Identification of Objective Measures of Neck/Shoulder Fatigue During Simulated Auto Work at Shoulder Height

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Pour ma famille proche,

Qui m’a toujours soutenu et valorisé mon éducation en tout temps.

CONTRIBUTION OF AUTHORS

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

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

David Pearsall, PhD, Associate Professor, Department of Kinesiology and Physical Education, McGill University, and Clark Dickerson, PhD, Assistant Professor, Department of Kinesiology, University of Waterloo, were members of the candidate's supervisory committee and contributed to the design of the research protocol.

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

Amanda Farias, MSc candidate, and Zachary Weber, MSc candidate, provided assistance during data processing.

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ABSTRACT

The aim of the Master's study was to determine key manifestations of fatigue related to car assembly work. This was done by assessing the relationships between multi-level data using high quality devices in a controlled, laboratory environment. Muscle output-related outcomes, fatigue perception outcomes, kinematic-related outcomes, sensory-proprioceptive outcomes, vascular outcomes and work performance were recorded during a speed fastening task completed at shoulder height. Work blocks of 5min were performed until subjects reached a state of fatigue (Borg CR10 ≥ 8/10) ; to assess cumulative effects of fatigue, two identical sessions separated by a lunch break were accomplished during the same day. Results in the study support the role of the flexed shoulder posture as the main source of fatigue in occupational tasks, and the importance of adequate blood delivery mechanisms to the extremities. Tools like Borg CR10 analog scale could be easy and friendly to use for an estimation of the fatigue recovery. Quantitative Sensory Testing applied at the neck/shoulder site could be helpful in the early identification of signs of fatigue. These tools may provide a way to objectively monitor fatigue at the work sites which, in turn, could aid to diminish the prevalence of work-related musculoskeletal disorders (MSDs).

RÉSUMÉ

L’objectif de ce projet de recherche était de déterminer des éléments clefs de la manifestation de la fatigue en relation aux sites d’assemblages automobiles. Ceci fut réalisé en évaluant les relations entre des données de différents niveaux utilisant des dispositifs de haute qualité dans un environnement de laboratoire contrôlé. Les résultats provenant de l’activité musculaire, de la perception de la fatigue, de la proprioception sensorielle, du débit sanguin ainsi que la performance des sujets ont été enregistrés lors d'une tâche de vissages de boulons complété à hauteur d'épaule. Des blocs de travail de 5min ont été effectuées jusqu'à ce que les sujets aient atteint un état de fatigue (Borg CR10 ≥ 8/10); pour évaluer les effets cumulatifs de la fatigue, deux sessions identiques séparés par une pause diner ont été réalisées dans la même journée. Les résultats de cette étude soutiennent le rôle de la posture de l'épaule fléchie comme la principale source de la fatigue dans les tâches professionenelles, ainsi que l'importance des mécanismes pour un débit sanguin adéquat aux extrémités. Des outils comme l’échelle analogique Borg CR10 pourrait être simple et conviviale à utiliser pour une estimation de la récupération de la fatigue. Le Test de Sensation Quantitatif appliqué à la région de l'épaule et du cou peut être utile dans l'identification précoce des signes de fatigue. Ces outils peuvent fournir un moyen afin de surveiller objectivement la fatigue sur les sites de travail qui, par la suite, pourrait aider à diminuer la prévalence des troubles musculo-squelettiques liés au travail (TMS).

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INTRODUCTION

In Germany, about 400 million working days for a total of 36 billions of euros have been evaluated to be lost due to sick leave consequent to musculoskeletal disorders (MSDs) (Karlheinz et al. 2012). Work-related MSDs are defined as "reoccurring musculoskeletal symptoms affecting an individual's activities, that can develop progressively and that are perceived to be partly or entirely related to a person's main work." (Stock et al. 2011). MSDs affect a large portion of the population, especially in industrialized countries, and are associated to numerous compensation claims, lost time, and health care costs (Feuerstein et al. 2003). When looking at all the different groups of diseases, MSDs is the one resulting in the highest work absenteeism or disability in many countries (Badley et al. 1994; Feeney et al.1998; Leijon et al. 1998; Woolf et al. 2010). According to Statistics Canada, 2.3 million Canadians are affected yearly by a MSD that is severe enough to limit their work and daily activities (Statistics Canada, 2001).

Local or muscular fatigue is hypothesized to be a precursor to MSDs (Iridiastadi et al. 2006). Different kinds of fatigue can be distinguished, such as general (whole-body), muscular or brain fatigue. Muscle fatigue has been described as an exercise-induced reduction in the ability of the muscle to produce force or power, whether or not the task can be sustained (Bigland-Richie et al. 1984). Workers' physical (local or muscular) fatigue may impair motor control, leading to diminished work quality, increase discomfort, reduce maximal capacity and/or increase risk of acute injury. In the USA, loss of productive time from workers with fatigue costs employers more than USD $136 billion each year (Ricci et al. 2007). The two main reasons for this are both absenteeism and "presenteeism" (defined as being present at work site but not performing at the expected level).

Performance of workers is highly dependent on their health. For a company to be competitive, workers' health is one of the key factors. Health and performance of workers have personal and societal consequences. In 2007, 62% of assembly line workers had MSDs (Sadi et al. 2007). Speed Fastening (SF) is widely used in the automotive manufacturing assembly (Ku et al. 2007) and is performed under a variety of work conditions. In different studies, similar low-force tasks performed to exhaustion at shoulder level showed evidence of fatigue (Fuller et al. 2009; Émery et al. 2012). It is also known that working with neck and/or body bent forward, arms above shoulders as well as precision work tasks, which are all work conditions found in the car assembly industry, are predictors of MSD (Wahlstedt et al. 2010).

Fatigue experienced in a work setting, especially in shoulder repetitive work, is a multidimensional construct (Barker et al. 2011). However, few studies have taken multiple kinds of measures that could reflect the many domains of fatigue to precisely identify the development of fatigue manifestations throughout a workday, and which physical changes could be related to changes in performance. Fatigue can affect sensory (Diannat et al. 2010) as well as motor (Madeleine. 2010) outcomes; however, few studies have quantified various sets of sensorimotor measures during a fatigue protocol. Moreover, the rates of fatigue recovery over a work day are not well known. Blood flow has been used as a marker in a few studies to infer muscle recovery after effort (Larsson et al. 1999; Strom et al. 2009). Thus, the present study is a first phase of a multisite study that is currently conducted in close collaboration with industry workers and stakeholders to design workplace-based tools and protocols to monitor fatigue in car assembly plants of participating enterprises based in Ontario and northern Michigan, as part of injury-preventative approaches. As a first step towards this long-term goal, the **general aim** of the current study was to determine key manifestations of fatigue related to car assembly work, using high quality devices in a controlled environment. The specific **objectives** were to quantify effects of fatigue and session (AM, PM), within these different domains: muscle output-related outcomes, fatigue perception outcomes, kinematic-related outcomes, sensory-proprioceptive outcomes, vascular outcomes and work performance.

The **hypotheses** were that fatigue would have negative effects on the worker's performance, would induce a decrease in sensory accurary characteristics and in pain thresholds as well as an increase in blood flow. We also hypothesized that these effects would be exacerbated in the second fatigue session of the day, i.e. in the afternoon session, such that we hypothesized that the lunch break in between the sessions would not be long enough in order to fully recover and get back to the initial pre-fatigue state (before the morning session).

This is the first study of its kind to assess the relationship between multi-level data in order to determine key manifestations of fatigue during simulated auto assembly work at shoulder height. It will help us identify precise and objective measurements related to fatigue. Moreover, it will advance our understanding of the effects of accumulated fatigue and the extent to which people recover during a day break. This information could then be used to design specific tools and approaches to track these variables during a work day, which could be used into the identification of more effective work-break regimens and overall more effective injury-preventative approaches.

LITERATURE REVIEW

MSD Epidemiology

Work-related musculoskeletal disorders (MSDs) are defined as "reoccurring musculoskeletal symptoms affecting an individual's activities, can develop progressively and are perceived to be partly or entirely related to a person's main work." (Stock et al. 2011). MSDs affect a large portion of the population, especially in industrialized countries, and are associated to numerous compensation claims, lost time, and health care costs (Feuerstein et al. 2003). In Germany, about 400 million working days for a total of 36 billions of euros have been evaluated to be the loss generated by sick leave in relation to MSDs (Karlheinz et al. 2012). Car manufacturers are particularly concerned because of their high prevalence of MSDs; Warner et al. (1998) reported that 65% of the losses of productivity per day in this specific sector are related to bodily strains. Repetitive arm movements appear to be present in several workplace tasks in assembly line work (Zakaria et al. 2002). They often lead to fatigue development, which is linked with alteration of movement patterns when performed over extended periods of time (Fuller et al. 2011).

Shoulder Characteristics

Following is a short review of the shoulder's anatomical characteristics (Drake et al. 2010). The shoulder is the region of upper limb that attaches to the trunk. The bony framework of the shoulder consists of the clavicle and scapula (which form the pectoral girdle), and the proximal end of the humerus. Three joints in the shoulder complex exist: sternoclavicular, acromioclavicular and glenohumeral joints. The sternoclavicular joint and the acromioclavicular joint link the two bones of the pectoral girdle to each other and to the trunk. The combined movements at these two joints enable the scapula to be positioned over a wide range on the thoracic wall, substantially increasing "reach" by the upper limb. The glenohumeral joint is the joint between the humerus and the scapula (p.668). The coordinated movement of the scapula, clavicle and humerus aiming to fully elevate the arm has been named scapulohumeral rhythm. The initial 30 degrees of abduction/flexion is primarily glenohumeral. The remained elevation would be glenohumeral and scapulothoracic joints moving simultaneous. A 2:1 ratio of glenohumeral to scapulothoracic movement is present: the scapula rotates upward one degree for every two degrees of upward arm movement. The shoulder complex allows various movements with different amplitudes: flexion, extension, internal and external rotation, adduction and abduction. The muscles acting to do these movements can be classified in three different subgroups depending on their role: to protect the glenohumeral joint, to pivot the scapula and to position the humerus. The glenohumeral protectors are the rotator cuffs and the long head of biceps brachii. The scapular pivoters are the trapezius, rhomboids, pectoralis minor, elevator of the scapula and the serratus anterior. The humeral positioners are the deltoid, pectoralis major and the latissimus dorsi. All these joints and muscles give the shoulder large movement amplitude, which is taken advantage of in many work tasks; a lot of work tasks rely on shoulder movements, especially those that involve repetitive work. However this can lead to fatigue, with fatigue being a common risk factor for shoulder injuries (Iridiastadi et al. 2006).

