trajectory symmetry through impaired movement acceleration and deceleration (Bottas et al. 2010).

Gates and Dingwell (2008, 2010) measured movement timing by observing the difference between the actual movement rhythm of repetitive task and the imposed rhythm, as subjects were to move following the beat of a metronome. They found no change in movement speed, a decrease in timing errors (Gates and Dingwell 2008), and increased movement stability (Gates and Dingwell 2010) in the post-fatigue condition. Another study of repetitive hammering and sawing, where movement rhythm was not constrained, revealed no change in average movement cycle duration or trajectory (Cote et al. 2005). However, in these tasks, fatigue led to a reorganization of movement strategies by altering the range of motion of joints around, and including the site of fatigue. This allowed for the task to continue even with fatigue and without altering the self-selected pre-fatigue movement rhythm (Cote et al. 2002; Cote et al. 2005; Mehta and Agnew 2010). Taken together, this suggests that, although various adaptations are present with fatigue, movement rhythm may be one aspect that is preserved by the system (Cote et al. 2005).

In the previous studies reviewed, motor learning may have been a factor involved in the maintenance of movement rhythm. Since performance was measured using the same task also used to generate fatigue, it is possible that the learning effects compensated the fatigue effects. Bosch et al. (2011) also observed rhythmic movements during a fatiguing task and compared the same task at two different working paces. Higher work pace was shown to result in a greater number of errors in the task (Bosch et al. 2011). In this case, subjects were allowed to correct errors, thereby not affecting the final quality of productivity, but possibly altering the working rhythm (Bosch et al. 2011). However this suggests that fatigue might affect working rhythm differently, depending on the speed of the task (Bosch et al. 2011). In summary, studies suggest that movement rhythm may be affected by fatigue. However, no studies to date have measured how accurate subjects can be in perceiving their own rhythm and how fatigue affects this ability. The mechanisms of rhythmic movement control, as for any other task, involve receiving and interpreting information, and planning and accomplishing the task. Therefore, it is possible that changes in one's ability to maintain a particular rhythm as fatigue develops may be associated not only to motor changes but in the ability to accurately perceive one's rhythm. Practically, a better understanding of these mechanisms could help predict changes in work pace that could occur during a workday and could affect productivity.

Gender

While men and women have many physiological similarities, important differences exist as well (Cote 2012). Firstly, fatigue affects men and women differently when it comes to endurance time. For instance, several have shown that time to fatigue is significantly longer in women than in men (Hunter et al. 2006; Albert et al. 2006). However, motor cortex stimulation of elbow flexors revealed that twitch torques were similar for men and women with fatigue, suggesting that the differences caused by fatigue between men and women are generated peripherally (Hunter et al. 2006). In addition, some mechanisms of fatigue may be task-specific. For example, when fatigue is generated from concentric exercise, elbow flexion torque during maximal contractions decreased to a greater extent in men than in women (Albert et al. 2006). Conversely, following fatigue from eccentric contractions, women exhibited greater decreases in maximal force of elbow flexors than men (Sewright et al. 2008).

To date, not many have studied differences in the way proprioception is affected by fatigue between men and women. Since it is well documented that men are stronger than women, higher strength in men could add to the impairement caused by fatigue on proprioception through a negative effect on blood supply to the muscles, as was explained earlier. In addition, further research found that, in response to fatiguing lower extremity activity, metabolites increased more in men than in women (Kent-Braun et al. 2002). Since altered afferent feedback may be responsible for changes in proprioception, it is possible that certain physiological mechanisms that differ between males and females may be responsible for differences in the way proprioception is affected by fatigue between the two genders.

So far, position sense following submaximal repetitive shoulder activity has led to controversial results regarding possible gender differences. For instance, both Pedersen et al. (1999) and Bjorklund et al. (2000) showed that while error in the ability to reproduce shoulder angles increased with fatigue in both men and women, error increased to a significantly greater extent in women. However, following an adjustment of the analysis according to each individual shoulder position assessed, it was revealed that no significant difference existed between men and women in the ensemble of shoulder positions (Bjorklund et al. 2003).

Fatigue has also caused men and women to show differences in the maintenance of postural control. For example, following whole-body fatigue from a rowing ergometer, women experienced greater variability of center of pressure displacement in the anterior-posterior direction than men (Springer and Pincivero 2009). Conversely, localized muscle fatigue of the plantar flexors caused greater center of pressure displacement variability than whole-body fatigue did, but was no different in women than in men (Springer and Pincivero 2009). In addition, no change was observed between men and women for mediolateral center of pressure displacement following both whole-body, and localized muscle fatigue (Springer and Pincivero 2009).

In summary, gender effects on position sense and posture sense remain equivocal, and no studies have investigated possible gender differences in the senses of force or rhythm. However, taken together, studies suggest differences in the mechanisms underlying the fatigue response between genders, with these differences possibly involving gender differences in how fatigue affects various components of proprioception. Gaining a better understanding of these issues may help understand why women report higher prevalence of neck/shoulder symptoms (Juul-Kristensen et al. 2004) and may help tailor more effective, gender-specific interventions.

In conclusion, studies have led to conflicting results in some cases, and have left some questions unanswered in others, with regard to how fatigue affects performance related to proprioceptive characteristics. It is important to quantify the mechanisms by which fatigue affects performance in order to better understand and predict the movement changes that will occur. This could then lead to more effective interventions to decrease incidences of work-related musculoskeletal injuries and consequently, decrease absences. By quantifying the effects of fatigue on proprioception in a laboratory setting using tasks that are related to occupational requirements, this study could serve as a stepping stone in the creation of preventative measures, rehabilitation techniques, and eventually understanding the long-term effects.

RESEARCH ARTICLE

The effects of repetitive motion-induced shoulder fatigue on proprioception.

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ABSTRACT

Neck/shoulder fatigue has been associated with increased risk of injuries and disorders. We have previously shown that healthy adults demonstrate whole-body compensatory strategies as a result of performing repetitive upper-limb fatiguing tasks. However, the effects of fatigue on various perceptual characteristics related to proprioception such as the senses of force, rhythm, and posture, are not well understood. Asymptomatic adults (13 male, 13 female) performed three tests with their dominant arm, followed by fatigue-inducing repetitive motions, and then repeated the same three tests. The three tests assessed force sense, rhythm sense, and posture sense. Results revealed a significant Time x Gender interaction effect on anterior-posterior (AP) center of pressure (CoP) range of motion (RoM) (P = 0.017) during a quiet standing task, whereby AP CoP RoM increased with fatigue in both genders but only significantly so in men. There was also a significant Time effect for AP CoP displacement during that task ($P = 0.024$). There were no Time or Interaction effects on relative force-matching accuracy ($P = 0.44$), nor on the ability to maintain a particular timing between touches during a repetitive task ($P = 0.69$). However, a significant Gender effect whereby males made 46.22% force-matching error compared with females' error of 5.93% on matching accuracy of a 12N load. Since our study involved relatively low efforts, compensations from unfatigued muscles possibly explains subjects' ability to preserve certain task characteristics despite being fatigued. However,

the significant effect of fatigue on postural stability during quiet standing may help us explain our previous findings on postural changes during the fatiguing repetitive task. We do not fully understand the mechanisms by which repetitive upper limb motion-induced fatigue may impair postural stability, but it is possible that these mechanisms could involve changes in other systems, occurring with global fatigue. More studies are needed to shed light into that question.

1. Introduction

Injuries and disorders of the neck/shoulder area are increasingly common (van Rijn et al. 2010; Nimbarte et al. 2012; Chang et al. 2012; Bodin et al. 2012) and can lead to decreases in performance in the workplace, and during activities of daily living, (Bigland-Ritchie and Woods 1984; Lomond and Côté 2011). Studies suggest that muscle fatigue, which is a common consequence of repetitive motions, is one of the major precursors to injuries and disorders of the neck/shoulder (Luopajarvi et al. 1979; Silverstein et al. 1998; Nordander et al. 1999; Herberts et al. 1981). Muscle fatigue can be defined as “an acute impairment in performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (Enoka and Stuart 1992). Studies have shown that fatigue leads to a decrease in maximal voluntary force output (Albert et al. 2006), as well as decreases in speed of task execution, accuracy (Bosch et al. 2011; Bottas et al. 2009), and proprioception (Myers et al. 1999).

