POSTURAL AND MUSCULAR ADAPTATIONS TO REPETITIVE WORK

POSTURAL AND MUSCULAR ADAPTATIONS TO REPETITIVE SIMULATED ASSEMBLY LINE WORK

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ABSTRACT

Few studies have shown the process of adaptation in muscle activity and joint angle during prolonged repetitive work. Fifteen healthy men performed 1 minute cycles of automotive-related tasks, which included a finger pull, knob turn, drill press and hose connector push. The experiment occurred on two days, separated by 24 hours. Day 1 required 61 cycles, with 5 cycles on day 2. Electromyography and kinematics of the upper extremity were analyzed at 12-minute intervals. Time to complete work cycle decreased by 6.3 s at the end of day 1 and 5.3 s on day 2. Peak EMG decreased for triceps brachii (TB), anterior deltoid (AD) and infraspinatus (IN) during work cycle, TB (finger pull), biceps brachii (BB), TB, AD, middle deltoid (MD) and IN during the hose insertion task. Peak EMG increased for MD and IN during the drill task. Mean EMG decreased for MD (work cycle), BB (hose insertion) and AD (finger pull), while MD and IN increased (drill task) and upper trapezius increased during the work cycle. EMG COV decreased for TB, AD, posterior deltoid and IN during the work cycle, TB during the finger pull task and AD during the hose insertion task. COV increased for BB during the work cycle, AD during the finger pull and for BB and lower trapezius during the drill press. Peak shoulder flexion decreased by 7.0° during the work cycle. Perceived discomfort increased by 1.2 units. This thesis found adaptations to highly repetitive but light work in only one hour, some of these changes persisted through the next day suggesting an adaptive process. This thesis is one of the first to examine adaptations to a highly repetitive simulated assembly work and has provided new insights into the evaluation of repetitive jobs as a whole and as isolated subtasks.

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TABLE OF CONTENTS

LIST OF TABLES

red indicates immediate need for changes. SI scores in green indicate safe, yellow indicates caution and red indicates hazardous.

LIST OF FIGURES

CHAPTER 1 – INTRODUCTION

Numerous industrial jobs require employees to make repetitive upper extremity exertions. These repetitive exertions can pose a unique challenge for the shoulder complex and may lead to the development of musculoskeletal disorders (MSD). These injuries can not only be a source of pain and lost income for the worker, but can also create a financial burden to the employers due to lost productivity and injury compensation. According to Health and Safety Ontario, work-related musculoskeletal disorders (WMSD) claims resulted in 2.5 million days off work and $1 billion in lost wages between 2003 and 2007. Of these claims, WMSD of the upper extremity have been second only to the low back as the most frequently reported injury from 2000 to 2009 (WSIB, 2009). Additionally, bodily reactions and exertions, which include repetitive motions and static postures, are the leading cause of injuries in the workplace (WSIB, 2009). Upper extremity WMSD have greater health care and rehabilitation costs compared to acute injuries and disorders that affect other body regions (Silverstein et al., 1998). Greater knowledge about how injuries develop, and what factors play a role in their development, is key to the prevention of such injuries.

Workplace epidemiology studies have shown a strong positive association between ergonomic risk factors and WMSD of the hand, wrist and shoulder (Bernard, 1997). Workers are often placed in, or assume, awkward, non-neutral postures in order to complete a specific task. Both repetition and awkward postures have been associated with the development of WMSD (Silverstein et al., 1987; Tanaka et al., 1997). In a manufacturing plant, many tasks along the assembly line are comprised of repetitive arm motions that require a variety of force exertions. Manual and powered hand tools are frequently used in the workplace. Although power hand tools provide a mechanical advantage, these tools pose unique stresses on the upper extremity, such as increased hand load and reaction forces at the shoulder (Oh and Radwin, 1997; 1998). Using a power tool generally requires workers to maintain a submaximal contraction in either an overhead or elevated arm position. Research has shown that maintaining a force level as low as 5% of maximum excitation can lead to fatigue, if sustained for over an hour (Sjogaard et al, 1988).