Muscle Fatigue: an Important MSD Risk Factor

The most influential hypothesis of muscular mechanism for MSDs associated with low-force tasks is the Cinderella Hypothesis (Hagg, 1991). According to Henneman's size principle (1965), the low-threshold motor units (MUs) connected to the Type 1 fibers are the first one to be activated during a muscle activity. When a task is repetitive or maintained during a long period of time, these previous MUs are constantly recruited and overload may happen. Overload will result in an accumulation of Ca 2+ and a build-up will occur (Gissel, 2000). This build-up is potentially harmful to the membranes of the muscle fibers, creating structural damage and muscle injury may result (Lexell, 1993; Visser et al. 2006). Low-force tasks performed at shoulder level to exhaustion showed evidence of fatigue in different studies (Fuller et al. 2009; Émery et al. 2012). Muscle fatigue has been described as an exercise-induced reduction in the ability of the muscle to produce force or power, whether or not the task can be sustained (Bigland-Richie et al. 1984; Søgaard et al. 2006). Fatigue can be subdivided as central or peripheral in origin. In a review conducted by Gandevia (2001) central fatigue was defined as a "progressive reduction in voluntary activation of muscle during exercise", whereas peripheral fatigue has been defined as the "fatigue produced by changes at or distal to the neuromuscular junction".

When dealing with central fatigue, mechanisms of fatigue can be differentiated at two levels: supraspinal and spinal. Supraspinal fatigue is identified when fatigue is produced by failure to generate output from the motor cortex. Moreover, while applying transcranial stimulation of the motor cortex during isometric MVCs, it has been observed that progressively more force to that generated voluntarily can be added, demonstrating an isolated supraspinal component involved in central fatigue. In earlier studies of central fatigue at the spinal level, attention was placed on muscle spindles inputs (Burke et al. 1978; Macefield et al. 1991), golgi tendon organ inputs (Lundberg et al. 1962; Kirsch et al. 1992) and small-diameter muscle afferent (group III and IV) sending signals about the altered muscle. Fatigue can impair the properties of all groups of muscle receptors resulting in changes in signals from Golgi tendon organs and small-diameter afferents. These changes will affect their direct contribution to proprioception and require central motor commands changes in order to compensate (McCloskey et al. 1974). Changes in various systems (cardiovascular, respiratory, endocrine, peripheral and central motor, CNS transmitter) can also be related to exercise and task failure. Widespread central actions of many of these systems make it impossible to identify one specific area responsible for central fatigue.

Studies have proposed some directions to elucidate the question "What causes muscle fatigue?". Results of different studies suggested that the mechanism that would be responsible for the decline in force depends on the task being performed. Type and intensity of exercise, muscle groups involved and environment in which the task is performed are different factors that will all influence the mechanism involved in muscular fatigue. Having taken this into consideration, researchers are now tending to identify the causes of task failure. As a result, one principle of muscle fatigue that emerged in the last century is called task-dependency. The principle of task-dependency states that there is no single cause of muscle fatigue and that the dominant mechanism depends on the characteristics of the task being performed (Barry et al. 2007). When trying to identify causes of task failure, basic physiologic processes like muscle acidification, muscle potassium efflux, glycogen depletion, capacity to use extra muscular fat stores, fatigue of respiratory muscles, and reflex inhibition due to rises in pulmonary capillary pressure have all been mentioned (Gandevia, 2001). Personal factors like age or sex might as well affect fatigability and time to task failure (Baudry et al. 2007; Hunter. 2004). So far, not one of them could be pointed out to be the cardinal “exercise stopper”. In this circumstance, we can now take a look at which strategies are used to maintain a repetitive task.

Co-activation, as well as other multi-muscle and multi-joint patterns, are strategies associated with joint stabilization that have been observed to occur with fatigue. These strategies include increased co-contraction of agonist-antagonist muscle pairs (Psek and Cafarelli. 1993), or changes in inter-muscular coordination between agonist groups (Danion et al. 2000). In a study done by Émery et al. (2012) where a repetitive pointing task was done until the subject reached exhaustion, subjects prioritized whole-body adaptation strategies that had no impact on their ability to maintain whole-body position sense. In another interesting study involving a repetitive hammering task, Côté et al. (2008) found that fatigue involves the contributions of remote, non-fatigued muscles, showing fatigue influencing motion at both local and global levels. Nevertheless, these strategies previously observed may lead to further fatigue and to the development of symptoms and injuries (Van Der Windt et al. 2000).

Measurements of Fatigue

Borg rating scales have been used to infer general and local fatigue (Borg, 1970, 1982). Several studies have used a score of 8 out of 10 on the Borg CR-10 analog scale to correspond to a state of fatigue in functional protocols (Côté et al. 2002; Emery et al. 2012; Fuller et al. 2011). The effects of fatigue on muscle characteristics are well documented and electromyography (EMG) has been widely used to document the changes at the muscle output (Gandevia Book 2001). Studies have shown that during sub-maximal contraction, fatigue induces an increase in the EMG RMS amplitude concomitant to a decrease in the EMG frequency content (Madeleine et al., 2002). Moreover, significantly increased EMG activity amplitude in the upper trapezius, biceps and deltoid muscles has been observed in previous studies, after having performed a low-force repetitive shoulder height task inducing fatigue (Côté et al. 2008; Fuller et al. 2009; Emery et al. 2012; Fedorowich et al. 2013). In addition, emergent measures are now used to look at the effect of fatigue on other sensorimotor modalities such as proprioception. One of them, quantitative sensory testing (QST) examines the sensory perception after application of different mechanical stimuli of controlled intensity (Krumova et al. 2012). Another somewhat frequently used approach uses pain and pressure thresholds (PPT) and detects the upper sensory limit when a normal pressure sensation becomes painful (Ylimen et al. 2007). Persson et al. (2003) showed that PPT scores increase following fatigue of the trapezius and deltoid muscles achieved with sustained contractions of up to 20min following the fatiguing effort, even though muscle activity increases returned to baseline levels immediately when the task was finished. In this study, the subjects reached the pain threshold at a higher pressure (higher PPT score), which could be interpreted as a loss in sensitivity. Quantitative sensory testing (QST) is a similar approach aimed at quantifying sensory detection thresholds, and has recently been used in conjunction with PPT measurements to assess the integrity of the sensory system, independently from the pain interpretation, also showing elevations in sensory detection thresholds with fatigue (unpublished results). Together, these multiple measurements approaches could potentially offer insight into how fatigue affects the entire sensorimotor system as a whole. Finally, to investigate the associations between the fatigue responses of the neuromuscular and vascular systems, blood flow has been looked at in a few studies as a measure of muscle recovery during and after effort (Larsson et al. 1999; Strom et al. 2009), with the underlying assumption of the necessity for a balance between damage and repair mechanisms in order to respond adequately to fatigue. Hyperaemia is defined as an increase in blood supply to tissues. Larsson et al (1993b) found hyperaemia with increased shoulder angle, shoulder torque and EMG activity within healthy women alternating 1 min periods of static contraction and rest.

Prevalence of Shoulder MSDs in Car Industries

In 2007, 62% of assembly line workers had MSDs (Sadi et al. 2007). In a car assembly study that lasted for a year, self-assessments of the pain that the workers had suffered for more than a week during the year was recorded, with results showing a symptom breakdown of 39% of neck pain, 38% of shoulder pain and 14% of arm pain (Ohlsson et al. 1989). Luopajärvi et al. (1979) found similar percentages concerning the symptoms of MSDs in car assembly workers: 37% in the neck and 5.9% in the hand. Speed Fastening (SF) is widely used in automotive manufacturing assembly (Ku et al. 2007). Workers in a car assembly predominantly use powered tools, which increase a worker's capacity but can also be associated with risk of injuries due to the tool's weight and vibration (Chang et al. 1999). Pistol grip, right angle, crows foot and tube nut tools are examples of the powered tools that are largely used in the Ford Motor Company, with an average of 960 of them found in a typical plant (Hagg et al. 2000). Within the same car assembly company previously mentioned, 55% of the workers use powered hand tools and 75% of them are screwdrivers and nutrunners (Van Bergeijk, 1987; Fenninkoh et al. 1999). Despite the omnipresence of powered tools in car assemblies, not enough is known about their ergonomics risks. Moreover, most of the information on injury risks associated with powered hand tools relates to forearm injuries, and little is known about how they affect neck and shoulder fatigue and associated whole-body changes.

We know that speed fastening in automobile industries involving powered tools are widely used at shoulder level, that unfortunately workers are highly affected by MSDs, but up to today, not a lot of researches have been focused on detecting fatigue in order to limit the risks of upper-body injuries.

RESEARCH ARTICLE

Identification of Objective Measures of Neck/Shoulder Fatigue During Simulated Auto Work at Shoulder Height

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ABSTRACT

Car assembly work has been linked to high rates of neck/shoulder musculoskeletal disorders, of which fatigue has been mentioned as a major risk factor. However, few studies have used a multi-systemic approach to describe the many possible facets of car assembly work-related fatigue. This project was designed to determine key manifestations of fatigue related to car assembly work. Fifteen healthy young adult males completed a speed-fastening task at shoulder height until they reached a state of fatigue (Borg CR10 ≥ 8/10,in two identical sessions separated by a lunch break. Electromyography (EMG) was recorded from eight muscles, Laser Doppler Flowmetry (LDF) from two sites, and Quantitative Sensory Testing (QST) and Pressure Pain Threshold (PPT) from three sites on the right upper body. Performance (number of bolts screwed in each sub-task and blocks of 5 min accomplished) was also recorded. Effects of Fatigue (pre, post) and Session (AM, PM) were computed. Significant Fatigue main effects were found in EMG RMS of the anterior deltoid ($p = 0.009$) and biceps brachii ($p = 0.032$), showing significant increases with fatigue. Significant main Fatigue effects were found for the QST of the upper trapezius ($p = 0.040$), with an average increase in threshold values with fatigue. Significant main Fatigue effects were found for forearm ($p = 0.023$) and shoulder ($p = 0.004$) LDF, with increases in blood flow to both locations with fatigue. The decliners' (subjects with a higher pre-fatigue Borg score in the PM compare to AM) forearm blood flow percent changes in the fatigue state were associated with the percent change of the number of blocks accomplished in the PM session ($r = 0.73$). Significant interaction effects were found for the maximum number of hand screwed (HS) bolts ($p = 0.008$), with performance being less decreased by fatigue in the PM. The reduction in number of blocks accomplished in the PM (-26%) was associated with the pre-fatigue increase in Borg CR10 scores in the PM vs in the AM ($r = -0.71$). Results suggest differences in fatigue and recovery pathways, with fatigue evidenced by sensory changes and recovery by vascular changes. This information could be used to design more effective work-break regimens and overall more effective injury-preventative approaches.

1. Introduction

Work-related musculoskeletal disorders (MSDs) affect a large portion of the population, especially in industrialized countries, and are associated to numerous compensation claims, lost time, and health care costs (Feuerstein et al. 2003). In 2007, 62% of assembly line workers had MSDs (Sadi et al. 2007). In Germany, about 400 million working days for a total of 36 billions of euros have been evaluated to be the loss generated by sick leave in relation to MSDs (Karlheinz et al. 2012). Car manufacturers are particularly concerned because of their high prevalence of MSDs. In a car assembly study that lasted for a year, self-assessments of the pain that the workers had suffered for more than a week during the year was recorded, with results showing a symptom breakdown of 39% of neck pain, 38% of shoulder pain and 14% of arm pain (Ohlsson et al. 1989). Luopajärvi et al. (1979) found similar percentages concerning the symptoms of MSDs in car assembly workers: 37% in the neck and 5.9% in the hand. Performance of workers is highly dependent on their health. For a company to be competitive, workers' health is one of the key factors. Health and performance of workers have personal and societal consequences.