Our proprioceptive abilities play an important role in the control of various aspects of movement such as limb position, joint angle, speed, and force (Kerr and Worringham 2002). Myers and Lephart (2000) describe proprioception as a set of sensory information that provides movement control and stability. Sensory information from the musculoskeletal system is detected by mechanoreceptors and sent to the central nervous system, where it is integrated with other afferent input in order to generate an appropriate motor response (Myers and Lephart 2000). Proprioception encompasses three main submodalities, including the sensations of kinaesthesia, or joint movement, joint position sense (Warner et al. 1996), and sense of force (Proske 2005). If our ability to receive and use proprioceptive information from various parts of the body is affected by fatigue, the risk of injury can increase (Safran et al. 2001; Warner et al. 1996). It has been well demonstrated that position sense accuracy in the upper extremity decreases with fatigue (Carpenter et al. 1998; Bjorklund et al. 2000; Myers et al. 1999; Emery and Cote 2012). However, in large part, the effects of fatigue on other aspects of proprioception are not well understood.

For one, the effect of fatigue on the sense of force has been the object of several previous experiments (Vuillerme and Boisgontier 2008). Studies focusing on the upper extremities have shown that fatigue caused decreases in the accuracy in estimating a required level of force (Jones and Hunter 1983a, b; Proske et al. 2004; Carson et al. 2002), which has been related to the sense of effort, which is thought to be central in origin (McCloskey et al. 1974; Allen et al. 2010). Several researchers have used a contralateral limb-matching procedure in which subjects are asked to estimate the force being produced by a fatigued muscle in the opposing limb. However, this method is used with the underlying assumption that one can accurately match a force with a contralateral limb, which can represent a confounding factor when studying the effects of fatigue on a muscle’s sense of force. Moreover, the absolute level of force used in the force matching protocols may play a role in the force-matching inaccuracies shown. In studies where the load was chosen as a percentage of the muscle’s strength, it was shown that with greater strength came lower time to fatigue (Hunter and Enoka 2001). This has been interpreted to be indicative of greater intramuscular pressure (Sadamoto et al. 1983), and consequently greater blood flow occlusion (Barnes 1980) being produced at higher force outputs, which could also result in decreased proprioceptive abilities. Thus, findings from studies on the effects of fatigue on the sense of force have been equivocal, likely due to the experimental methods used, especially in selecting the load used for the fatiguing and force-matching parts of the protocol.

Another well-documented effect of fatigue is on postural stability. Several researchers have shown decreases in postural stability, as measured with increases in displacements of the center of pressure (CoP) under the feet in the standing position, to occur with fatigue. This has been shown to occur when fatigue was induced at the ankle muscles (Corbeil et al. 2003; Pinsault and Vuillerme 2010; Gribble and Hertel 2004), or in other muscles; indeed, localized fatigue of the upper trapezius and levator scapulae muscles also resulted in decreased control of the center of pressure (Vuillerme et al. 2005; Naussbaum 2003). Vuillerme, Pinsault, and Vaillant (2005) suggested that this can be attributed to decreased cervical area proprioception, and hypothesized as to the importance of this muscle group to postural stability. Moreover, increased center of pressure movements have been shown to develop during upper extremity repetitive tasks in both standing (Fuller et al. 2009) and seated (Gates and Dingwell 2011) positions. However, in these tasks, subjects were free to move their trunk and only the arm tasks were constrained, such that the increased center of pressure displacements may have been voluntary in order to mechanically contribute to the arm movement task component; this interpretation is supported by the observation that the center of pressure shifted laterally, towards the side of the unfatigued arm, throughout the arm movements, suggesting an arm-task specific adaptation. However, the voluntary nature of these postural adaptations remains to be clarified.

While several studies have investigated the effects of fatigue on the sense of force, no known studies to date have assessed the ability to maintain the rhythm of a task in the presence of fatigue. However, some aspects that may relate to this characteristic include the ability to maintain movement accuracy, movement speed and movement timing consistency. To date, repetitive motion-induced fatigue of the shoulder has not been shown to affect timing consistency, end-point trajectory or accuracy, or movement duration of the fatiguing task (Gates and Dingwell 2008, 2010; Emery and Cote 2012). Instead, shoulder fatigue led to a reorganization of movement strategies by altering the range of motion of proximal joints around, and including the site of fatigue (Cote et al. 2002; Cote et al. 2005; Mehta and Agnew 2010). Previous findings suggest that these adaptations delay fatigue, and maintain the integrity of the task (Fuller et al. 2011; Fuller et al. 2009; Gates and Dingwell 2011; Cote et al. 2005), suggesting that movement rhythm consistency may be one aspect that the system prioritizes in organizing fatigue adaptations. However, in these previous studies, subjects were allowed to move at their own preferred rhythm, in other words rhythm was not constrained and rhythm accuracy was not measured. Thus whether one's accuracy in following a set rhythm is preserved despite fatigue, such as what chain employees are required to do during a work day, is not known.

Previous studies have shown differences in how males and females respond to fatigue (Cote 2012). For instance, females have shown a longer time to fatigue than males in some studies (Hunter et al. 2006; Albert et al. 2006). However, performance differences in response to fatigue between males and females may be task-specific. For example, when fatigue is generated from concentric exercise, elbow flexion torque decreased to a greater extent in men than in women (Albert et al. 2006). Conversely, following fatigue from eccentric contractions, women exhibited greater decreases in maximal force output of elbow flexors than men (Sewright et al. 2008). In addition, whole-body fatigue caused females to experience greater variability of center of pressure displacement in the anterior-posterior direction than males (Springer and Pincivero 2009), although local muscle fatigue of the plantar flexors caused no difference between males and females' CoP variability and mediolateral CoP displacement (Springer and Pincivero 2009). Gender differences in the fatigue response also seem to affect the role of proprioception, although these findings remain controversial. For instance, larger errors in shoulder position sense were previously observed in women (Pedersen et al. 1999). Bjorklund et al. (2000) supported these findings in showing that while position sense error of shoulder adduction and horizontal abduction increased with fatigue in both men and women, error increased to a significantly greater extent in women. However, following an adjustment of the analysis according to each individual shoulder position assessed, it was revealed that no significant difference existed between men and women in the ensemble of shoulder positions tested (Bjorklund et al. 2003). Taken together, these studies suggest differences in the mechanisms underlying the fatigue response between genders, with these differences possibly involving gender differences in how fatigue affects components of proprioception.

In summary, a review of the literature suggests that little is known about how fatigue may lead to decreases in performance. The mechanisms by which this occurs, which could involve fatigue effects on various perceptual characteristics related to proprioception such as the senses of force, rhythm, and posture, are not well understood. The integrity of these perceptual characteristics is essential for accurate movement control and coordination. Moreover, impairments in these aspects may affect everyday functioning such as various work-related tasks. The main objective of this research was to quantify the effects of upper limb repetitive-motion induced fatigue on the senses of force, rhythm, and posture. We hypothesized that fatigue would lead to decreases in the accuracy displayed by all three submodalities, and that there would be gender differences in performance across related tasks.

2. Methods

2.1 Participants

Twenty-six subjects (13 men, 13 women; 28.4 (±11.3) years; average height 172.72 (±6.64) cm and 161.78 (±5.99) cm, respectively) were recruited from the community through personal contacts to participate in a repeated measures study design. All subjects were right-handed, healthy volunteers and were excluded if they had a history of upper limb, shoulder or neck pain or injury within the last year. All subjects provided written, informed consent prior to participation. Ethical approval was obtained from the Montreal Centre de recherche interdisciplinaire en réadaptation (CRIR) and all data collection took place at the research facility of the Jewish Rehabilitation Hospital, Laval, Quebec.

2.2 Experimental Protocol

Subjects performed three tests with their right arm, followed by fatigue-inducing repetitive motions, and then repeated the same three tests. The three proprioceptive modalities assessed were related to the senses of force, rhythm, and posture. Force sense was assessed with two tests, one in which the load was one known weight used by all subjects, and the other in which the load was calculated relative to each subject's maximal shoulder force. All tests were randomized per subject in the pre-fatigue condition and repeated in the same order in the post-fatigue condition.

Before beginning the force sense tests, subjects performed two trials of maximal voluntary isometric contractions (MVIC) of dominant shoulder elevation against a fixed resistance from a seated position (Fig. 1A). These trials were performed in ramp-up, ramp-down fashion and lasted approximately 5s. Following the MVIC, both force sense tests were administered, in a random order. In one, we required subjects to perform three trials of shoulder elevation against a load of 30% of their MVIC, using the same setup as for the MVIC. This value was chosen based on the approximate weight experienced by the upper trapezius while holding the arm in 90° of abduction. The other force sense test was also performed using the same setup, however all subjects were asked to exert 12.73 N of force. This value was chosen based on the approximate level of force needed by the shoulder during activities of daily living such as holding grocery bags. During the MVIC and both force sense tests, all subjects were reminded to keep their ankles crossed and under the chair with their arms hanging by their sides. The subjects were allowed to perform one practice trial in which they received feedback verbally and from an oscilloscope (Tektronix 2221, Tektronix, Inc., Beaverton, OR, USA), followed by three test trials performed without feedback. For all test trials, subjects were instructed to signal when they reached the desired level of force by pressing an indicator button held in their contralateral (left) hand.