Within the manufacturing industry, workers are subjected to a variety of postures while conducting the same repetitive job for multiple hours during the workday. These conditions may put workers at risk to develop MSD. Research on the development and prevention of WMSD of the upper extremity has focused primarily on the effects of posture and repetition (e.g. Madeleine et al., 1999). Repetitive muscle use generally leads to a reduced functional capacity of that muscle, otherwise known as fatigue (Enoka and Stuart, 1992). Recent studies have shown evidence for the reorganization of activity within individual muscles as a result of the development of fatigue (Holtermann et al., 2008; Madeleine and Farina, 2008). The relationship between posture and repetitive movement, including its influence on postural adaptations are not well understood. Furthermore, few studies have shown the effects of repetitive movement over time. Thus, a better understanding of the temporal changes in regards to muscle and posture is required.

Work-related musculoskeletal disorders in the automotive industry can be difficult to understand due to the large number of factors that can play a role. Fatigue is commonly referred to as a process rather than an event (Enoka and Stuart, 1992), however many studies treat fatigue more like a single event (i.e. pre- and post-fatigue testing protocols). Additionally, studies have shown the development of fatigue as a result of repetitive movements. Thus, a better knowledge of the adaptations that occur as a result of repetitive movements is required, especially during the development of fatigue.

Much of the existing research has primarily focused on determining the magnitude of the effects of various risk factors (i.e. load, frequency, posture, etc.) and the interaction of such factors on the development of MSD (e.g. Côté et al., 2005; Zakaria et al., 2002). Most studies link highly repetitive tasks with fatigue and examine the effects of repetitive tasks pre- and post-fatigue, such that there is a lack of knowledge on how these effects develop. Furthermore, it is imperative to not only understand the changes that occur but the nature of these changes. A better understanding of the process involved with highly repetitive tasks and its effects on muscle activity and joint angles throughout the development of fatigue is needed, especially prior to individuals noticing fatigue. Additionally, it is important to examine whether these adaptations are robust and persist over time. Knowledge of any learning effects can be helpful for future job training and design.

The objective of this thesis was to examine postural and muscle activity adaptations to highly repetitive simulated assembly line work. Using three-dimensional motion tracking and surface electromyography (EMG), we attempted to determine how the muscle activity and joint ranges of motion of the upper extremity changed over time while performing a cycle of repetitive tasks. Moreover, this study examined whether participants learned to adapt to these conditions.

1.1 Purpose

The purpose of this thesis was to:

1. Determine the changes in muscle activity and posture over time at the upper extremity.
2. Evaluate whether participants exhibit a learning effect by retesting kinematics on a second visit

1.2 Hypotheses

As the experiment progresses in time:

1. Mean and peak elbow and shoulder angles will decrease to reduce the moment at the shoulder.
2. Mean and peak muscle activity will increase over time
3. The time to complete the work cycle on day 1 will increase.

CHAPTER 2 – REVIEW OF LITERATURE

2.1 Work-related Musculoskeletal Disorders of the Upper Extremity

Work-related musculoskeletal disorders (WMSD) are injuries related to muscles, tendons, ligaments, nerves and surrounding structures. These types of disorders have been found to be related to repetitive loading and non-neutral postures (Bernard, 1997). Conditions most commonly seen at the upper extremity are tendinosis, tendonitis, tenosynovitis, impingements, epicondylitis, and carpal tunnel syndrome. These injuries can cause pain or numbness, temporary or permanent disability, work time lost as well as an increase cost for workers' compensation (Bernard, 1997).

Injury statistics in Ontario indicate the high prevalence of WMSD. In 2009, a report by Workplace Safety and Insurance Board (WSIB) indicated that WMSD of the upper extremity were second to low back as the most frequently claimed injury from 2000 to 2009. Additionally, bodily reactions and exertions which include repetitive motions and static postures are the leading cause of injuries in the workplace (WSIB, 2009). In Ontario, WSMD claims resulted in 2.5 million days off work between 2003 and 2007and result in cost to employers that was greater than $1B (Health & Safety Ontario, 2011).

A number of internal and external factors have been proposed to contribute to the development of WMSD. Figure 2.1 demonstrates the relationships developed in the literature, which suggests the role numerous workplace (external) factors and individual characteristics (internal factors) play on pain, discomfort and disability. External factors may include load, repetition, posture and other social or organizational factors.