Repetitive arm movements appear to be present in several workplace tasks in assembly line work (Zakaria et al. 2002). They often lead to fatigue development, which is linked with alteration of movement patterns when performed over extended periods of time (Fuller et al. 2011). Various joints and muscles give the shoulder large movement amplitude, which is taken advantage of in many work tasks; a lot of work tasks rely on shoulder movements, especially those that involve repetitive work. We know that speed fastening in automobile industries involving powered tools is widely used at shoulder level. Pistol grip, right angle, crows foot and tube nut tools are examples of the powered tools that are largely used in the Ford Motor Company, with an average of 960 of them found in a typical plant (Hagg et al. 2000). Despite the omnipresence of powered tools in car assemblies, not enough is known about their ergonomics risks. Moreover, most of the information on injury risks associated with powered hand tools relates to forearm injuries, and little is known about how they affect neck and shoulder fatigue and associated whole-body changes. Low-force tasks performed to exhaustion at shoulder level have shown evidence of fatigue (Fuller et al. 2009; Émery et al. 2012). Unfortunately, fatigue is a common risk factor for shoulder injuries (Iridiastadi et al. 2006) but up to today, little research has focused on the identification of tools to detect work-related fatigue in order to limit the risks of upper-body injuries.

Fatigue can be subdivided as central or peripheral in origin. In a review conducted by Gandevia (2001) central fatigue was defined as a “progressive reduction in voluntary activation of muscle during exercise”, whereas peripheral fatigue has been defined as the “fatigue produced by changes at or distal to the neuromuscular junction”. Changes in various systems (cardiovascular, respiratory, endocrine, peripheral and central motor, CNS transmitter) can be related to exercise and task failure. The interactions of many of these systems make it impossible to identify one specific area responsible for central fatigue.

Muscle fatigue has been described as an exercise-induced reduction in the ability of the muscle to produce force or power, whether or not the task can be sustained (Bigland-Richie et al. 1984; Sogaard et al. 2006). Studies have proposed some directions to elucidate the question “What causes muscle fatigue?”. Results of different studies suggested that the mechanism that would be responsible for the decline in force depends on the task being performed. The principle of task-dependency states that there is no single cause of muscle fatigue and that the dominant mechanism depends on the characteristics of the task being performed (Barry et al. 2007). So far, no mechanism could be pointed out to be the cardinal “exercise stopper”. In this circumstance, we can now take a look at which strategies are used to maintain a repetitive task.

Fatigue experienced in a work setting, especially in shoulder repetitive work, is a multidimensional construct (Barker et al. 2011). Different tools have been employed to try to detect fatigue. Borg rating scales have been used to infer general and local fatigue (Borg, 1970, 1982). The effects of fatigue on muscle characteristics are well documented and electromyography (EMG) has been widely used to document the changes at the muscle output (Gandevia, 1995). In addition, emergent measures like pressure pain threshold (PPT) have recently been used to look at the effect of fatigue on other sensorimotor modalities such as proprioception. Persson et al. (2003) showed that PPT scores increase following fatigue of the trapezius and deltoid muscles achieved with sustained contractions of up to 20min following the fatiguing effort, even though muscle activity increases returned to baseline levels immediately when the task was finished. In this study, the subjects reached the pain threshold at a higher pressure (higher PPT score), which could be interpreted as a loss in sensitivity. Quantitative sensory testing (QST) is a similar approach aimed at quantifying sensory detection thresholds, and has recently been used in conjunction with PPT measurements to assess the integrity of the sensory system, independently from the pain interpretation, also showing elevations in sensory detection thresholds with fatigue (unpublished results). Together, these multiple measurements approaches could potentially offer insight into how fatigue affects the entire sensorimotor system as a whole. However, few studies have taken multiple kinds of measures that could reflect the many domains of fatigue to precisely identify the development of fatigue manifestations throughout a workday, and which physical changes could be related to changes in performance.

The **general aim** of the current study was to determine key manifestations of fatigue related to car assembly work, using high quality devices in a controlled environment. The specific **objectives** were to quantify effects of fatigue and session (AM, PM), within these different domains: muscle output-related outcomes, fatigue perception outcomes, kinematic-related outcomes, sensory-proprioceptive outcomes, vascular outcomes and work performance. We hypothesized that fatigue would have negative effects on the worker’s performance, would induce a decrease in sensory accuracy characteristics and in pain thresholds as well as an increase in blood flow. We also hypothesized that these effects would be exacerbated in the second fatigue session of the day.

2. Methods

2.1 Participants

A convenience sample of 15 healthy young adult males (mean age = 27.1 ± 3.28 years; mean height = 1.78 ± 0.07 m; mean mass = 79.8 ± 12.0 kg) was recruited by the researchers from the institutional social network. The inclusion criteria were to be novice in the use of a right angle tool, between the ages of 20-50 years, available for 2 sessions during the same day, and free of neurological and musculoskeletal injuries. The study was performed at the Occupational Biomechanics and Ergonomics Lab (OBEL) of the Jewish Rehabilitation Hospital in Laval, Quebec. Informed, written consent was given by the participants prior to partaking, by signing forms approved by the Research Ethics Board of the Center for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal.

2.2 Procedure

As part of this study, each subject completed two identical sessions, one in the morning (AM) and one in the afternoon (PM). The sessions were separated by a one-hour break, during which a lunch was provided (in order to mimic a lunch break at work). Upon arrival in the morning, the subject signed the consent form. Then, anthropometric measures were collected. Adjustment in height and distance of the workstation were made in order to have the subjects working at shoulder height. For the height of the workstation, we measured the distance from the acromion to the ground (with shoes on). The middle row of the workstation was adjusted to that height. Then we asked the subject to hold the right angle tool in their dominant hand, stand in front of the workstation and raise their arm until it was parallel to the ground and the tool touched the workstation. When the position was adjusted, a mark was made on the ground to delimit the corresponding foot position, in order to keep foot position constant during and between sessions. The adjusted work position is displayed in Figure 1.

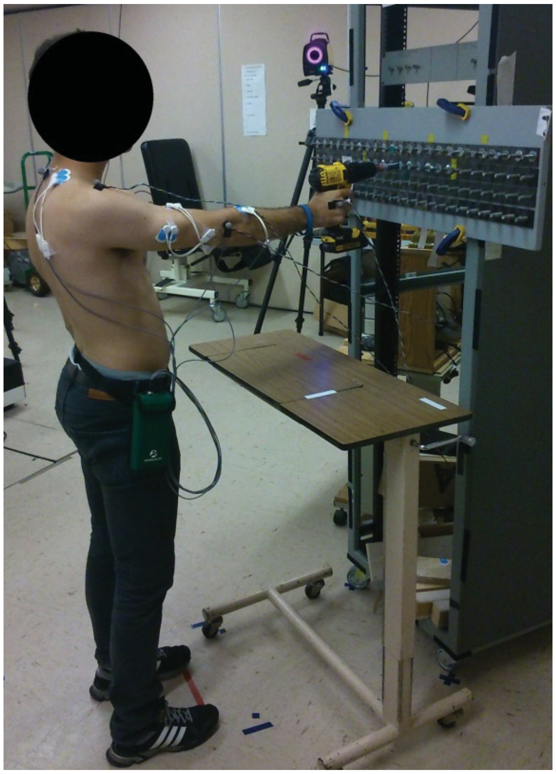

Figure 1. Workstation set-up

Then the protocol was explained to the subjects. The next step was the placement of the electrodes on the 8 chosen muscles: Upper-Trapezius (UT), Middle-Trapezius (MT), Lower-Trapezius (LT), Infraspinatus (IS), Anterior Deltoid (AD), Biceps Brachii (BB), Triceps Brachii (TB) and Wrist Extensor (Wext). Afterwards, the participants sat comfortably on a chair, with their arm resting on a height-adjustable table with their knees and hips flexed at 90°. The shoulder of their dominant arm was flexed 90°, horizontally abducted 45° and supported passively on the table. Quantitative Sensory Threshold (QST) was then tested at marked locations on the UT, AD and BB of the working arm with a twenty-monofilament kit of nylon Semmes-Weinstein monofilaments attached to a plastic handle (Touch-TestTM Sensory Evaluator, North Coast Medical Inc.). The kit contains monofilaments with different thicknesses ranging within the logarithmic scale of 1.65 to 6.65. It corresponds to an applied force fitting on a scale of 0.008g to 300g (Bell-Krotoski et al. 1995). Thus, as the nylon monofilaments progressively increase in thickness/diameter, so does the force stimuli they apply. Researchers did not give any feedback to the subjects, who kept their eyes closed throughout the testing (Gondring et al. 2011; Scheudrers et al. 2008). Each monofilament was applied once at an angle of 90° on the surface of the skin with just enough pressure in order to cause the monofilament to buckle/bow to approximately 90 degrees (Rommel et al. 2001). If the monofilament slipped on the skin of the participant, we applied it a second time (Massy-Westropp, 2002). If the subject detected a cutaneous sensory stimulus, the subject said “yes” and the size of the monofilament was recorded as the QST threshold value. If not, the next thicker filament was applied immediately until the threshold filament was identified. Then, Pain Pressure Threshold (PPT) measures were taken with an electronic pressure algometer (Somedic production AB, Sweden) at the same three marked locations used for QST. Pressure was applied perpendicular to the surface of the skin with a constant increase rate of 40KPa/s and a padded mechanical foot plate of 1 cm^2 in surface area (Andersen et al. 2010). The subjects held a signal button in their contralateral hand and were instructed to push it as soon as the sensation of pain appeared in association with the pressure stimulus. The button was connected to the algometer via a cable. The display unit on the side of the algometer was able to show and save the threshold PPT values in kilo-Pascals (Persson et al. 2003). Three trials per location were performed with 30 seconds rest in between. To avoid an order effect, the order in which the three sites were tested was randomized (Andersen et al. 2010) and was kept the same for the 4 times, for both QST and PPT testing (pre- and post-fatigue, AM and PM). Subjects were asked to have closed eyes for both tests.