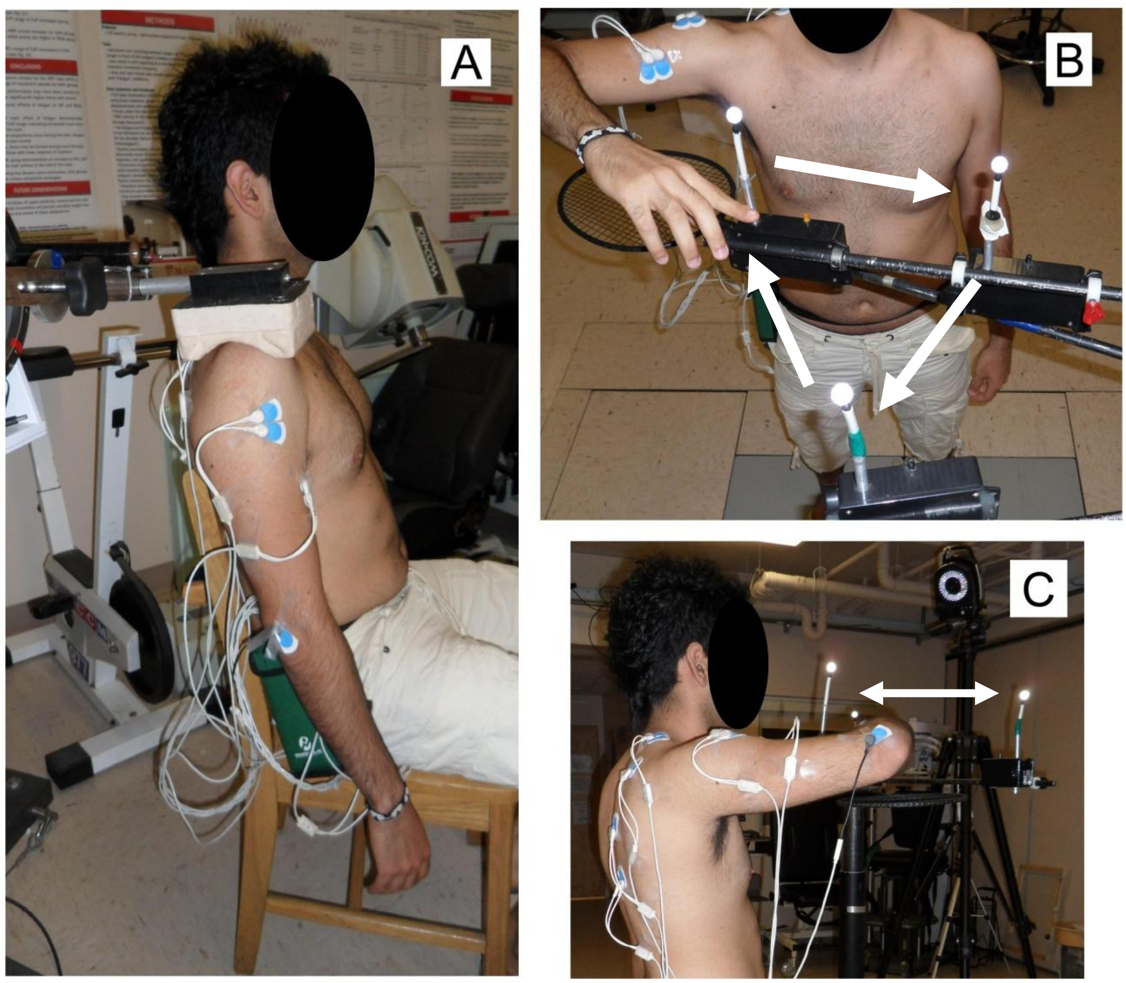

Fig. 1. Experimental setup for each of the following: A) Maximal voluntary isometric shoulder elevation and force-matching tasks; B) Rhythm sense task; C) Repetitive pointing fatiguing task. Arrows indicate movement direction.

The rhythm sense test required subjects to alternate touching three targets placed in a transverse plane, with the vertical position of all three targets adjusted to each subject's shoulder height. The targets were set up in a triangular pattern with a base of 24 cm and a height of 22 cm (Westgaard and Bjorklund 1987; Nederhand et al. 2000), with the center of the base of the triangle aligned with each subject's sternum (Fig. 1B). In a standing position, with the non-dominant hand resting at their side and the dominant hand elevated to shoulder height, subjects were instructed to alternate touching each target in a clockwise rotation with their dominant hand to a beat of 88 touches per minute. Subjects performed the task for 10 seconds with the help of a metronome and then continued for 30 seconds without auditory feedback. A mesh barrier (elliptically shaped, major axis: 24.5 cm, minor axis: 20.5 cm) was placed under the elbow trajectory, serving as a reminder to keep the entire arm moving in a horizontal plane at shoulder height throughout the task.

The posture test consisted of a 30-second period of quiet standing with each foot placed on one of two force plates. Foot position consistency was controlled by instructing subjects to align each foot along markings on the force plates, with 25.4 cm between the insides of each midfoot. Subjects were instructed to stand in a comfortable position, with both eyes closed and both arms at rest by their sides. Instructions were to "stand as still, and as symmetrically as possible". Prior to the recorded quiet standing period, subjects received feedback on their postural stability by briefly viewing live force plate output.

2.3 Fatigue Protocol

Subjects performed a repetitive pointing task (RPT) to fatigue with the dominant arm. This protocol was set up similarly to that of the rhythm sense test using the touch-sensitive targets and an elliptically shaped mesh barrier. However subjects alternated touching two targets, aligned with each subjects' midline, one at 100% of arm's length, and the other at 30% of arm's length (Fuller et al. 2009) (Fig. 1C). Subjects were instructed to touch one target each second (1 Hz movement rhythm), as guided by a metronome and were asked to rate their self-perceived shoulder exertion on a 0-10 scale, according to a large printout of the Borg CR-10 scale (Borg 1982b) at the end of every minute. The RPT continued until subjects were either no longer able to maintain the 1 Hz rhythm, the elbow made contact with the mesh barrier, or they reported a perceived exertion of 8 or higher out of 10 on the Borg CR-10 scale.

At the completion of each test in the post-fatigue condition, subjects were asked to re-evaluate their self-perceived level of shoulder exertion. If the rating was less than 8, they were asked to perform the RPT again before beginning the next post-fatigue test. Again, subjects reported their self-perceived level of shoulder condition at the end of every minute, and the RPT was performed until the same stoppage criteria as earlier were satisfied.

2.4 Data Acquisition

Disposable Ag/AgCl surface electrodes (Ambu™, Denmark) were applied on selected muscles in a bipolar configuration, parallel to muscle fibres, with a center-to-center distance of 3 cm (Basmajian and Blumenstein 1980). The skin was cleaned with an alcohol swab, and shaven, when necessary. EMG data were collected from the upper, middle, and descending fibres of the trapezius, the supraspinatus, middle deltoid, and biceps brachii, and a ground electrode was placed on the right lateral epicondyle. To avoid crosstalk between neighbouring muscles and ensure the quality of data, recommended guidelines were respected (Basmajian and Blumenstein 1980), and an inspection of the signals was conducted prior to performing experimental trials. A TeleMyo 900 EMG measurement system recorded the electrode signals, at a sampling frequency of 1,080 Hz.

All forces measured during the MVIC and force sense tests were collected via a fixed resistance apparatus, equipped with a load cell (Standard 402 FSR, Interlink Electronics, Inc., Camarillo, CA, USA). The load cell was calibrated prior to each testing session, yielding a conversion factor, used to express output in terms of percent error.

Touch-sensitive targets with a length of 6 cm, a radius of 0.5 cm, and a response time of 130 ms (Quantum Research Group Ltd.) were used during both pre-fatigue and post-fatigue rhythm sense tests, and during the RPT. The analog signals obtained from the touch-sensitive targets were collected using Workstation software (Vicon Motion Systems Ltd., Oxford, UK).

During the posture test, each foot was placed on one of two triaxial strain gauge force plates (AMTI© OR6-7, AMTI Inc, Watertown, USA) which measured ground reaction forces and moments applied by each foot at a sampling frequency of 1,080 Hz.

2.5 Data Analysis

For MVIC trials, the peak force value across all trials was kept and used as the MVIC value, from which the 30% MVIC force level to be matched was calculated. For force sense trials, force signals collected from the load cell were partitioned according to the signal recorded from the indicator button, and averaged over the time period that the button was activated. Load cell output was used to calculate percentage error of the actual force in comparison with the expected force for both the pre- and post-fatigue conditions and for both force sense tests.