The shoulder complex is the most versatile joint in the body and, as such, it is characterized by its large range of motion and inherent lack of stability. The large mobility not only allows for the performance of a wide range of activities, from activities of daily living to occupational tasks, but it also means the shoulder is highly susceptible to injury.

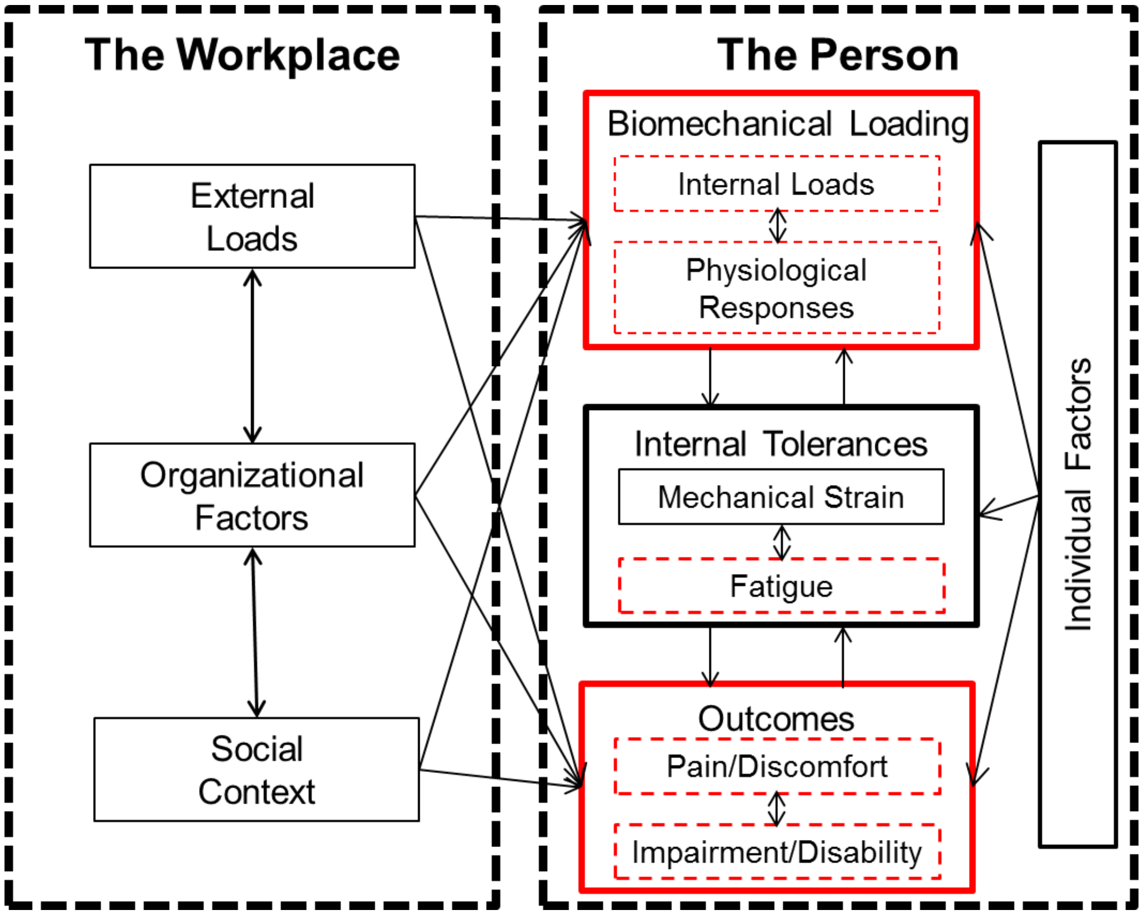

Figure 2.1. Schematic representation of the external and internal factors that may play a role in the development of pain and disability. Figure adapted from Radwin et al., 2002 and National Research Council and the Institute of Medicine 1999, 2001.