We then let the subjects familiarized themselves with the protocol, performing one block of the task (approximately 5 min). After making sure that the electrodes and attached cables were fixed with medical tape, the participant was instructed in completing maximum isometric voluntary contractions (MIVC). The UT was tested with the arm at the side; participants elevated their shoulder against resistance applied on the shoulder. For the AD, the subject applied a shoulder flexion effort with the arm flexed 45°, against resistance applied on the upper arm. The MT MIVC action consisted of scapula adduction with the shoulder at 90°flexion. The LT action was performed with the shoulder in an angle of 90° flexion and the scapula depressed against resistance applied under the upper arm. The BB and TB were tested with the hand supinated and the elbow flexed slightly less than 90°, the resistance was applied on the anterior side of the forearm for the BB and posterior side for the TB. The Wext was tested by performing wrist extension from a neutral wrist angle, forearm pronated, with the arm resting on a table at 90° flexion in the elbow, against resistance applied on the dorsal part of the hand. The subjects were asked to lay down on their belly on a massage table with their dominant arm positioned in 90° abduction, elbow flexed at 90° in order to do an external rotation to activate the IS. A rigid frame structure was custom adapted to subject sizes to allow external resistance to be applied in the procedures for the first 6 muscles listed above, while resistance was applied manually for the Wext and IS. For each, two ramp-up, ramp-down, five-second MIVC trials were completed for each muscle with encouragement to push as hard as possible in the designated force direction. One minute of rest was given between each of the trials to ensure maximum effort was given in the next trial. The kinematic markers were then placed. The two Laser Doppler Flowmetry electrodes were placed and the baseline vascular measures were taken when the subject adopted a relaxed and static state in the same position as when we collected QST and PPT. Then, we performed a Shoulder Positioning Test (SPT). The subject stood in a comfortable posture, arms to the side of the body, holding the indicator button in their non-dominant hand. They were asked to close their eyes, raise their dominant arm, elbow extended, with their thumb pointing toward the sky until it was perceived to be parallel to the ground. Once the perceived horizontal was reached, they were asked to press the button and hold that position for 25 sec. This allowed identifying the kinematics associated with this perceived arm horizontal position. Finally, the subject proceeded to the fatiguing task (detailed in the next section). In it, performance was recorded by counting the number of bolts screwed with the right angle tool or by hand as well as the number of times the subjects reached the target. This was done after each 30 sec of each task. Subjects indicated their rating of self-perceived exertion in shoulder and neck region with the help of a Borg CR-10 analog scale (Borg, 1982). Scores on the Borg

CR-10 analog scale were recorded after each block. Discomfort was rated using a full body map and discomfort scale (Messing et al. 2008; Antle et al. 2013).

2.3 Protocol

Speed fastening is widely used in automotive manufactures (Ku et al. 2007). Three different speed-fastening subtasks were used to screw the bolts into the different rows of the workstation (Figure 2. a).

(a) (b)

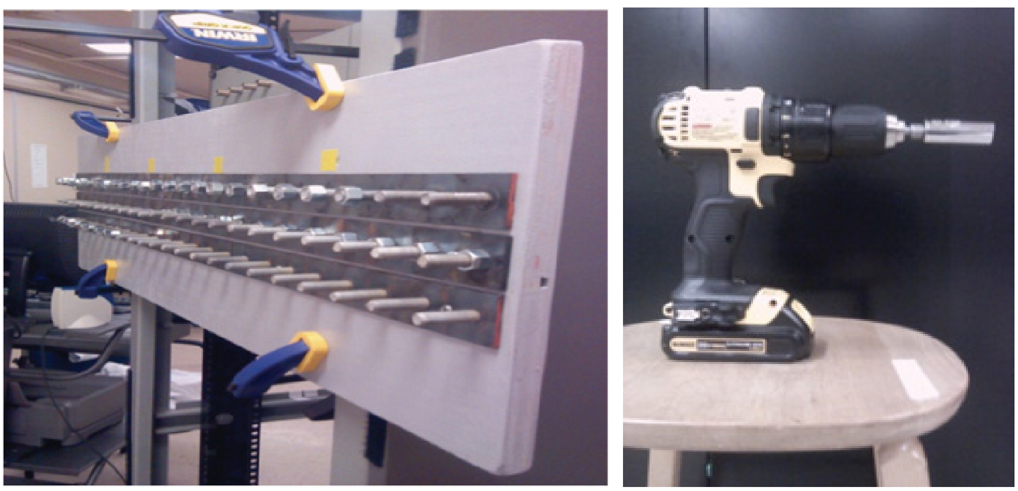

Figure 2. a (left) Close-up picture of the different raws

b (right) right angle tool used to do the TS and TR tasks (DeWALT DCD780C2 ,1.5kg)

The first subtask was Tool Screwing (TS) and consisted of screwing the bolts (pre-screwed at the edge of the nut) with the electric tool (Figure 2. b) on the first row of the working station. For the Tool Reaching (TR) task, subjects were asked to align the electric tool with a bolt pre-screwed and to push the tool in and out of the screw. The last task was Hand Screwing (HS) and consisted of screwing the bolts with the same hand that was also doing the other 2 subtasks until their edge was aligned with the screw. Each task was asked to be done as fast as possible in order to create an effect of fatigue relatively quickly.

Altogether, the subject accomplished blocks of 5 min using a 50% work cycle (based on Gooyers et al. 2012). In Figure 3, the sequence followed within each block is displayed. Note, during the second round, instead of 30 s rest, the subjects were asked to rate their discomfort on the CR 10 Analog Scale as well as the full Body Map Discomfort. The subject was to continue this work cycle until they scored 8 (out of 10) on the CR 10 Analog Scale. They were unaware of this stoppage criterion. QST and PPT were tested in the fatigue state right after the experimental task was stopped.

One block of the tasks (4 min)   *Right after (1min)*

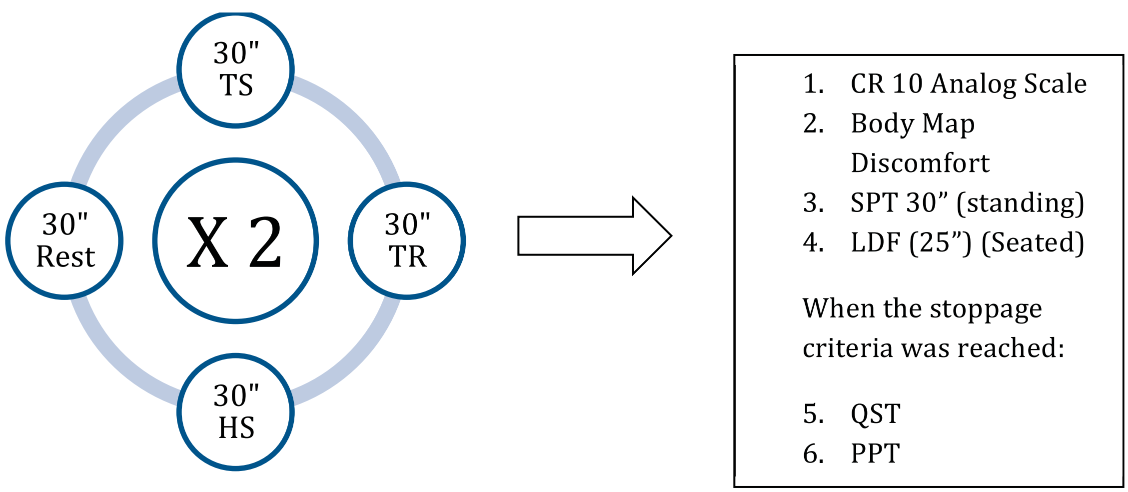

Figure 3. Sequence of subtasks in a working block

2.4 Instrumentation

The participant was fitted with electromyographical (EMG) recording equipment (TeleMyo, Noraxon, USA, 10-350 Hz operating bandwidth). EMG data was recorded using a sampling frequency of 1080 Hz. Eight muscle areas of the right arm, shoulder and trunk were identified by locating specific anatomical landmarks through palpation and putting a mark on the skin overlaying the site using an eyeliner pen. The skin sites were prepared by being shaved and then cleaned with rubbing alcohol to allow for better signal transmission. The Ag/AgCl surface electrodes (Ambu, Del) were then placed side by side in bipolar configuration, parallel to the muscle fibers. The pen marks ensured that the eight electrode pairs were placed exactly at the same location each session. Electrodes were placed on the following sites: upper trapezius (UT): midpoint between C7 spinous process and acromion; middle trapezius (MT): midpoint between the thoracic spine and the medial border of the scapula; lower trapezius (LT): midpoint between the T8 spinous process and the inferior angle of the scapula; infraspinatus (IS): under the spine of the scapula, midpoint between medial and lateral side of the scapula; anterior deltoid (AD): between the lateral 1/3 of the clavicle and the deltoid tuberosity of the humerus; biceps brachii (BB): belly of the muscle; triceps brachii (TB): 60% of midline between acromion and olecranon; wrist extensor (Wext): over the muscle belly, approximately 2 finger widths distal to the elbow (Basmajian & Blumenstein, 1980). A reference electrode was placed over the right external epicondyle. Following this, the participant was outfitted with the vascular recording equipment. Two Laser Doppler Flowmetry (FloLAB Monitor, Moor Instruments, Devon, England) electrodes were used to measure skin blood flow: one positioned over the right UT, medial to the UT electrodes (shoulder LDF - SLDF), and the second over the right Wext muscles, between the Wext electrodes and the external epicondyle (forearm - LDF FLDF). Kinematic characteristics wererecorded in three dimensions using passive, reflective markers. A series of 24 markers were fixed to the skin using double-sided adhesive tape on the principal anatomical landmarks of the trunk and upper limbs according to the Vicon Plug-In Gait (VICON, Oxford Metrics ltd., Oxford, UK) upper body model. Marker spatial coordinates were captured (120 Hz) using a high-resolution, six-camera Vicon MX3 motion capture system (Vicon-Peak, Oxford metric Ltd., Oxford, UK).

2.5 Data Analysis

EMG data was filtered using a dual-pass 4^{th} order Butterworth band-pass of 20-500 Hz. The signals collected during the AM and PM sessions were full-wave rectified. Root-mean-square (RMS) values were calculated over 25 1-s non-overlapping windows for each collection period and the average of the 25 RMS values in order to have a representative mean amplitude value for each muscle every time data was gathered. We then normalized to the EMG data gathered during the MIVC, to be expressed as % MVIC. The data collected from LDF was integrated over non-overlapping 1 s windows for the 25 s time series. The initial LDF collection taken in the morning before the tasks started was considered the baseline blood flow measure. The 25, 1-s windows were averaged to obtain one representative value of blood flow following each work block, and a percent change of that value obtained from the baseline was calculated. All analyses were done using Matlab software (Mathworks, Massachusetts, USA).

For the analysis of QST and PPT, data were collected and analyzed from 4 times: before and right after (set to be the fatigue state) each session. In term of performance, data on the number of bolts screwed were collected and analyzed from 4 times as well: the first and last working block for each subtask during each session. In order to account for the possibility of performance improvement beyond the values recorded in the first block (i.e. evidence of learning), we also performed statistical comparisons between peak performance and post-fatigue performance values, at both morning and afternoon sessions.

2.6 Statistical Analysis

Fatigue (pre vs post task for most variables; in addition, for performance, peak vs post-task) x Session (AM vs PM) repeated measures ANOVAs were run on the RMS, Performance, PPT, QST and LDF variables. Pearson Correlation Coefficients were computed for the following variables: subject's performance in term of number of blocks accomplished, Borg's scores as well as LDF. Significance was set as $p < 0.05$. All analyses were run using SPSS software.

3. Results

3.1 Evidence of Fatigue

3.1.1 Fatigue and Task Difficulty

Every participant stopped the fatigue protocol according to the stoppage criteria of perceived exertion with final average scores of 8.35 (± 0.43) in the morning session (AM) and 8.52 (± 0.49) in the afternoon session (PM). In addition, a main Fatigue effect [$F(1,14) = 80.0$, $p = 0.000$] as well as a main Session effect [$F(1,14) = 6.03$, $p = 0.028$] were observed on Borg ratings. On average, scores were significantly higher at the end of the sessions compared to the beginning ($t = 0.039$), and were significantly higher during the PM session than during the AM session ($t < 0.001$) (see **Figure 1**).