For posture sense trials, ground-reaction moments and forces recorded over the periods of interest were low-pass filtered at 10 Hz with a dual-pass fourth-order Butterworth filter, and CoP trajectories in AP and

ML were calculated across the time periods of interest. To compute postural stability, two methods were used. First to compute CoP displacement, CoP time series were rectified and root-mean-square (RMS) amplitudes were calculated per second (Eq. 1), and averaged over 30 seconds. In addition, the difference between the maximum and minimum COP position in each direction was used to quantify range of motion (ROM). Both methods were applied on both AP and ML time series. To compute postural symmetry, two methods were used: first, the average CoP position across each 30s sample of interest was calculated in both AP and ML. In addition, the average relative weight under each foot over each 30s sample of interest was computed.

Eq. 1 $RMS = \sqrt{\frac{\sum_{i=1}^{n}(x_i)^2+(x_i+1)^2+\cdots+(x_i+n)^2}{n}}$

For rhythm sense trials, activation times of each target were used to identify the moment of target touches in order to calculate the average delay in activation between two targets throughout the 30-second trial. The difference between the average delay between consecutive target touches and the reference delay computed from the set rhythm of 88 touches per minute was computed. In addition, total duration between the first and last touches for 30 touches was also used to calculate average speed. This was then used to calculate percent error in actual speed compared with the expected speed of 1.47 touches*s^{-1}.

EMG data collected during the fatigue protocol and during all tests were filtered using a dual-pass 4^{th}-order Butterworth bandpass filter (20-500 Hz). EMG data were then filtered for heartbeats by identifying one reference heartbeat per trial, and cross-correlating it with the remaining signals to remove heartbeats from all 6 muscle signals. Signals were then rectified. To verify that the RPT was effective in inducing muscle fatigue, EMG collected during the first and last 30 seconds of the RPT were compared. For each muscle, RMS was calculated over 30 1-s windows, and an average EMG RMS value was obtained. In addition to this analysis, EMG data collected during the experimental tasks were also analyzed to verify that muscle fatigue effects remained during the performance of the proprioception trials. Average EMG RMS amplitudes for the 30-second rhythm sense test were also calculated based on 30 1-s windows. For the force sense tests, average RMS amplitudes were calculated on 100-ms windows corresponding to the time during which the indicator button was activated. All EMG RMS values were normalized to represent a percentage of the highest 100 ms EMG RMS window calculated from the MVIC trials. In addition to EMG amplitude analyses, the amount of electromyographic variability was calculated as standard deviations of each averaged normalized EMG RMS parameter, expressed as a percentage of average EMG RMS values. All analyses were performed using Matlab software (MathWorks, Massachusetts, USA).

2.6 Statistical Analysis

Data were averaged for all three trials of the relative force sense and the absolute force sense tests for each subject, as well as throughout each 30 second trial of both posture sense tests and rhythm sense tests. For all dependent variables, the effect of fatigue was measured using a two-way repeated measures analysis of variance (ANOVA), with pre-fatigue and post-fatigue comparisons as a within-subjects variable and male and female comparisons as a between-subjects variable. All statistical analyses were computed using Statistica, v. 7.0 software (Statsoft, Tulsa, OK, USA), and statistical significance was set at $p < 0.05$.

3. Results

3.1 Evidence of Fatigue

Average time to termination of the repetitive pointing task (RPT) was 6.02 minutes (± 3.27 min). T-test results showed no significant difference in time to fatigue between males (5.35 ± 2.16 min) and females (6.69 ± 4.07 minutes, $P = 0.21$). 25 out of 26 subjects ended the RPT after reporting their perceived shoulder exertion to be 8 or greater on the Borg CR-10 scale, as per one stoppage criterion. One subject terminated the RPT herself, stating that she could no longer continue, and reporting her perceived shoulder exertion to be 7 on the Borg CR-10 scale. Data analysis did not reveal this subject's data to be an outlier, and it was therefore not excluded from the analysis.

When comparing data collected during the first and last minute of the RPT, there were main Time effects on EMG RMS of the supraspinatus and biceps brachii, both muscles showing significant increases with time ($F = 27.19$ (1,22), $P = 0.00003$ and $F = 11.48$ (1,22), $P = 0.002$, respectively) (Fig. 2). There was a main Time effect for the within-subject standard deviation (SD) of the supraspinatus EMG RMS in which it significantly increased ($F = 6.65$ (1,22), $P = 0.01$). There was also a significant Time x Gender effect on the lower trapezius ($F = 4.36$ (1,22), $P = 0.04$) (Fig. 3), with post-hoc analysis revealing that EMG RMS increased for males ($F = 8.83$ (1,11), $P = 0.013$), and did not change for females ($F = 2.09$ (1,11), $P = 0.18$), with time.

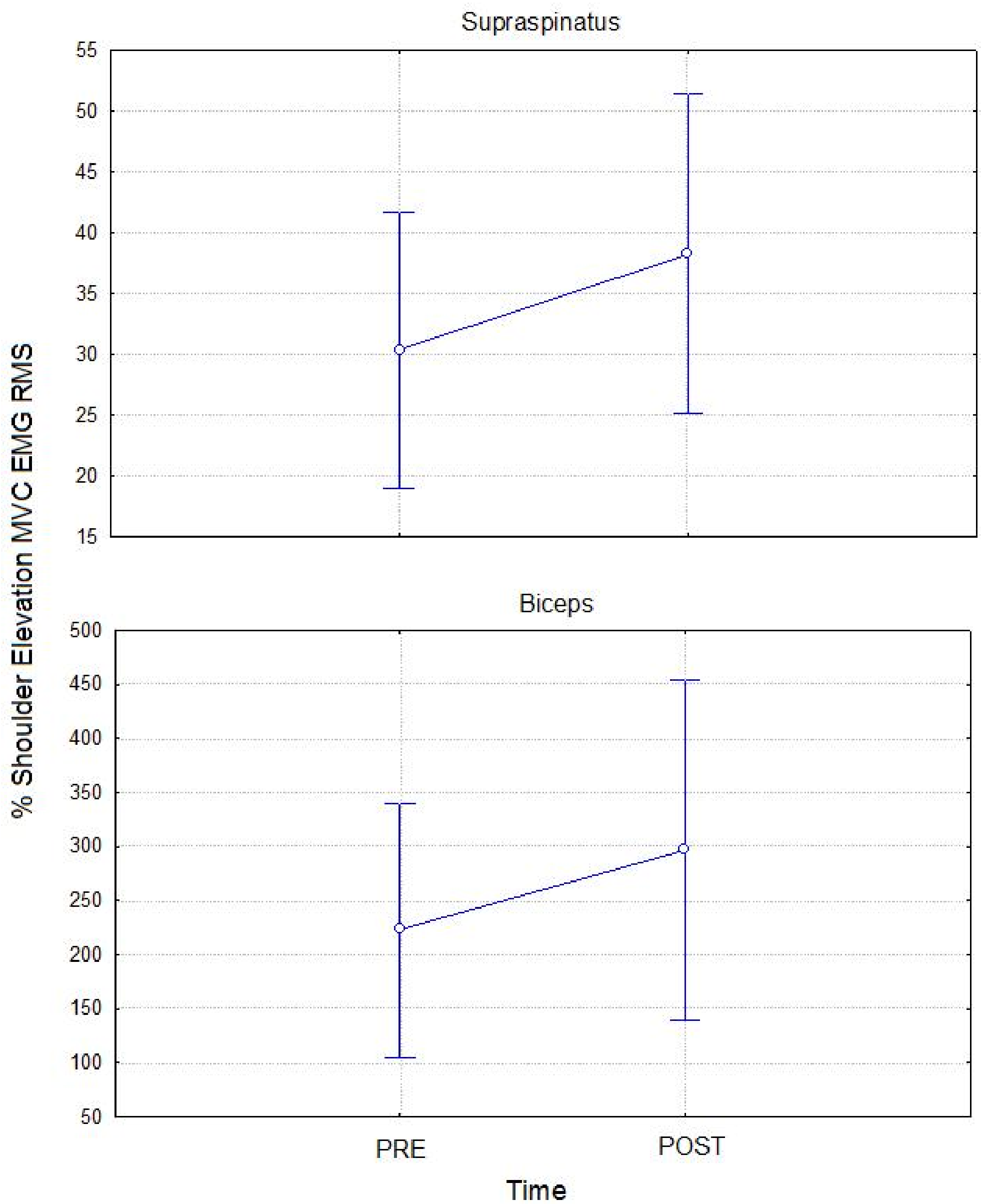

Fig. 2. Average Supraspinatus and Biceps Brachii root-mean-squared amplitude during the last 30 seconds of the first minute (Pre) and the last 30 seconds of the last minute (post) of the repetitive pointing task. Vertical lines represent 95% confidence intervals.