Awkward or non-neutral postures have been documented as major risk factors for WMSD especially pertaining to the upper extremity. These awkward postures have been known to place muscles in mechanically disadvantaged positions requiring greater effort (Zakaria et al., 2002). At the shoulder, postures above 90°shoulder flexion have been shown to have a positive relationship with WMSD (Svendsen et al., 2004); hence most ergonomic tools consider work above shoulder level to be an additional risk, such as the Rapid Upper Limb Assessment or RULA (McAtamney and Corlett, 1993). For example, Levitz and Iannotti (1995) found the compression placed on the supraspinatus tendon to be greatest between 60 and 120 degrees of arm elevation due to the narrowing of the gap between the humeral head and acromion. Au and Keir (2007) showed muscle activity values as high as 24% with the arm abducted to 90°. There is also evidence that sustained or repetitive work in shoulder flexion or abduction at 60° may also lead to the development of tendonitis at the shoulder and non-specific shoulder pain (Bernard, 1997). Additionally, an exposure-response relationship was found for life time work with the shoulder elevated and negative shoulder health, more specifically supraspinatus tendinopathy (Svendsen et al., 2004). This suggests that not only is posture a key indicator of shoulder injury but the time spent in these postures can also cause negative effects to shoulder joint health. Evidence also suggests that there is an effect of specific shoulder postures being strongest where there is combined exposure to several physical factors like holding a tool while working overhead (Bernard, 1997).

Low level sustained contractions have also been associated with the development of muscle related disorders. Workers are often required to maintain a constant posture at the shoulder while doing work with the hands, which places the shoulder under constant loading. For example, workers may install an automotive part while using a drill or other power tool. Sustained low level contractions, even as low as 5% MVC, can cause muscular fatigue if sustained for over an hour (Sjogaard et al, 1988). This suggests that even work that would be perceived as low effort (especially at the shoulder) may be more hazardous than previously believed.

Another major risk factor in the development of WMSD is repetition. On a manufacturing line, workers are subjected to the same job exposures for multiple hours each day. Highly repetitive work has been shown to be positively correlated with the development of UE WMSD, especially when continuous shoulder abductions and flexions are involved (Hagberg and Kvamstrom, 1984; Viikari-Juntara, 1998). A review by Malchaire and colleagues (2001) found that 75% of the studies reviewed demonstrated a significant relationship between repetitive movements and UE disorders. This may be explained by the notion that repetitive muscle use tends to lead to a decrease in the functional capacity of the muscle which consequently leads to the development of muscle fatigue (Vollestad, 1997). Furthermore, repetitive motions tend to be dynamic in nature. Dynamic factors, such as velocity and acceleration, have been found to be associated with higher injury risk at the wrist and therefore should be taken into consideration when examining potential injury risk (Marras and Schoenmarklin, 1993).

Factors such as load, repetition and posture can act independently with the development of WMSD; however it is rare that a worker will only be subjected to one of these factors in the workplace. In the research on the development of WMSD, the interaction between two or more of these factors should be the key focus. Chiang and colleagues (1993) tested the relationship between force and repetition and found a significant interaction. Similarly, Keir and Brown (2012) examined the effects of load and frequency on muscular loading on a cyclic task and found a three-fold increase in muscle activity from low load-low frequency to high force-high frequency, with the latter being statistically greater for all muscles tested. Therefore, these results suggest the importance of examining the interaction of multiple risk factors and how these relate to injury risk.

In summary, work-related musculoskeletal disorders are a large source of burden for employees and employers. The major risk factors for work-related injuries, and their effects on the body, are well documented in the literature. In industry, workers are very likely to encounter one or more of these factors; however employers cannot eliminate all risk factors when designing a job. Thus it is important to determine how these effects develop over time.

2.2 Repetitive Movements

Few studies have shown how highly repetitive work affects muscle activity across multiple segments, especially in the upper extremity. Much of the research examines the effects of fatigue on the body as induced by highly repetitive movements. Forestier and Nougier (1998) examined the effects of fatigue on throwing a ball at a target and found that, once fatigued, the arm moved more in an ‘all-together’ manner, meaning that peak velocities occurred at the same time for the proximal and distal joints. Contrary to this, Côté and colleagues (2005) found an increased time delay between peak proximal and distal joint velocities when individuals were fatigued during a repetitive hammering task. These studies suggest altered multi-segmental movement when adapting to fatigue, however they support the notion that more research needs to be done as there is disagreement on the effects of repetitive movements and fatigue.