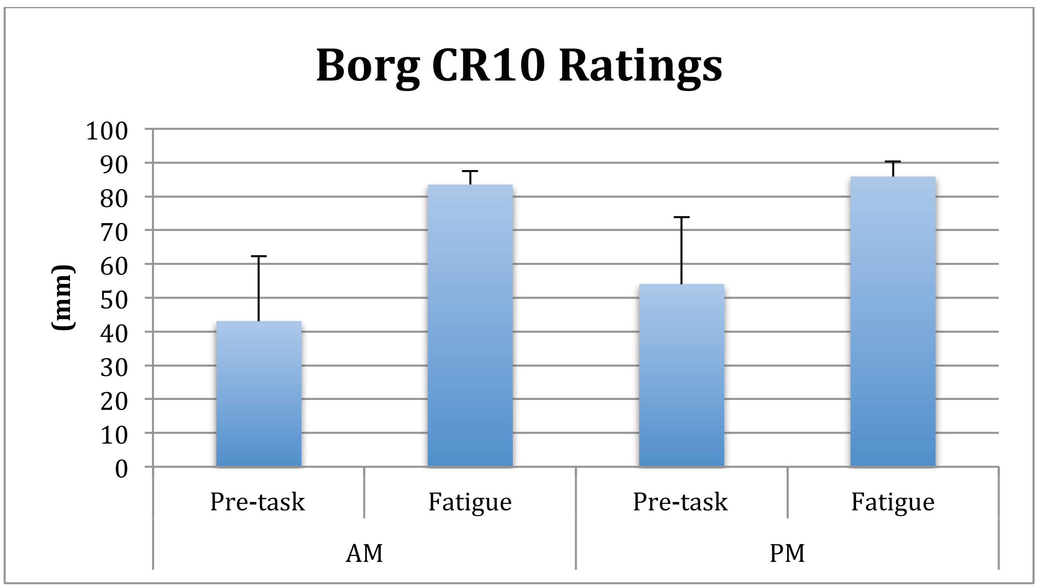

Figure 1 Borg CR10 ratings before and after each session, scored on an analog scale of 10 cm (mean +SD).

3.1.2 Fatigue and Muscle Activity

Significant Fatigue main effects were found in EMG RMS values of the AD [$F(1,9) = 10.87$, $p = 0.009$] and BB [$F(1,9) = 6.44$, $p = 0.032$] showing significant increases with time (see **Table 1**). These results indicate a success in the task to induce fatigue in these muscles.

Measures Sites	AM (AVG(SD))		PM (AVG(SD))		Fatigue Main Effect	Time Main Effect	Fatigue X Session
	Pre-task	Fatigue	Pre-task	Fatigue			
UT	11.42 (6.85)	12.75 (5.93)	10.64 (5.75)	11.16 (5.44)	_	_	_
AD	14.44 (4.47)	17.59 (5.54)	14.72 (5.02)	16.60 (5.66)	0.009	_	_
BB	2.40 (1.49)	3.01 (1.82)	2.76 (2.06)	3.19 (2.27)	0.032	_	_
RWE	1.31 (1.06)	1.93 (1.25)	2.32 (4.24)	1.96 (2.92)	_	_	_

Table 1 Summary of results from EMG RMS (% of MIVC) under pre-task and Fatigue condition in both sessions ($p < 0.05$).

3.1.3 Fatigue and Performance

The number of blocks accomplished in the PM session decreased by 26% (from 6.3 (±3.2) in the AM, to 4.6 (±4.3) in the PM).

Significant Fatigue x Session interaction effects were found when looking at the maximum number of hand-screwed (HS) bolts in each session: [$F(1,14) = 9.55$, $p = 0.008$], with performance being less decreased by fatigue in the PM. A main Fatigue effects was found as well: [$F(1,14) = 22.7$, $p = 0.000$].

For the set of data from the first block of each session, significant main Fatigue effects were found for the tool screwing (TS) task [$F(1,14) = 21.5$, $p = 0.000$]. Main Fatigue effects were detected as well for the maximum number of bolts screwed with the tool [$F(1,14) = 18.7$, $p = 0.001$] and for the maximum number of reaches completed during the tool reaching (TR) task in each session [$F(1,13) = 30.3$, $p = 0.000$]. This shows that a decrease in the performance parameters of these tasks happened with fatigue within sessions.

Main Session effects were found for the TS task [$F(1,14) = 17.4$, $p = 0.001$], showing a lower number accomplished in the afternoon session, compared to in the morning session. Main Session effects were also found for the maximum number of bolts screwed with the tool [$F(1,14) = 12.1$, $p = 0.004$], showing a lower number accomplished in the PM session.

3.2 Explanatory Mechanisms of the Fatigue Response

3.2.1Fatigue and Sensory Characteristics (QST)

Significant main Fatigue effects were found for the Quantitative Sensory Testing (QST) results of the UT [$F(1,14) = 5.11$, $p = 0.040$], with an average increase in threshold values with fatigue. Moreover, as depicted on **Figure 2**, values were the highest in the fatigue state of the PM session, although there were no significant Session or interaction effects.

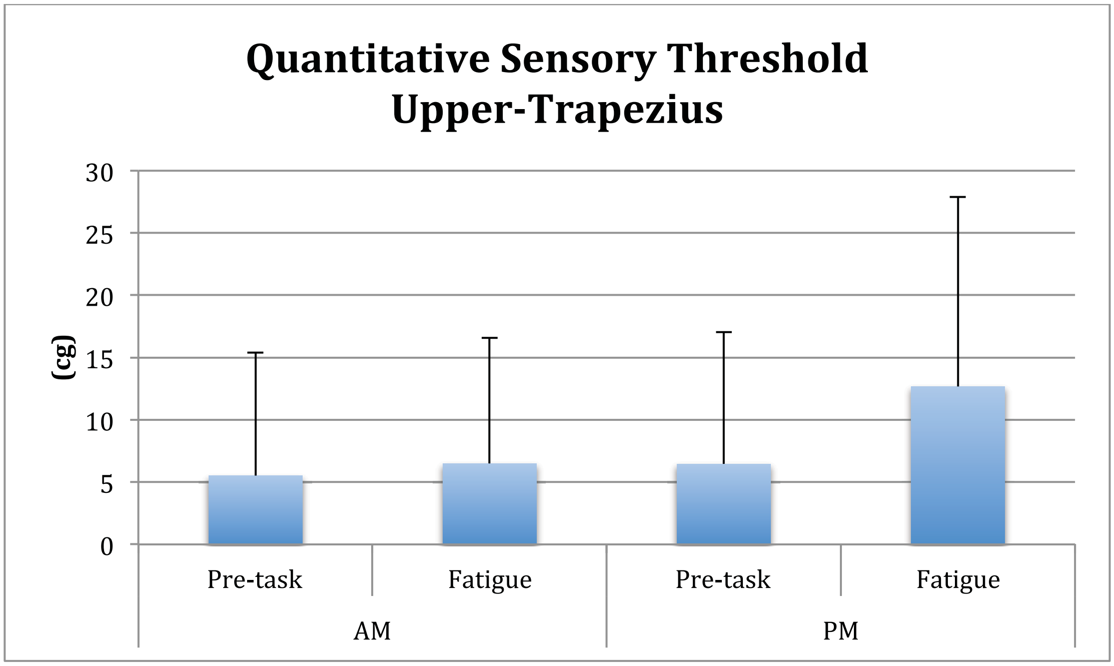

Figure 2: Quantitative Sensory Threshold (QST) at the upper-trapezius (UT) under pre-task and Fatigue conditions in both sessions (mean +SD). There is a significant main Fatigue effect ($p < 0.05$).

3.2.2 Fatigue and Pain Sensation (PPT)

No significant results were found on PPT values (see **Table2)**. The fatigue and session values were the following: AD: Fatigue [$F(1,14) = 0.16$, $p = 0.70$], Session [$F(1,14) = 0.86$, $p = 0.37$], Fatigue X Session [$F(1,14) = 2.56$, $p = 0.13$]; UT: Fatigue [$F(1,14) = 0.61$, $p = 0.45$], Session [$F(1,14) = 0.013$, $p = 0.91$], Fatigue X Session [$F(1,14) = 0.41$, $p = 0.84$]; BB: Fatigue [$F(1,14) = 3.15$, $p = 0.10$], Session [$F(1,14) = 0.047$, $p = 0.83$], Fatigue X Session [$F(1,14) = 0.008$, $p = 0.93$].

Measures Sites	AM (AVG(SD)) Pre-task	AM (AVG(SD)) Fatigue	PM (AVG(SD)) Pre-task	PM (AVG(SD)) Fatigue	Fatigue Main Effect	Time Main Effect	Fatigue X Session
UT	281.38 (112.08)	295.71 (145.86)	282.04 (119.87)	291.60 (128.57)	_	_	_
AD	303.02 (142.29)	290.91 (151.23)	273.82 (169.37)	293.18 (185.71)	_	_	_
BB	272.98 (132.40)	301.62 (185.42)	275.02 (171.30)	305.16 (207.75)	_	_	_

Table 2 Summary of results from PPT (kPa) under pre-task and Fatigue condition in both sessions ($p < 0.05$).

3.2.3 Fatigue and Blood Flow

We found significant main Fatigue effects at the forearm location [$F(1,9) = 7.50$, p = 0.023] and at the shoulder location [$F(1,9) = 14.3$, p = 0.004] showing an increase in normalized blood flow to both locations with fatigue (see **Figure 3**). There were no session effects.

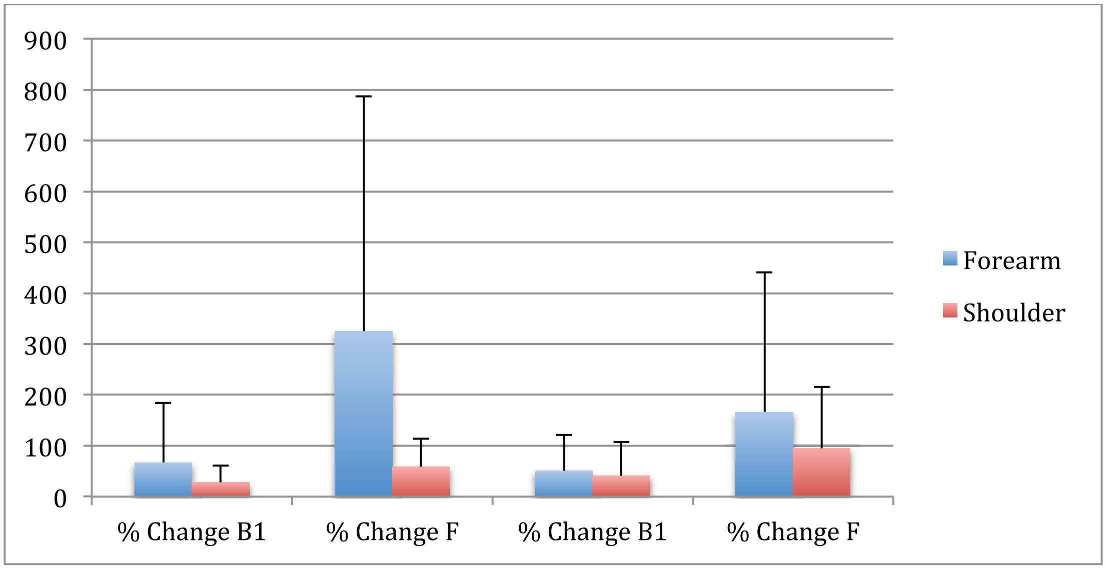

Figure 3: Percent change in the first block compared to morning baseline (% Change B1) and percent change in the last block compare to morning baseline (% Change F) for both shoulder and forearm in each session (mean +SD). There is a significant main Fatigue effects for both location ($p < 0.05$).