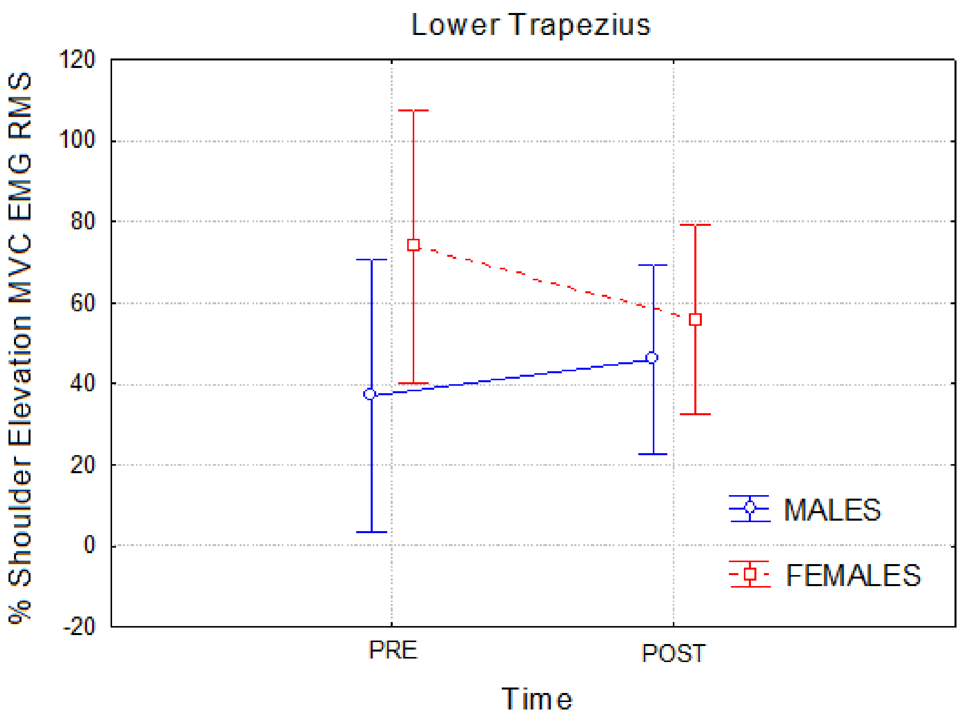

Fig. 3. Time x Gender Interaction effect of % maximal shoulder elevation EMG root-mean-square amplitudes for the lower trapezius during the last 30 seconds of the first minute (Pre) and the last 30 seconds of the last minute (post) of the repetitive pointing task for males (solid blue line) and females (dotted red line). Vertical lines represent 95% confidence intervals.

3.2 Force Sense

There were no significant Interaction or Time effects on measures of the sense of force (F = 0.36 (1,24), P = 0.55 and F = 1.28 (1,24), P = 0.27, respectively) as assessed with our absolute force matching protocol. However there was a main effect of Gender in which males overestimated the target force value, and their error in doing so was significantly higher than the error of females (F = 5.99 (1,24), P = 0.022; Fig. 4), who were closer to the target value. In addition, there was a main Time effect on the within-subject EMG RMS SD of the biceps brachii collected during this task, which increased (F = 5.40 (1,24), P = 0.029). There were also significant Gender effects on the upper trapezius and middle deltoid EMG RMS in which the amplitudes were greater in females than in males (F = 6.82 (1,24), P = 0.015 and F = 5.63 (1,23), P = 0.026). There was also a main Gender effect on within-subject SD of the middle deltoid EMG RMS collected during this task, where it was higher in females (F = 5.42 (1,23), 0.029).

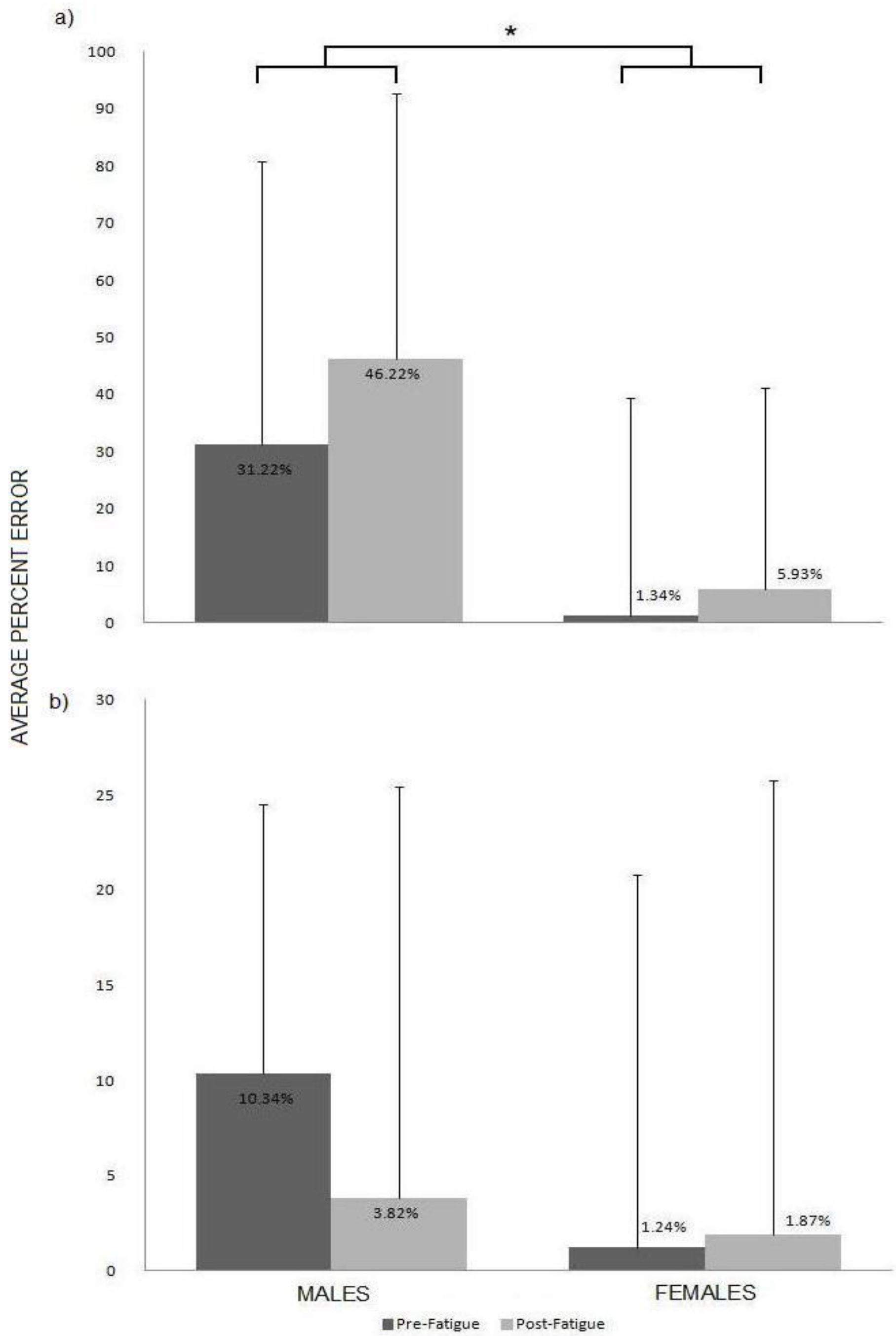

Fig. 4. Average percent error for males and females during the absolute (a) and relative (b) force sense tasks. Significant values are indicated by symbols (*p = 0.022) and denote a significant Gender effect. Vertical lines represent standard deviations.

There were no significant Main or Interaction effects on the sense of force measured with our relative force-matching protocol (F = 0.62 (1,24), P = 0.44, F = 0.42 (1,24), P = 0.52 and F = 0.73 (1,24), P = 0.40, respectively). The accuracy of men and women was not statistically different when using the relative force matching protocol, with an average of 3.82% error in males and of 1.87% error in females, and it was not affected by fatigue, with 5.79% error before and 2.84% error after fatigue. There was a main Time effect for the RMS of the upper trapezius collected during this task, in which it increased (F = 5.86 (1,24), P = 0.023). There was also a significant Gender effect on the upper and lower trapezius (F = 14.39 (1,24), P = 0.00089 and F = 4.74 (1,24), P = 0.039, respectively) in which females showed greater EMG RMS than males. There was a significant Time x Gender effect on the SD of the middle trapezius EMG RMS recorded during this task (F = 5.27 (1,23), P = 0.031). Post-hoc analysis revealed that in females there was a significant increase (F = 5.00 (1,12), P = 0.045) whereas in males there was no change (F = 0.81 (1,11), P = 0.39). There was a main Time effect for the middle deltoid EMG RMS SD in which it increased (F = 4.77 (1,23), P = 0.039). There was a Gender effect of the EMG RMS SD for the upper trapezius in which females were greater than males (F = 6.27 (1,24), P = 0.019).