Furthermore, muscle activity during multi-joint movements has also been shown to change over time. Bonnard and colleagues (1994) examined the effect of repetitive jumping on muscle activity and found that, over time, participants began recruiting their gastrocnemius muscles earlier in the jumping movement. These changes in muscle activity may also be the cause of, or be caused by, larger adaptations such as visible changes in movement behaviour. For example, changes in lifting behaviour have been shown to occur throughout repetitive lifting tasks (Marras and Granata, 1997), which suggests a change in muscle activity was required to complete the task, or the movement characteristics needed to change, which may result is different muscle activity.

A large focus of the literature has been on the effects of repetitive movements between healthy and injured individuals. Côté and colleagues (2005) examined the effect of fatigue on repetitive hammering and found that injured individuals used smaller trajectories, lower ranges of motion and lower peak velocities and accelerations in one or more joints than those of healthy individuals. Similar results were found when comparing sawing movements between fatigued and non-fatigued individuals (Côté et al., 2002). When examining injured workers, Lomond and Côté (2011) found that supraspinatus was more active in injured individuals, when performing a repetitive reaching task, than a control group. This knowledge is important for understanding adaptations that result from injury; however, it is important to understand adaptations prior to injuries occurring.

Previous research in the area of repetitive movements provides a window of insight into muscular and postural adaptations, although much of the literature has focused on pre- and post-fatigue states rather than the continuous process throughout the fatiguing task. Fuller and colleagues (2011) is one of few studies that examined the changes in muscle activity and upper limb movement over time when performing a repetitive task. Results showed an increase in trapezius activation and an increase in joint range of motion over time, but also showed how these adaptations occurred over time. This temporal analysis could provide a better understanding as to when adaptations that may be harmful occur. This study only examined one muscle and, therefore, more research is needed to create a better understanding of all the upper extremity muscles.

Research findings in this area have been controversial. Previous studies have focused on a small number of shoulder muscles and, therefore, a better understanding of changes in all muscle activity involved is required as well as improved understanding of when these changes occur over time is needed.

2.3 Ergonomic Assessment Tools

Many industrial workplaces rely on ergonomic assessment tools to evaluate the injury risk of certain jobs. These tools can be very helpful; however they do not provide the employer with an in-depth understanding of the injury risk throughout the entire job.

Some tools are very specific and only deal with certain regions of the body rather than examining the job on a large scale. For example, the Rapid Upper Limb Assessment (RULA) and Strain Index (SI) only use the worst posture during their assessments (McAtamney and Corlett, 1993; Moore and Garg, 1995). One of the main limitations of these assessment tools is that they tend to be conducted once and only provide a small snapshot of what that job entails. They are also unable to account for the risk associated with combining multiple tasks within one job. Moreover, ergonomic assessments have a large area for subjectivity between “high injury risk” jobs and “low injury risk” jobs. For example, using SI, a score lower than 5 is “probably safe” and a score greater than 7 is “probably hazardous” (Moore and Garg, 1995). Therefore, a score between 5 and 7 would require the ergonomist or employer to judge whether a job was safe and whether modifications should be made. A better understanding of how our bodies adapt over time would help provide some insight into this gray area.

These tools are very useful for employers as they are very economical and can raise red flags regarding job safety. It is important continually improve ergonomic assessment techniques in order to prevent the development of WMSD as jobs and technology are continually changing. In order to improve these techniques, we need to create a better understanding of how these risk factors affect muscle activity and segment movement. We especially need to know how these adaptations persist over time.

2.4 Summary

In summary, work-related musculoskeletal disorders in the manufacturing industry can be difficult to understand due to the large number risk factors that may be involved. There is a great deal of research that has documented the acute effects of these risk factors, especially in pre- and post-fatigue states. Many recommendations have advocated for multiple rests and job rotation in order to avoid reaching fatigue. This poses the question, what happens during the development of fatigue? The purpose of this study is to attempt to fill part of the gap in the literature by focusing on understanding the process involved in muscle and joint angle adaptations before signs of fatigue.