3.3 Associations Between Variables

The reduction in number of blocks accomplished in the PM (-26%) was associated with the pre-fatigue increase in Borg CR10 scores in the PM vs in the AM ($r = -0.71$) (see **Figure 4**). This indicates that people who had the strongest pre-fatigue increase in Borg CR10 scores to start the PM session were the ones who displayed the largest reduction of blocks accomplished in the PM session.

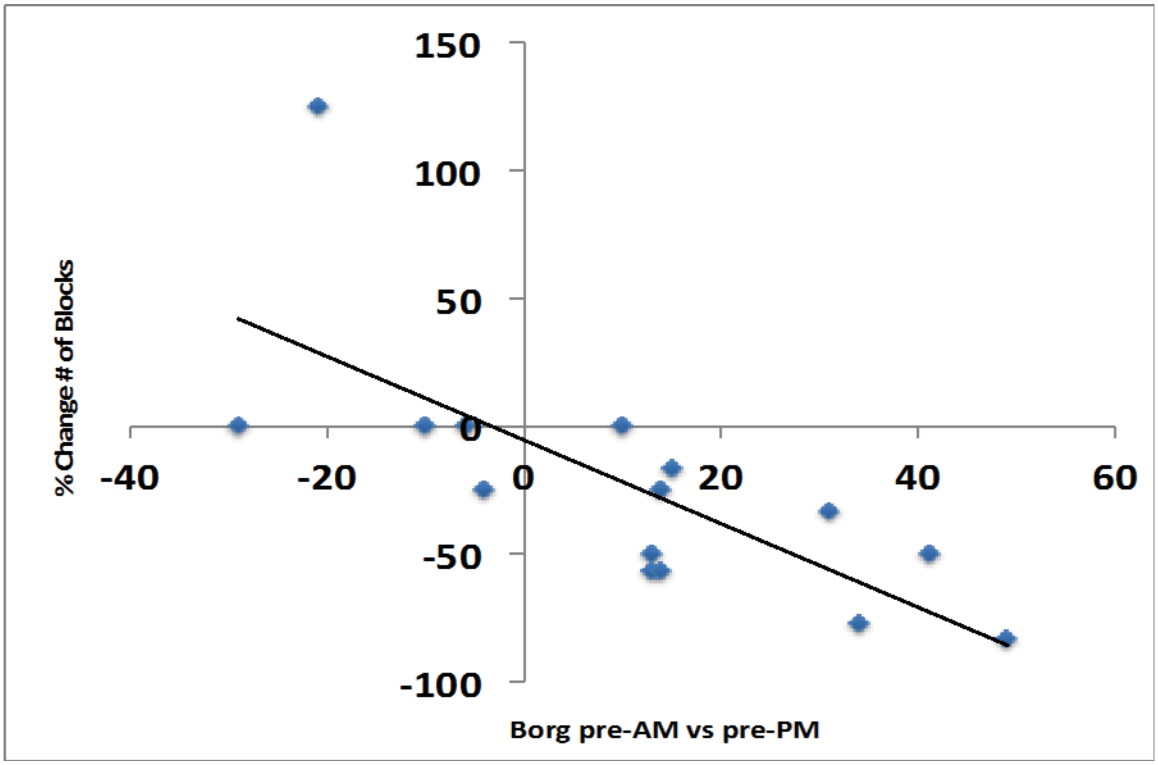

Figure 4 Correlation between the reduction in number of blocks accomplished in the PM and the pre-fatigue increase in Borg CR10 scores in the PM vs in the AM (r= -0.71).

3.4 Characteristics of the Decliners vs Improvers

A subject was identified as an "improver" if his PM pre-fatigue Borg score was lower than his AM pre-fatigue Borg score. A "decliner" would be the opposite, with a higher pre-fatigue Borg score in the PM compared to AM.

The decliners' forearm blood flow percent changes in the fatigue state were associated with the percent change of the number of blocks accomplished in the PM session (r = 0.73). This indicated that within the subjects scoring a higher pre-fatigue Borg in the PM, an increased blood flow in the forearm was correlated with the decrease of performance.

4. Discussion

The purpose of this study was to determine key manifestations of auto-assembly work-related fatigue, using a laboratory protocol, state-of-the-art tools and methods. The task itself was done at shoulder height and consisted of manipulating a bolt-screwing right angle tool at shoulder height and perform three auto-assembly-like tasks, at shoulder height. The fatigue protocol was performed once in the morning, and again in the afternoon. We hypothesized that fatigue would significantly affect multi-systemic measures, more so in the afternoon.

4.1 Evidence of Fatigue

Several studies have used a score of 8 out of 10 on the Borg CR-10 analog scale to correspond to a state of fatigue in functional protocols (Côté et al. 2002; Emery et al. 2012; Fuller et al. 2011). Therefore in our study, when the participants reached an 8 on the scale, the protocol was stopped. This stoppage criterion was used to ensure that the participants reached a relatively similar perceived state of task-related fatigue at the end of each session. A main Fatigue effect as well as a main Session effect were observed on Borg ratings. This suggests that fatigue had the same effect on perceived task difficulty in the AM and PM sessions. However, qualitatively, we can observe that ratings did not return to baseline at the beginning of the PM session. Added to the fact that participants also reached exhaustion sooner in the afternoon, this indicates that the 1 hour lunch break was not sufficient to fully recover in terms of perceived task difficulty. Moreover, the reduction in number of blocks accomplished in the PM was associated with the pre-fatigue increase in Borg CR10 scores in the PM vs in the AM. This indicates that people who had the strongest pre-fatigue increase in Borg CR10 scores to start the PM session were the ones who displayed the largest reduction of blocks accomplished in the PM session. In other words, we believe that the subjects who perceived the task difficulty being about the same at the onset of the AM and PM sessions, are the one that recovered the fastest during the lunch break in order to perform similarly the same in the AM and PM session. Borg scale ratings are typically used to assess how task difficulty increases, but are less often used to judge recovery. Our results suggest that Borg ratings could be used to predict not only current exhaustion, but also as an indication of fatigue recovery and to predict the ensuing fatigue response. This could represent a powerful tool to use in the workplace to prevent fatigue-related injury development, although further studies are required to test this.

4.2 Fatigue and Performance

When looking at each subdivision of the task, different results came out. Significant Fatigue x Session interaction effects were found when looking at the maximum number of hand-screwed (HS) bolts, with less effect of fatigue on performance in the PM. This could be due to a lower maximum number of HS bolts combined with higher post-task number in the PM session, indicating more constant performance in the PM. Main Fatigue effects were found as well for the HS task. We can possibly interpret these results saying that the participants tended to pace themselves at a more constant rate in the afternoon while doing the HS subdivision task in order to last longer but despite this, the decrease in performance is still seen at the fatigue state.

Main Fatigue effects were also observed for the maximum number of bolts in the TS and TR subdivisions. This showed us that a decrease in the performance happened with fatigue within one session. Main Sessions effects were also found for the maximum of bolts screwed during the TS task that showed a lower number accomplished in the PM session. When looking at the set of data analyzed from the first block of each session, main Fatigue effects as well as main Session effects were found for the TS. This indicates that not only a decrease of the performance occurred within one session, a decrease of performance happened in the afternoon compared to the morning.

If we look at the factors that could lead to MSDs development in the neck/shoulder area, height is present in all three different tasks; the weight of the tool is present in the TS and TR. On top of height and weight, torques forces will be added concerning the TS task (Potvin et al. 2004). Interestingly enough, HS is the only subdivision where an interaction effect has been found in the data analyzed. HS does not involve the weight or torque forces associated with the tool but is instead characterised by fine movements of pronation and supination at the wrist. Given these task difference, the observation that task performance is more constant in the PM could be explained by two reasons: the muscles responsible for the pronation/supination action for HS might not be as directly fatigued ; the fatigue effects are compensated by a learning effect in the motor task.

Overall, shoulder fatigue (as validated with EMG and Borg measures) corresponded with declines in performance with the tool and screws. The chosen tasks rely largely on two motor aspects: the ability to maintain an adequate shoulder posture (the work height being at shoulder height and thereby requiring maintaining a somewhat stable 90 degree shoulder flexed posture), and the ability to manipulate the right angle tool (TS, TR) or the screws (HS), both requiring adequate motor performance with the hand and fingers. Previous studies have shown that fine motor performance with the forearm or hand can be affected by fatigue or injury at the shoulder (Madeleine et al. 1999; Madeleine. 2010). This can be explained either by the nerve or blood vessels uniting the proximal and distal regions of the upper limb, such that optimal performance during fine dexterous tasks are difficult to achieve with impairment at the neck and-or shoulder region (Visser et al. 2006). This is particularly relevant to jobs that involve a lot of dexterous tasks in a variety of shoulder postures. Thus, it is recommended that not only from a shoulder injury-preventative approach, but also a fine motor performance goal, prolonged upper limb tasks be performed in work planes much below shoulder height (Sood et al. 2007; Gooyers et al. 2012; Rosati et al. 2014).

Studies in the past have shown that during sub-maximal contraction, fatigue induces an increase in the EMG RMS amplitude concomitant to a decrease in the EMG frequency content (Madeleine et al., 2002). Moreover, significantly increased EMG activity amplitude in the upper trapezius, biceps and deltoid muscles has been observed in previous studies, after having performed a low-force repetitive shoulder height task inducing fatigue up to the same stoppage criteria (Borg CR10 score of 8) (Côté et al. 2008; Fuller et al. 2009; Emery et al. 2012; Fedorowich et al. 2013). The present results show significant Fatigue main effects for the EMG RMS average values of the AD indicating a success in the task to induce muscle fatigue. Thus, the experimental tasks used in our study induce local fatigue in the anterior deltoid and biceps brachii muscles. These muscles are thus the ones most likely to suffer from auto-assembly work performed in front of the body, at shoulder height. Even though the amounts of muscle activity displayed during these tasks, relative to those collected during maximal voluntary efforts of these same muscles, are relatively small (about 15% for the AD, less than 5% for the BB), these significant activity amplitude increases with fatigue indicate an increased load on the muscle. The fact that there were no Session or Interaction effects on these measures suggests that the lunch break was effective in allowing these muscles to recover their ability to fire and react to fatigue in the afternoon session. However this does not mean that all neuromuscular aspects have the same ability to quickly recover. Also, it is unknown whether for instance this ability to recover would be the same at the beginning vs at the end of the week. Further longitudinal studies need to be conducted to elucidate this question.