3.3 Posture Sense

Table 1 summarizes the center of pressure characteristics during the quiet standing task. Figure 5 depicts sample data for one subject representing typical CoP trajectories in the pre- and post-fatigue conditions. A significant Time x Gender effect on CoP range of motion (ROM) was found in the anteroposterior direction (F = 6.63 (1,23), P = 0.017) with post-hoc analysis revealing that males showed an increased ROM post-fatigue (F = 8.25 (1,12), P = 0.014), while females showed no change (F = 0.03 (1,1), P = 0.86). A significant Time effect on anteroposterior displacement (average CoP RMS) was also found (F = 5.81 (1,23), P = 0.024), where AP CoP displacement increased with fatigue. However, there were no Main or Interaction effects on average CoP positions, neither in the AP nor ML directions (F = 3.19 (1,23), P = 0.087 and F = 0.34 (1,23), P = 0.57, respectively), nor were there any significant effects on the difference between the percent of total weight under the right foot and the left foot (F = 0.08 (1,23), P = 0.77).

Table 1

Mean (SD) and P-values of center of pressure (CoP) characteristics during quiet standing in anteroposterior (AP) and mediolateral (ML) directions for males (M) and females (F).

	Pre-fatigue (mean (SD))		Post-fatigue (mean (SD))		Time X Gender *P*<0.05	Time *P*<0.05	Gender *P*<0.05
	M	F	M	F			
% total weight under right foot	50.80 (1.79)	49.98 (1.92)	50.39 (1.53)	49.76 (2.91)	ns	ns	ns
CoP Position							
AP	1.64 (8.37)	-1.55 (6.01)	8.84 (12.47)	-1.15 (8.85)	ns	ns	ns
ML	81.30 (14.27)	87.99 (11.86)	81.87 (11.33)	91.02 (14.86)	ns	ns	ns
CoP ROM							
AP	11.35 (4.23)	9.37 (3.94)	22.52 (15.22)	9.48 (3.59)	0.017	0.013	0.009
ML	3.89 (1.04)	3.94 (2.32)	5.78 (2.68)	3.72 (2.10)	ns	ns	ns
CoP Displacement							
AP	6.55 (5.40)	5.33 (2.99)	11.91 (9.55)	7.63 (4.15)	ns	0.024	ns
ML	81.30 (14.27)	87.99 (11.86)	81.88 (11.33)	91.02 (14.86)	ns	ns	ns

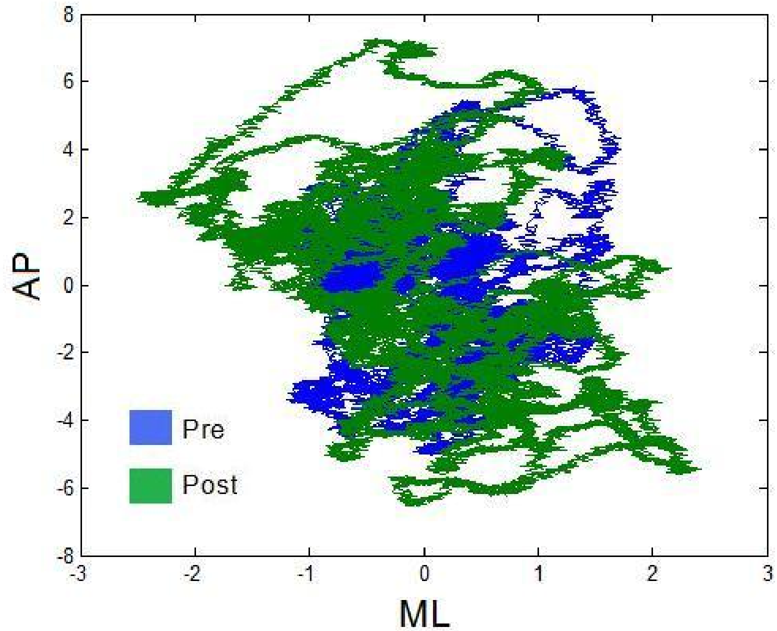

Fig. 5. Representative data for one subject showing CoP position trajectory during the 30-second quiet standing posture sense task in the pre-fatigue (blue) and post-fatigue (green) conditions.

3.4 RhythmSense

There were no Interaction effects in the time that it took for subjects to make 30 touches, nor in the average time delay between touches (F = 2.14 (1,24), P = 0.16 and F = 0.16 (1,24), P = 0.69, respectively). Middle trapezius, lower trapezius and biceps brachii EMG RMS recorded during this task all significantly increased with time (F = 6.97 (1,23), P = 0.015, F = 6.17 (1,24), P = 0.020, and F = 18.73 (1,24), P = 0.00023, respectively). In addition, there was a main Time effect of the biceps brachii EMG RMS SD in which it increased (F = 10.62 (1,24), P = 0.0033). A significant Gender effect for the supraspinatus showed that females had a greater

EMG RMS than males, and greater EMG RMS SD (F = 6.22 (1,24), P = 0.019 and F = 5.86 1,24), P = 0.023, respectively).

4. Discussion

4.1 Evidence of Fatigue

The objective of this study was to understand how posture and movement characteristics associated with shoulder proprioception, such as the senses of shoulder force, of upper limb movement rhythm, and of postural control, are affected by fatigue from a repetitive pointing task. Average time to termination of the repetitive pointing task (mean 6.02 ± 3.27 min) was similar to that in previous studies using the same repetitive pointing task (Lomond and Cote 2010; Emery and Cote 2012; Fuller et al. 2009). Repetitive arm movements at shoulder height have been shown to cause fatigue as identified by an increase in the EMG RMS amplitudes of fatigued muscles (Bigland-Ritchie et al. 1986; Fuller et al. 2009). Our findings show significant increases of the EMG RMS of the supraspinatus, and biceps brachii muscles during the RPT. Moreover, our findings also show an increase in the variability of the EMG RMS of the supraspinatus, with increased EMG variability being another accepted, albeit less well documented sign of muscle fatigue (Fuller et al. 2011). Variability of the biceps also increased during the absolute component of the force sense task, and middle trapezius and middle deltoid variability increased during its relative component. Taken together the increases in EMG RMS amplitudes, in EMG signal variability, and in levels of perceived exertion at the end of the repetitive pointing task confirm that the task was successful in inducing fatigue in the neck and shoulder area. In addition, the observation of Time effects on the EMG data recorded during the experimental tasks further support that muscle fatigue was present until the post-fatigue experimental tasks were completed.

Recent studies, also focusing on upper limb fatigue, showed a longer time to fatigue for women compared with men (Hunter et al. 2004; Albert et al. 2006), however our results did not show any significant difference in this parameter between the two genders. This could be because our fatigue protocol targeted the shoulder musculature, rather than the elbow flexors, which was the targeted muscle group in these previous studies. Moreover, our EMG analyses show that the effects of the RPT on muscle activity characteristics of both genders are mostly similar. However, our fatiguing task significantly increased the EMG RMS of the lower trapezius in males only, suggesting that greater fatigue was reached in this muscle at the end of the task in males, compared to females. This is consistent with findings of a previous study also using EMG analysis indicating that females are more fatigue-resistant than males for a task targeting the trapezius muscle (Nie et al. 2007). This is possibly due to a greater work effort required by males, as a result of a greater relative arm mass, in comparison to females. Moreover, we have recently shown that there are gender differences in load sharing within different parts of the trapezius

(Johansen et al. 2012). Thus, since the trapezius is an important contributor to tasks performed at shoulder level such as the RPT used in this study, it is possible that the observed gender differences may be related to differences in the control of this muscle group between men and women (Cote 2012), such as lower motor variability in females, for example.