CHAPTER 3 – MANUSCRIPT

Postural and Muscular Adaptations to Repetitive Simulated Assembly Line Work

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3.1 Abstract

Few studies have shown the process of adaptation in muscle activity and joint angle during prolonged repetitive work. Fifteen healthy men performed 1 minute cycles of automotive-related tasks, which included a finger pull, knob turn, drill press and hose connector push. The experiment occurred on 2 days, separated by 24 hours. Day 1 required 61 cycles, with 5 cycles on day 2. Electromyography and kinematics of the upper extremity were analyzed at 12-minute intervals. Time to complete work cycle decreased by 6.3 s at the end of day 1 and 5.3 s on day 2. Peak EMG decreased for triceps brachii (TB), anterior deltoid (AD) and infraspinatus (IN) during work cycle, TB (finger pull), biceps brachii (BB), TB, AD, middle deltoid (MD) and IN during the hose insertion task. Peak EMG increased for MD and IN during the drill task. Mean EMG decreased for MD (work cycle), BB (hose insertion) and AD (finger pull), while MD and IN increased (drill task) and upper trapezius increased during the work cycle. EMG COV decreased for TB, AD, posterior deltoid and IN (work cycle), TB (finger pull) task and AD during the hose insertion task. COV increased for BB (work cycle), AD (finger pull) and for BB and lower trapezius during the drill press. Peak shoulder flexion decreased by 7.0° during the work cycle. Perceived discomfort increased by 1.2 units. This thesis found adaptations to highly repetitive but light work in only one hour, some of these changes persisted through the next day suggesting an adaptive process. This thesis is one of the first to examine adaptations to a highly repetitive simulated assembly work and has provided new insights into the evaluation of repetitive jobs as a whole and as isolated subtasks.

Keywords – repetitive movement; posture; upper extremity; surface EMG;

3.2 Introduction

In the industrial workplace, jobs that require repetitive upper extremity exertions can pose a unique challenge for the shoulder complex and may lead to the development of shoulder disorders. Shoulder injuries in the workplace may result in pain and lost income for the worker, and also create a financial burden to the employers due to lost productivity and compensation. In Ontario, disorders of the upper extremity have been second only to the low back as the most frequently claimed injury from 2000 to 2009 (WSIB, 2009). Additionally, bodily reactions and exertions which include repetitive motions and static postures are the leading cause of injuries in the workplace (WSIB, 2009). It has been shown that upper extremity WMSD have greater health care and rehabilitation costs compared to acute injuries and disorders that affect other body regions (Silverstein et al., 1998). Also, workplace epidemiology studies have shown a strong positive association between occupational ergonomic factors, including posture, force and repetition, and disorders of the hand, wrist and shoulder (Bernard, 1997).

Both repetition and awkward postures have been associated with the development of WMSD at the upper extremity (Silverstein et al., 1987; Tanaka et al., 1997). Workers are often placed in, or assume, awkward, non-neutral postures in order to complete a specific task. In a manufacturing plant, many tasks along the assembly line are comprised of repetitive arm motions that require a variety of force exertions. Many of these jobs include the use of power tools and although these tools provide a mechanical advantage while performing tasks, they pose unique stresses on the upper extremity (Oh and Radwin, 1997; 1998). For example, hand tools can increase the load on the joints due to the weight of the tool. Additionally, workers must account for reaction forces and vibrations produced when the tool is in use.

Research has shown that repetitive muscle use generally leads to a reduced functional capacity of that muscle, otherwise known as fatigue. There is evidence to support the notion that there is reorganization of activity within individual muscles as a result of fatigue (Holtermann et al., 2008; Madeleine and Farina, 2008); however our understanding of how these changes occur over a prolonged period of time is lacking. Furthermore, previous research has focused on the acute effects of repetition on EMG and kinematics of the upper extremity within pre- and post-fatigue states. Fuller and colleagues (2011) is one of few studies that examined the changes in muscle activity and upper limb movement over time when performing a repetitive task, however only one muscle was assessed. This raises the question, what changes are occurring to the muscles and joints of the upper extremity during the development of fatigue? Thus, there is a need for a better understanding of the temporal changes in muscle activity and joint angles with respect to repetitive tasks over a prolonged period.