Even though, as mentioned above, the effects of fatigue on muscle activity were the same in the morning as in the afternoon sessions, the participants reached the stoppage criteria earlier in the afternoon than in the morning session, with a number of blocks accomplished decreased by 26%, showing an overall decrease in performance in the afternoon. Thus, despite similar muscle activity levels, suggesting a similar motor ability to accomplish the task, the subjects reached exhaustion sooner. This suggests that the system must base its sense of exhaustion on sensations other than that provided by the motor output.

Pain and Pressure Threshold (PPT) is related to the upper sensory limit when a normal pressure sensation becomes painful (Ylinen et al. 2007). No significant results were found on PPT values (see **Table 2**). These results are contrary to previous findings that have shown that fatigue affects pressure pain thresholds….. the reasons why our results do not show effects on PPT are unclear. This indicates that pressure pain thresholds method might not be effective in detecting signs of fatigue within subjects that are novice to this instrumentation (possible lack of detecting their own threshold of pain).

Quantitative Sensory Testing (QST) is meant to measure the sensitivity to the lightest point pressure (Bell-Krotoski et al. 1995). During a screw-driving task, touch sensitivity of both index and thumb fingertips was significantly affected, showing an increased threshold over time (Diannat et al. 2010). In our study, significant main Fatigue effects were found for the QST with results of the UT showing an average increase in threshold values with fatigue. Figure X displays that qualitatively, values increased drastically at the fatigue state of the PM session which could possibly be due to an accumulation of metabolites or gradual development of motor impairment leading to a loss of sensitivity. Thus, this could possibly explain an accumulated fatigue effects that is small and slow at first, but that could be sufficient to be detected and integrated into the sense of exhaustion, that shows a progression from the morning to the afternoon session.

4.3 *Fatigue and Blood Flow*

We found significant main Fatigue effects at the forearm location and at the shoulder location showing an increase in normalized blood flow to both locations with fatigue. There were no session effects. This indicates that subjects in a fatigue state show a need in bringing more blood to the working sites. These findings clearly illustrate the multisystemic response to local muscle fatigue, with blood delivery increased at both the regions accumulating fatigue (shoulder) and responsible for performing the fine motor task (forearm). However, the exact role of blood flow in fatigue-related performance is not clear. On one hand, the absence of session or interaction effects suggest that blood flow information may not play a crucial role in contributing to the sense of effort, since similar increases with fatigue are observed in morning and afternoon sessions. On the other hand, within the group of "decliners", forearm blood flow percent change in the fatigue stage was positively associated with the percent change of the number of blocks accomplished in the PM session, such that the smallest increases in blood flow to the forearm were correlated with the biggest decreases of performance. However this relationship was not observed with shoulder blood flow, but only with forearm blood flow, such that it would make more sense that blood flow information would be associated to fatigue-related functional declines in hand and finger performance, rather than fatigue-related increases in perceived shoulder exhaustion.

In a study done by Samani et al (2011), it was suggested that shoulder pain plays a role in the coordination of wrist flexor and extensors during computer work, which could be classified as a fine motor task, and comparable to the demands during the HS task. In our study, when the subjects reached the stoppage criteria (based on their pain perception in the shoulder area), a subgroup (decliners) stood out and performed fewer blocks in the PM, which means they reached their level of exhaustion earlier. Furthermore, an increase in their forearm blood flow at that time was correlated to this previous decline of performance (number of blocks); moreover, we found an interaction effect in the performance during the HS task, which involves forearm muscle (pronation and supination of the wrist). Thus the forearm could be a key site where fatigue will be induced and lead to exhaustion while performing a task at shoulder height.

4.4 A Unified Model for Multisystemic Mechanisms of Shoulder Height Work-related Fatigue.

Taken together, our results point to two distinct mechanisms that could explain the manifestations of shoulder height work-related fatigue. First, fatigue and exhaustion experienced at the shoulder during shoulder-height task could be due to changes at the muscle's sensory detection level. Our data supports this pathway, much more than one using feedback from the motor output or based on any interpretation of sensory information as pain. Second, declines in fine motor performance that would be consequent to this sense of effort could be at least exacerbated by sub-optimal blood delivery to the working forearm and hand muscles in such a flexed shoulder posture, at least in those that show the largest accumulated declines in performance.

This supports the role of the flexed shoulder posture as the main source of fatigue in occupational tasks, and the importance of adequate blood delivery mechanisms to the extremities, which likely themselves depend on other inherent personal factors.

4.5 Limitations

A few limitations exist in relation to this study. The first one concerns the fact that the subjects were all novices in using this electric tool. The results could be different coming from professionals that work with these tools on a daily basis. In line with this, the subject's practice session with the tool was only one block of 5 minutes. It is possible that an ongoing learning effect in the morning (combining with, or compensated from, the fatigue effects) could play a part in differences between the two sessions. We chose to include only male participants as they have a much higher presence within the auto industry, so that these results may not be transferrable to female workers. In addition, most of our participants were young adults, so that our results may not apply to older workers. Finally, in our study we limited the participant's movements, whereas in an assembly line the workers may have greater freedom of movement to achieve the tasks, as well as potentially the possibility to alternate between different kinds of tasks as part of their job description. As a whole, our results should be extrapolated with great caution beyond the experimental conditions, which include our measurements at a selection of body sites (i.e. it is possible that other fatigue-related changes would occur at other muscles and joints not measured here).

5. Conclusion

The goal of this study was to determine key manifestations of auto-assembly work-related fatigue in a laboratory environment. We used several tools in order to identify which ones would be sensitive to change over two fatigue-inducing sessions held on the same day (morning, afternoon). From our findings, the Borg CR10 analog scale could be an easy and friendly tool to use for an estimation of the recovery process to help predict if a worker will perform at his/her full potential or not on two consecutive sessions. Moreover, our results show that a method of QST recording applied at the UT site was effective in quantifying a loss of sensitivity related to a fatigue state. Finally, the performance decrease in the afternoon session varied depending on the kind of task performed. Together, our results could help identify effective and easy-to-use methods of measuring fatigue in workplaces such as auto assembly plants, which could help prevent work-related MSDs.

Acknowledgements

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CONCLUSION

This is the first study of its kind to assess the relationship between multi-level data in order to determine key manifestations of fatigue during simulated auto work at shoulder height. It can contribute to the identification of measurements related to fatigue.

The present results show significant Fatigue main effects for the EMG RMS average values of the AD. In previous studies, significantly increased EMG activity amplitude in the upper trapezius, biceps and deltoid muscles has been observed, after having performed a low-force repetitive shoulder height task inducing fatigue up to the same stoppage criteria (Borg CR10 score of 8) (Côté et al. 2008; Fuller et al. 2009; Emery et al. 2012; Fedorowich et al. 2013). An important part of the study was to look at how fatigue would influence the performance of the subjects. When observing the maximum number of hand-screwed (HS) bolts, Fatigue x Session interaction (with less effect of fatigue on performance in the PM) as well as main Fatigue effects were found. These results suggest that the participants tended to pace themselves at a more constant rate in the afternoon while accomplishing the HS sub-task, possibly to prolong task performance, but despite this, the decrease in performance was still seen at the fatigue state. Main Fatigue effects were also observed in the Tool-Screwing (TS) and Tool-Reaching (TR) subtasks, showing that a decrease in the performance happened with fatigue within one session for all the subtasks. On the other hand, when looking at muscle activity, even though the effects were the same in the morning as in the afternoon sessions, the participants reached the stoppage criteria earlier in the afternoon than in the morning session, with a number of blocks accomplished decreased by 26%, presenting an overall decrease in performance in the afternoon. Thus, despite similar muscle activity levels, suggesting a similar motor ability to accomplish the task, the subjects reached exhaustion sooner. This suggests that the system must base its sense of exhaustion on sensations other than that provided by the motor output.

Sensitivity threshold was also measured in this study using Quantitative Sensory Testing (QST). Significant main Fatigue effects were found for the QST with results of the UT showing an average increase in threshold values with fatigue; qualitatively, values increased drastically at the fatigue state of the PM session which could possibly be due to an accumulation of metabolites or gradual development of motor impairment leading to a loss of sensitivity. Thus, this could possibly explain an accumulated fatigue effect that is small and slow at first, but that could be sufficient to be detected and integrated into the sense of exhaustion, that shows a progression from the morning to the afternoon session.

From the different factors that could lead to MSD development in the neck/shoulder area, workstation height is present in all three different subtasks; the weight of the tool is present in the TS and TR. On top of height and weight, torques are added in the TS task (Potvin et al. 2004). Interestingly enough, HS is the only subdivision where an interaction effect has been found in the data analyzed. HS does not involve added weight or torques associated with the tool but is instead characterised by fine movements of pronation and supination at the wrist. Given these task difference, the observation that task performance is more constant in the PM could be explained by two reasons: the muscles responsible for the pronation/supination action for HS might not be as directly fatigued ; the fatigue effects are compensated by a learning effect in the motor task.

Another center of interest of the study was to look at the muscle recovery process; for this, we measured blood flow, which has been used as a marker in a few studies to infer muscle recovery after effort (Larsson et al. 1999; Strøm et al. 2009). We found significant main Fatigue effects at both forearm and shoulder, showing an increase in normalized blood flow to both locations with fatigue. This suggests that in a fatigue state there is a need in bringing more blood to the working muscles, which is effectively met by increased blood delivery. These findings clearly illustrate the multisystemic response to local muscle fatigue, with blood delivery increased at both the regions accumulating fatigue (shoulder) and also to those responsible for performing the fine motor task (forearm). When the subjects reached the stoppage criteria, a subgroup (decliners) stood out and performed fewer blocks in the PM, which means they reached their level of exhaustion earlier. Furthermore, an increase in their forearm blood flow at that time was correlated to this previous decline of performance (number of blocks); moreover, we found an interaction effect in the performance during the HS task, which involves forearm muscle (pronation and supination of the wrist). Thus the forearm could be a key site where fatigue will be induced and lead to exhaustion while performing a task at shoulder height. Future research focusing on the forearm could have some beneficial effects to help detecting fatigue.

Taken together, our results point to two distinct mechanisms that could explain the manifestations of shoulder height work-related fatigue. First, fatigue and exhaustion experienced at the shoulder during shoulder-height task could be due to changes at the muscle's sensory detection level. Second, declines in fine motor performance that would be consequent to this sense of effort could be at least exacerbated by sub-optimal blood delivery to the working forearm and hand muscles in such a flexed shoulder posture, at least in those that show the largest accumulated declines in performance. This supports the role of the flexed shoulder posture as the main source of fatigue in occupational tasks, and the importance of adequate blood delivery mechanisms to the extremities, which likely themselves depend on other inherent personal factors.

Beside helping to detect manifestation of fatigue, this study advances our understanding of the effects of accumulated fatigue and the extent to which people recover during a day break, it would be interesting in the future to extend this protocol to 2 days to extend our understanding of muscle recovery. This information could then be used to design specific tools and approaches to track these variables during a work day, which could be used into the identification of more effective work-break regimens and overall more effective injury-preventative approaches. Tools like Borg CR10 analog scale could be easy and friendly ways to estimate the recovery process and help predict if a worker will perform at his/her full potential or not. QST applied at the UT site could be helpful in determining a loss of sensitivity related to a fatigue state.