4.2 Effects of Fatigue on Posture Sense

The effects of localized muscle fatigue on postural control during dynamic tasks have been reported previously (Sparto et al. 1997; Naussbaum 2003; Vuillerme et al. 2005). We have also shown that localized upper limb muscle fatigue induces whole-body, postural changes, namely a postural shift towards the contralateral side, as well as increased anterior-posterior CoP range of motion during the repetitive pointing task (Fuller et al. 2009). However, in this previous study, subjects received no particular instructions related to postural control as they accomplished the repetitive pointing task, and we had not measured postural characteristics during quiet standing trials. In the current study, subjects performed pre- and post-fatigue quiet standing trials and despite the specific instructions to the subjects to maintain a posture as symmetrical and as still as possible, anterior-posterior CoP range of motion increased in males and anterior-posterior displacement also increased in both genders after fatigue. As was previously stated, following our fatiguing protocol, fatigue developed in the neck and shoulder musculature. Therefore, our results support those of Pinsault and Vuillerme (2010), who found that CoP displacement increased with cervical muscle fatigue during quiet standing in suggesting that postural stability can be affected by fatigue even in remote muscles not responsible for maintaining quiet standing posture. The properties of muscle receptors are altered with fatigue from both submaximal repetitive contractions and isometric contractions (Gandevia 2001). As a result, altered metabolite concentrations have been shown to affect the central nervous system (Gandevia, 2001), thereby affecting the body as a whole and not only the muscles directly targeted by the fatiguing task. Our results thus suggest that previously reported and presently confirmed increases in postural range of motion occurring with neck-shoulder fatigue may be involuntary consequences of central fatigue. However, the current results also show that fatigue did not affect subjects' ability to maintain a symmetrical posture. This other finding rather supports the interpretation that the previously described postural shift towards the contralateral side during the RPT is a voluntary, task-specific strategy aimed to reduce the negative impact of muscle fatigue on the upper limb movement component of the repetitive pointing task (Fuller et al. 2009), since in the current study, when not performing the arm movement (i.e. in quiet standing trials), subjects are able to maintain a symmetrical posture even with RPT-induced fatigue. Taken together, these findings thus suggest that muscle fatigue may differentially affect postural stability and postural orientation, which is consistent with the notion that postural control incorporates two different purposes of stability and orientation (Massion 1998). Our results also support recent findings from studies using dual task paradigms to study standing balance, which show the direction-specific ability of the system to stabilize standing posture in AP and ML directions (Kang and Lipsitz 2010).

Our results on the effects of fatigue on postural sense also show gender differences. In our population, females were significantly shorter than males (1.62 ± 0.06 m and 1.73 ± 0.07 m, respectively). Since our protocol employed a standardized foot position during quiet standing, all subjects stood with their feet at an equal distance apart, causing females to have a relatively larger stance, on average, and therefore a greater base of support, relative to their height. Since a shorter height and wider base of support are both known to promote postural stability (Hageman et al. 1995), we believe this to be a possible explanation for the increase in CoP AP range of motion seen in males but not in females. This is consistent with findings showing that localized lower extremity muscle fatigue in all-male populations increased CoP displacement (Vuillerme et al. 2005; Pinsault and Vuillerme 2010; Corbeil et al. 2003). However, only few studies have compared how fatigue affects postural stability of men and women, with some showing no differences between both (Springer and Pincivero 2009). More studies are needed to settle this issue and to shed light into underlying mechanisms of fatigue-related postural control.

4.3 Effects of Fatigue on Force Sense

Previous studies showed that force sense was impaired with fatigue in upper-extremity contralateral limb-matching tasks (Proske et al. 2004; Jones and Hunter 1983a, b; Carson et al. 2002). However our results show that neither the absolute nor the relative force matching tasks displayed significant effects of fatigue on force matching accuracy. This could again be related to the fact that all of these previous studies investigated muscles of the elbow region. To gain a better understanding of mechanisms relating force sense and fatigue, we selected loads in two different ways, one relative to subjects' strength, and the other using a common load across all subjects. Previous studies have shown that greater fatigue-related impairments were observed in people exerting a higher absolute force output, which had been explained by a mechanism involving higher blood flow occlusion and therefore the production of more fatigue-related metabolite at higher absolute force outputs (Mitchell 1990). Since Wesche (1986) previously showed that blood flow occlusion can occur in submaximal contractions as low as 10-20% maximal force, we had thus hypothesized that our loads of 30% MVC would be sufficient to show fatigue-related force accuracy impairments. Moreover, we had hypothesized that stronger individuals (men) would suffer from more blood flow occlusion-related impacts of fatigue, and therefore would show more fatigue-related accuracy reductions than women in the relative component of the force sense task. However, as was the case for women, the force accuracy of men was not affected by fatigue. The other finding of interest for this set of analyses was that men were indeed less accurate than women, but surprisingly, not in the relative but in the absolute force matching test, where the selected weight would represent a lighter load for them, relative to their maximal capacity, compared to women.

Thus, since in this task, the target force was the same for every subject, regardless of their individual maximal capacities, the gender difference could indicate that the 12.73N load was in fact too light for men to sense and reproduce with accuracy. In comparison, this weight did not affect the accuracy of women as much. In another comparable study, Mehta and Agnew (2010) fatigued the upper extremity with a task requiring the shoulder musculature to repetitively sustain the weight of an elevated arm plus the weight of a drill. In this case, authors found that females committed greater errors than males in the accuracy of an overhead drilling task. However, while this task also brought females closer to their maximal strength than males, it also brought them closer to their maximal strength than our task, which involved forces of only 12.73 N of shoulder elevation, assuming that the drill in this previous study weighed more than 12.73 N. Together, our findings suggest that the relationship between force output and accuracy may not be a linear one. Indeed, non-linear relationships between movement characteristics such as load and speed with accuracy have been documented previously (Schmidt and Sherwood 1982), where the system may perform more or less efficiently depending on where the task falls within the range of habitual performance. More studies are needed to understand the mechanisms relating force, accuracy and fatigue, and whether gender differences can mediate these mechanisms.

4.4 Effects of Fatigue on Rhythm Sense

Our results revealed that the ability to maintain a particular rhythm during the performance of a repetitive task is not changed with fatigue. Recent studies showed that task accuracy and work pace were maintained during fatiguing repetitive work (Bosch et al. 2011). In the case of that study, fatigue was generated from the task itself, thereby causing a possible positive effect of learning that could have compensated for the negative effect of fatigue. However in our study, the fatiguing task was different from the experimental task and subjects received no indication of their rhythm accuracy in pre-fatigue recordings, and nevertheless, in agreement with the previous study, we did not see an effect of fatigue on the ability to follow the set movement rhythm. These results can be interpreted in a way similar to our interpretation of findings from previous studies, in that they could reflect an ability of the system to operate whole-body adaptations, even in the presence of fatigue, that help preserve some important task characteristics constant (Cote et al. 2002; Cote et al. 2005; Mehta and Agnew 2010). In the present experiment this could mean that maintaining accuracy and timing of the touches was considered the main task objective by the system, and that the part of the system responsible for producing overall movement rhythm was not affected by muscle fatigue.

4.5 Limitations

Some sources of limitations could have affected the quality and validity of our findings. One main source of limitation for this research is due to the measurement error generated by the load cell, which was used to measure shoulder elevation forces, of which the accuracy varied by approximately 3% from one session to the next. Another limitation is associated with the rigid apparatus on which the load cell was fixed. Despite our efforts to create a rigid link between segments of the frame, slight motion of a few millimeters to centimeters was created by the applied force, which could have affected force measurements especially during maximal voluntary contractions of the strongest subjects. Therefore, we obtained quasi-isometric efforts, rather than pure isometric ones. In addition, our rhythm sense protocol required subjects to support the weight of their arm during the rhythmic movements. Therefore, our rhythm sense task combined the requirement of lifting the arm and following a rhythm, i.e. did not test rhythm sense in isolation from the needs to maintain arm posture and movement, which were themselves likely affected by fatigue. Also, in order to control for consistency in the pre- and post-fatigue posture sense tests, we required that subjects stand with feet at a constrained distance apart, which may not necessarily have been the most comfortable foot position that subjects would have chosen themselves.

4.6 Delimitations

Some methodological choices are important to mention in that they have consequences on to whom and what conditions our results may apply. While our intention for the absolute component of the force-matching task was to select forces that resembled those experienced in real-life situations, the absolute force of 12 N that was used may have been too light to reflect force-matching accuracy in daily life circumstances involving heavier loads. The same can be said about our relative force matching results, which only apply for loads around 30% MVIC. Our results of rhythm accuracy also only apply to tasks performed at shoulder height and at the specific rhythm selected. Our results of posture sense only apply to the quiet standing posture and to characteristics of the overall standing posture (i.e. do not reflect the ability of a person to maintain cervical postural alignment, for instance). Lastly, our results only apply to young healthy adults.

5. Conclusion

The results of our study show that localized upper extremity repetitive motion-induced fatigue affects some perceptual such as posture sense, but not rhythm sense, and that males and females' sense of force is affected differently. Proprioception is a set of sensory information that provides movement control and stability (Myers and Lephart 2000) by coordinating various aspects of movement such as limb position, joint angle, speed, and strength (Kerr and Worringham 2002). So far, studies have mostly explained proprioceptive deficits occurring with fatigue through the concept of sense of effort, which is central in origin. Therefore, since our study involved relatively low efforts during our experimental tasks, it is reasonable to not have found many effects of fatigue. This could reflect that the body has access to many unfatigued muscles to compensate, in order to preserve important task characteristics (such as, in the present case, sense of rhythm). However, the significant effect of fatigue on postural stability during quiet standing is interesting in that it helps us explain our previous findings on postural changes during the fatiguing repetitive task. We do not fully understand the mechanisms by which repetitive upper limb motion-induced fatigue may impair postural stability, but it is possible that these mechanisms could involve changes in other systems, occurring with global fatigue. More studies are needed to shed light into that question.