The purpose of this study was to improve the understanding of the effects of highly repetitive tasks on joint angles and muscle activity of the upper extremity over the course of an hour. The objectives were to determine how EMG and joint angles change over time and whether a learning effect occurs following a single hour of the task. We hypothesized that, over the hour task, joint range of motion would decrease in order to reduce moments at the shoulder, muscle activity will change due to changes in kinematics and the time to complete the work cycle will increase.

3.3 Materials and Methods

3.3.1 Participants

Fifteen healthy right hand dominant male participants were recruited from the university population (mean age 21.9 ± 2.7 years; height 1.76 ± 0.07 m; mass 73.3 ± 10.7 kg). Descriptive anthropometric data are presented in Appendix A (Table A.1). Participants were excluded if they had an upper limb or shoulder pain/injury within the last year. All participants provided written, informed consent prior to participation in the study. This study has been approved by the Hamilton Health Sciences/Faculty of Health Sciences Research Ethics Board at McMaster University.

3.3.2 Task Overview

Participants performed 61 repetitions of a cyclic work simulation task involving 4 sub-tasks which was repeated each minute. The experimental setup consisted of four tasks to simulate those commonly performed in the automotive industry and was secured to a height adjustable table. The 4 tasks consisted of (i) a two-finger pull, (ii) turning a knob, (iii) an anterior drill push and (iv) a hose push connection (Figure 3.4). Participants were required to complete 6 finger pulls, 6 full rotations at the knob, maintain a 50% of maximum drill press force for 10 seconds, followed by 6 hose connector pushes. Tasks 1, 2 and 4 were pass/fail completions with clear target criterion (Table 3.1). In order to complete task 3, subjects were required to sustain the push force at 50% of their maximum exertion for 10 seconds. Visual feedback was provided for the participants on a monitor using custom software (LabView, National Instruments, Austin, TX). Force levels were set at 50% of the maximum exertion for tasks 1, 3 and 4. The experimental set up was centered with tasks placed at 30 cm on either side of the midline with tasks 1 and 4 set at umbilicus level and tasks 2 and 3 at shoulder level (Figure 3.1). Participants were required to stand at 60% of their total reach distance from the workstation frame.

All data were collected in 1 minute segments at 12 minute intervals using custom software (LabView, National Instruments, Austin, TX) for a total of 61 minutes. An electrical switch was used to indicate the start and end of the active work cycle (effort time) for each participant. Three-dimensional reaction forces and moments applied at the shoulder height drill task were recorded using a 6 degree of freedom force transducer (MC3-500, AMTI, Watertown, MA). Figure 3.2 indicates force and moment orientations for the load cell on the drill task. Forces from the finger pull and hose connector push tasks were recorded using two linear force transducers (MLP-300, Transducer Techniques, Temecula, CA). EMG and force data were sampled at 2400 Hz (16-bit, USB-6229 BNC, National Instruments, Austin, TX). The force at the finger pull task will be denoted as pull and the force at the hose insertion task will be denoted as push force.

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Table 3.1

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Figures 3.1 and 3.2

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3.3.3 Protocol

Participants came in for two testing sessions separated by a minimum of 24 hours. In the first session, participants repeated the cycle for a total of 61 minutes, while on the second day they performed 5 cycles (5 minutes). On day 1, height, weight, maximum arm reach, shoulder and umbilicus heights were recorded and used to set the height of the apparatus. Maximum arm reach was defined as the distance from the acromion process of the scapula to the third metacarpophalangeal (MCP) joint, shoulder height was measured from the acromion process to the ground, and umbilicus height was measured from the umbilicus to the ground.