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APPENDICES

A. Consent Form (English Version)

CRIR Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Consent form

Hôpital juif de réadaptation Jewish Rehabilitation Hospital

1 - Title of project

Measuring Fatigue in the Workplace: Force Steadiness, Motor Coordination, and Hand-Arm Steadiness (A506-AWH)

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

Adrien Moufflet, Master's student, Jewish Rehabilitation Hospital Research Centre, (450) 688-9550 ext. 4827

3 - Project description and objectives

Local fatigue in muscle, as a result of prolonged activity, may lead to pain, discomfort, impaired motor control and performance. Preliminary evidence show that fatigue measures, such as force steadiness, motor coordination, and hand/arm steadiness tests, may be useful in monitoring fatigue, but they have only been used in laboratory settings. This research will evaluate the feasibility of using sensorimotor, vascular and performance-related fatigue measures during work and determine whether these measures can detect the difference in fatigue development between morning and afternoon work sessions. In this part of the study, participants will be asked to perform a series of tests to measure fatigue before a simulated work shift, during breaks, and at the end of the day. Results of this study may help identify practical and reliable fatigue measures that can be used to assess injury risk in the workplace based on fatigue response.

4 - Nature and duration of participation

The research project in which I am invited to participate aims at evaluating how fatigue affects behavior and performance during a simulated work task. The experimental procedure takes place at the research center of the Jewish rehabilitation hospital. I am asked to participate in two experimental sessions that will last approximately two hours each, with a lunch break in between. There will be one preparation phase to begin the morning session. Each of the two sessions will contain a baseline measurement phase, an experimental phase and a post-fatigue measurement phase.

The preparation phase will last about 30min. During the preparation phase, surface electrodes will be applied on the skin over my spine and dominant upper limb and lower limb muscles in order to measure their activity and the blood flow underneath. 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 the baseline and the post-fatigue measurement phases, which will last about 30min each, the researcher will apply a light touch stimulus and a pressure stimulus over my shoulder region. I will be seated, eyes closed, and will be asked to indicate when I feel the stimulus, and when I feel pain associated with it, by pressing a button.

During the experimental phase, which will last about 1h, I will perform a task of driving nuts into screws that will be fixed in a wall in front of me, using a battery-powered tool and my dominant arm. I will perform this task in a specific sequence. I will be instructed to accomplish the task as quickly and precisely, with respect to the sequence, as possible. Every 4min, I will interrupt the task, close my eyes and hold the tool with a straight arm at shoulder height. I will then rest my arm on a table for a few seconds while I indicate my level of discomfort. I will begin the experimental task again and will continue this sequence until I am asked to stop.

Finally, I will be asked to rate your discomfort and soreness 24h, 48h and 72h after the protocol. This will be done through a telephone or email interview.

5 - 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 ergonomics, human movement and musculoskeletal disorders.

6 - 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.

7 - Personal inconvenience

The duration of both experimental sessions (approximately 2 hours each), and the fact that they both have to be performed on the same day 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.

8 - Access to my medical file

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

9 - 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.

10 - Questions concerning the study

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

11 - 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.

12 - 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.

13 - Monetary compensation

No monetary compensation will be given to me for participation in this protocol. My lunch and transportation costs will be reimbursed upon presentation of receipts.

14 - 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 Adrien Moufflet or Julie Côté at the numbers indicated on the 1st page. I may also contact Ms. Michelle Nadon, 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__.

B. Consent Form (French Version)

CRIR Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Formulaire de consentement

Hôpital juif de réadaptation Jewish Rehabilitation Hospital

1 - Titre du projet

Mesurer la fatigue au travail : Stabilité de la force, coordination motrice et stabilité de la main et du bras (A506-AWH)

2 - Responsable(s) du projet

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

Adrien Moufflet, étudiant à la maîtrise, centre de recherche de l'hôpital juif de réadaptation, (450) 688-9550 poste 4827

3 - Description du projet et de ses objectifs

La fatigue musculaire localisée résultant de l'activité prolongée peut amener de la douleur, de l'inconfort, et des altérations du contrôle moteur et de la performance. Des données préliminaires démontrent que des mesures de fatigue comme la stabilité de la force, la coordination motrice et les tests de stabilité de la main et du bras peuvent être utiles afin de déceler la fatigue; cependant, ces mesures ont jusqu'à présent été utilisées uniquement en laboratoire. Cette recherche évaluera la faisabilité d'utiliser des mesures sensorimotrices, vasculaires et de performance en tant que mesures de fatigue durant le travail et déterminera si ces mesures peuvent détecter des différences de développement de fatigue entre des séances de travail du matin et de l'après-midi. Dans ce volet de l'étude, on demandera aux participants d'effectuer une série de tests de mesure de fatigue avant un quart de travail simulé, durant les pauses et à la fin de la journée. Les résultats de cette étude pourraient contribuer à identifier des mesures de fatigue fiables et d'usage pratique qui pourraient être utilisées pour évaluer le risque de blessure au travail associé à la réponse de fatigue.

4 - Nature et durée de la participation

Le projet de recherche auquel je suis invité(e) à participer cherche à évaluer comment la fatigue affecte mon comportement et ma performance durant une tâche de travail simulée. La procédure expérimentale sera effectuée au centre de recherche de l'hôpital juif de réadaptation. On me demande de participer à deux séances expérimentales d'une durée approximative de deux heures chacune, avec une pause repas entre les deux. Il y aura une phase de préparation au début de la séance du matin. Chacune des deux séances comportera une phase de mesures de départ, une phase expérimentale et une phase de mesures post-fatigue.

La phase de préparation durera environ 30 minutes. Durant la phase de préparation, des électrodes de surface seront fixées sur la peau des muscles de ma colonne et de mon bras dominant afin de mesurer leur activité et le flux sanguin sous la surface. Des marqueurs réfléchissants seront fixés sur la peau de mon cou, ma colonne, mes bras et mes jambes afin d'enregistrer leurs déplacements. Aucune de ces procédures n'est effractive.

Durant les phases de mesures de départ et post-fatigue, qui dureront environ 30min chacune, le chercheur appliquera un léger stimulus de toucher et un stimulus de pression sur mon épaule. Je serai assis, les yeux fermés, et on me demandera d'indiquer quand je ressens le stimulus, et lorsque je ressens de la douleur en lien avec le stimulus, en appuyant sur un bouton.

Durant la phase expérimentale, qui durera environ 1h, j'effectuerai une tâche de vissage d'écrous sur des vis fixées sur un mur en face de moi en utilisant un outil à batterie avec mon bras dominant. J'effectuerai cette tâche dans une séquence spécifique. On me demandera d'effectuer cette tâche aussi rapidement et précisément que possible, par rapport à la séquence. Chaque 4min, j'interromprai la tâche, je fermerai mes yeux et je maintiendrai l'outil avec le bras en extension, à la hauteur de l'épaule. Ensuite, je reposerai mon bras sur one table pendant quelques secondes pendant que j'évalue mon niveau d'inconfort. Ensuite, je reprendrai la tâche expérimentale et je continuerai cette séquence jusqu'à ce qu'on me dise d'arrêter.

Finalement, on me demandera d'évaluer mon inconfort et ma raideur 24h, 48h et 72h après la fin du protocole. Ceci sera effectué par entretien téléphonique ou par courriel.

5 - Avantages pouvant découler de ma participation

Je ne retirerai personnellement aucun avantage à participer à cette étude. Toutefois, j'aurai contribué à l'avancement des connaissances portant sur l'ergonomie, le mouvement humain et les blessures musculo-squelettiques.

6 - Risques pouvant découler de ma participation

Aucune des procédures décrites n'est effractive. Je comprends que ma participation à cette recherche ne me fait courir aucun risque médical.

7 - Inconvénients personnels

La durée de chaque séance expérimentale (environ 2 heures chacune) et le fait qu'elles doivent être effectuées le même jour peut représenter un inconvénient pour certaines personnes. La possibilité que quelques petites surfaces (8, 3x3 cm chaque) de la peau sur les muscles de mon cou et de mon bras doivent être rasées avant d'y apposer les électrodes peut aussi représenter un inconvénient pour moi. Bien qu'il soit hypo-allergène, le ruban adhésif utilisé pour maintenir les électrodes sur la peau peut occasionnellement provoquer de légères irritations de la peau. Le cas échéant, une lotion hypo-allergène sera appliquée pour soulager l'irritation cutanée. Aussi, je vais ressentir de la fatigue vers la fin de la séance expérimentale, ce qui pourrait occasionner de la sensibilité, de la raideur et/ou de la douleur dans la région du cou et de l'épaule durant et/ou après la séance. S'ils se manifestent, ces symptômes devraient disparaître dans les 48 heures suivant la fin du protocole expérimental. Un clinicien sera présent en tout temps pendant les séances expérimentales en cas de complications.

8 - Accès à mon dossier médical

Aucun accès à mon dossier médical n'est requis pour cette étude.

9 - Confidentialité

Tous les renseignements personnels recueillis à mon sujet au cours de l'étude seront codifiés afin d'assurer la confidentialité. Ces données seront conservées au centre de recherche de l'Hôpital juif de réadaptation et gardées sous clé par un responsable de l'étude pour une période de cinq ans suivant la fin de l'étude. Après cette période, les données seront détruites. Seuls les membres de l'équipe de recherche y auront accès. En cas de présentation des résultats de cette recherche sous forme écrite ou orale, rien ne pourra permettre de m'identifier.

10 - Questions concernant cette étude

Les chercheurs présents lors de la collecte des données s'engagent à répondre de façon satisfaisante à toutes mes questions concernant le projet de recherche.

11 - Retrait de la participation du sujet

Ma participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est entendu que je pourrai, à tout moment, mettre un terme à ma participation. En cas de retrait de ma part, les documents électroniques et écrits me concernant seront détruits.

12 - Clause de responsabilité

En acceptant de participer à cette étude, je ne renonce à aucun de mes droits ni ne libère les chercheurs, le commanditaire ou les institutions impliquées de leurs obligations légales et professionnelles.

13 - Indemnité compensatoire

Aucune compensation financière ne me sera offerte pour ma participation à cette étude. Mes coûts de repas et de transport me seront remboursés sous présentation de pièces justificatives.

14 - Personnes ressources

Si je désire poser des questions sur le projet ou signaler des effets secondaires, je peux rejoindre en tout temps Adrien Moufflet ou Julie Côté aux numéros indiqués à la 1ère page. Je peux également contacter Madame Michelle Nadon, commissaire locale à la qualité des services de l'HJR, au (450) 688-9550 poste 232.

De plus, si j'ai des questions sur mes droits et recours ou sur ma participation à ce projet de recherche, je peux communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse suivante: anolet.crir@ssss.gouv.qc.ca

CONSENTEMENT

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

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

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

NOM DU SUJET ______________________________________

SIGNATURE ______________________________________

Signé à ________________________, le __________, 20_____.

ENGAGEMENT DU CHERCHEUR

Je, soussigné (e), ______________________________, certifie

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

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

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

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

____

Signature du responsable du projet ou de son représentant

Signé à __________________, le _____________ 20__.