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CONCLUSION

This research describes the effects of localized upper-extremity repetitive motion-induced fatigue on perceptual characteristics related to proprioception of posture sense, rhythm sense, and force sense. Our results reveal that fatigue caused a decreased ability to maintain postural stability of a quiet standing postural task, despite specific instructions to maintain a posture as still as possible. However, rhythm, force, and postural symmetry accuracy remained unchanged even with fatigue. The significant effect of fatigue on postural stability during quiet standing is interesting in that it helps us explain our previous findings of postural changes during the fatiguing repetitive pointing task, suggesting that the decrease in postural stability occurring with neck/shoulder fatigue may be an involuntary consequence of central fatigue. Conversely, the findings that individuals can maintain the same postural symmetry with fatigue supports our interpretation of previous findings that the mediolateral shifts observed to occur with fatigue during the repetitive pointing task reflect a voluntary strategy to facilitate the arm sub-task. The results that rhythm sense was maintained even with fatigue suggest the effectiveness of the body’s compensatory strategies in preserving certain important task characteristics, such as the ability to maintain a rhythmic movement constant, in this case.

Our results also show that males and females were affected differently by fatigue in terms of the sense of posture and force-matching abilities, supporting the hypothesis that the mechanisms underlying the fatigue response differ between genders. In turn, these gender differences in the fatigue response may help explain why one gender (females) might be at greater risk for developing neck/shoulder musculoskeletal disorders. Further research is needed to better understand the mechanisms responsible for different responses between males and females, in order to better predict the risk factor and eventually, tailor preventative measures to each gender.

Since many neck-shoulder musculoskeletal disorders have been linked to muscular fatigue from repetitive movements, a complete understanding of the mechanisms involved in the body's response to fatigue is important. This will allow future studies to focus on the development and operation of rehabilitative and preventative measures, as well as the adaptation of these measures to each gender.

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APPENDIX A

Consent Form

Experimental analysis of whole-body coordination changes associated with repetitive upper limb motion: what, when, why? (CRSNG-RGPIN 312333-05)

CRIR Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Consent form

Hôpital juif de réadaptation Jewish Rehabilitation Hospital

1 - Title of project

Experimental analysis of whole-body coordination changes associated with repetitive upper limb motion: what, when, why? (CRSNG-RGPIN 312333-05)

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

Kim Emery, M.Sc., research assistant, Jewish Rehabilitation Hospital research center, (450) 688-9550 ext. 4827

3 - Preamble/Introduction

We are asking you to participate in a research project involving the analysis of your movements when you are fatigued. Before agreeing to participate in this project, please take the time to study and carefully consider the following information.

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

This consent form may contain words that you do not understand. We invite you 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 objectives of this research are to describe the time sequence of within- to between muscle changes occurring with repetitive motion-induced fatigue, and to assess the effects of fatigue on postural and proprioceptive characteristics. This project also aims at assessing gender differences in these fatigue responses. 24 healthy subjects will be recruited for this project (12 men, 12 women) and will perform a laboratory assessment protocol twice, with at least 48 hours in between. The long-term objective of this project is to better understand how humans coordinate posture and repetitive arm motion and how fatigue affects this coordination. This research will provide knowledge and tools to identify, treat and prevent musculoskeletal disorders.

5 - Nature and duration of participation

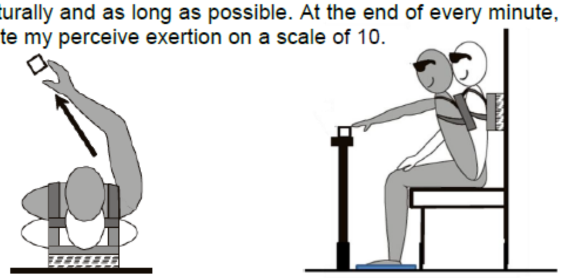
The research project to which I am invited to participate aims at understanding how we coordinate posture and repetitive arm motion and how fatigue may affect this coordination. The experimental procedure takes place at the research center of the Jewish Rehabilitation Hospital. I am asked to participate in two experimental sessions, 48 hours apart, which will last approximately two hours each. Each of the two experimental sessions will be separated in four different phases:

<u>Phase 1</u>: preparation (30 minutes),
<u>Phase 2</u>: pre-fatigue tests (30 minutes),
<u>Phase 3</u>: fatigue procedure (20 minutes) and
<u>Phase 4</u>: post-fatigue tests (30 minutes).

During <u>Phase 1</u>, surface electrodes will be applied on the skin over my neck and dominant upper limb muscles in order to measure their activity. Reflective markers will be fixed on the skin over my neck, trunk, arms and legs in order to record their positions. A heart rate monitor will be placed on my chest with an elastic band. None of these procedures is invasive.

During <u>Phase 2</u>, I will be asked to push upward with my dominant shoulder as hard as I can, against a rigid frame. I will be asked to repeat the task but this time, pushing at 30% of my maximum. Then, I will be asked to perform 10 consecutive reaches with my dominant arm moving between two targets, following the beat of a metronome, and then at the same rhythm but without the metronome, eyes closed. Then, I will be asked to stand as stable and symmetrically as possible. Finally, I will be asked to rest my dominant arm on a movable table. The table will move and I will have to push a button when I will feel that my arm has reached a horizontal position. For each task, I will perform three consecutive trials, with rest in between.

During <u>Phase 3</u>, I will stand on two force plates placed on the floor and I will wear a harness. The harness will restrict (session 1) or not (session 2) the movements of my trunk (see Figure below; however for this study, I will be standing, not seated). These two sessions will be assigned in a random order. Once I will be ready, I will perform a repetitive reaching task with my dominant arm, as naturally and as long as possible. At the end of every minute, I will be asked to rate my perceive exertion on a scale of 10.



During Phase 4, I will perform the same tests as those performed in Phase 1. Between trials, I will keep my dominant arm horizontal, at shoulder height. This experimental procedure will be repeated in identical fashion (except for the trunk harness in the fatigue protocol) during the 2nd experimental session conducted a minimum of 48 hours later.

6 - Advantages associated with my participation

I will not personally benefit from any advantage by participating in this study. However, I will contribute to the advancement of knowledge of human movement and musculoskeletal disorders.

7 - Risks associated with my participation

None of the techniques used are invasive. I understand that my participation in this project does not put me at any medical risk.

8 - Personal inconvenience

The duration of each experimental session (approximately 2 hour each) may represent an inconvenience for me. The possibility that some small regions (8, 3x3 cm each) of the skin over my neck and arm muscles have to be shaven before placing the electrodes might also represent an inconvenience for me. Although it is hypo-allergenic, the adhesive tape used to fix the electrodes on my skin may occasionally produce some slight skin irritation. Should this happen, a hypo-allergic lotion will be applied on my skin to relieve skin irritation. Also, I will experience some fatigue towards the end of each protocol, which may cause some tenderness, stiffness and/or pain in the neck-shoulder area during and/or following the session. These symptoms should dissipate within 48 hours following the completion of the protocol. A clinician will be present at all times during the experimental sessions.

9 - Access to my medical file

No access to my medical file is required for this study.

10 - Confidentiality

All the personal information collected for this study will be codified to insure confidentiality. Information will be kept under locking key at the research center of the Jewish Rehabilitation Hospital by one of the persons responsible for the study for a period of five years following the end of the study. Only the people involved in the project will have access to this information. If the results of this research project are presented or published, nothing will allow my identification. After this five-year period, data will be destroyed.

11 - Questions concerning the study

The researchers present during the testing should answer my questions concerning the project in a satisfactory manner.

12 - Withdrawal of subject from study

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

13 - Responsibility

By accepting to enter this study, I do not surrender to my rights and do not free the researchers, sponsor or the institutions involved from their legal and professional obligations.

14 - Monetary compensation

No monetary compensation will be given to me for participation in this protocol.

15 - Contact persons

If I need to ask questions about the project, signal an adverse effect and/or an incident, I can contact at any time Julie Côté, Ph.D., or Kim Emery, M.Sc., at the numbers indicated on the 1st page. I may also contact M. Michael Greenberg, local commissioner for the quality of services at the JRH, at (450) 688-9550, extension 232.

Also, if I have any questions concerning my rights regarding my participation to this research project, I can contact Mme. Anik Nolet, Research ethics co-ordinator of CRIR at (514) 527-4527 ext. 2643 or by email at anolet.crir@ssss.gouv.qc.ca

CONSENT

I declare to have read and understood the project, the nature and the extent of the project, as well as the risks and inconveniences I am exposed to 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**__.

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