Bipolar surface EMG was collected from eight muscles of the right upper extremity and trunk (10-1000 Hz; CMRR>115 dB at 60 Hz; input impedance ~10 GΩ; AMT-8, Bortec Biomedical Ltd., Calgary, AB). The muscles monitored were the biceps brachii (BB), triceps brachii (TB), anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), lower trapezius (LT) and infraspinatus (IN). Prior to placement of disposable Ag-AgCl bipolar surface electrodes (MediTrace 130, Kendall, Mansfield, MA), each site was prepared by shaving and scrubbing with isopropyl alcohol. Electrodes were placed over the belly of each muscle, parallel to the muscle fibre direction with an inter-electrode distance of 2.5 cm (see Figure 3.2). Electrode placements were confirmed using palpation and manual resistance tests. A quiet EMG trial was collected at the start of collection and used to remove signal bias from each EMG channel. Static and dynamic maximum voluntary exertions (MVE) were performed for each muscle in a seated position to determine the maximal voluntary excitation of the muscles of interest. The MVE protocol for each muscle is shown in Table 3.2. Maximal exertions were held for 5 seconds and performed twice, separated by 1 minute. If there was a discrepancy of 10% or greater between the 2 exertions, a third trial was collected. The greatest activity value obtained for each muscle during any of the MVE trials was used as the maximum value for normalization. The participants then performed three maximal voluntary force trials for tasks 1, 3 and 4. Task force levels were set to normalize the force for each task and provide visual feedback for the drill push. Twenty-six reflective markers were fixed to the trunk, left shoulder and right upper extremity using two-sided tape (Figure 3.3). Three-dimensional kinematics of the right upper limb were recorded at 60 Hz using 11 cameras in a passive motion capture system (Motion Analysis Corporation, Santa Rosa, CA). EMG and force data were synchronized with kinematics and collected at 2400 Hz.

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Figure 3.3

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Participants performed a familiarization protocol in which they practiced all 4 tasks and rehearsed the force profile required for the drilling task. Once the participants were comfortable with the protocol, they were instructed to complete the 4 tasks with their right arm sequentially in a clockwise direction starting and ending with a button press. They were able to complete the tasks at their own pace within a 1-minute span (similar cycle time to that found on an automotive assembly line). Participants were asked to rate their level of perceived discomfort for the entire body over all four tasks every 5 minutes using the Borg Scale (Borg, 1990) (Appendix C). They repeated this protocol until they reached a level of perceived discomfort of an 8 or higher on the Borg Scale (Côté et al., 2002) or until they were unable to complete all four tasks within the 1 minute cycle in two consecutive cycles. The subjects were not made aware of the stoppage criteria; however no subjects required these criteria.

On day 2, participants were told that they would follow a similar to protocol as day 1 but without EMG. Participants were only required to complete 5 cycles of the experimental protocol. At the end of day 2, participants were debriefed about the purpose of day 2.

3.3.4 Data Analysis

The data were collected every third minute (cycle) over the course of 61 minutes. Analyses was conducted at 12-minute intervals starting with the first minute (minute 0, 12, 24, 36, 48, 60) of the experimental collection on day 1 and the every minute on day 2. If data were missing, the sample prior to the missing data (i.e. 3 minutes earlier) was used with the exception of the first trial for which the following sample was used. Work cycle time was determined as the time between the start and end button presses as determined using the lead edge of the 5 V square wave produced by pressing the button. Each trial was windowed into the work cycle and the three sub-tasks (finger pull, drill push and pipe push). The pipe push, drill push and finger pull were windowed using a force level exceeding 1 N, 1 N and 1.5 N above the mean noise level, respectively. Kinematics were windowed using the same frame numbers as determined by the force level cut-off. Day 1 and day 2 kinematics were windowed for the work cycle and the drill press task only.

Raw EMG was full wave rectified and low pass filtered with 3 Hz cut-off (dual pass, 2^{nd} order Butterworth filter). The maximum activity was found for each muscle during the MVE trials and used to normalize each EMG signal so that it was represented as a percent of maximum. Raw kinematic data was digitized using motion capture software (Cortex 1.3.0.475, Motion Analysis Corporation, Santa Rosa, CA) and imported to a motion capture analysis program for processing (Visual3D, C-Motion, Inc., Rockville, MD). The trunk, pelvis, upper arm and forearm segments were modelled and local coordinate systems were created for each. An additional shoulder segment was created from the sternum to the acromio-clavicular joint in order to model the clavicle and calculate shoulder elevations. Zero shoulder elevation was defined as level with the clavicle segment. Figure 3.4 shows the axes system as defined by the model. The relative angles between segments of interest were defined according to ISB standards for the upper extremity (Wu et al., 2005). Raw kinematic and kinetic variables were dual-pass filtered with a 2^{nd} order Butterworth filter with a cut-off of 10 Hz.

****

Figure 3.4

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The minimum, peak, and mean were calculated for each of our variables. The coefficient of variation (COV) was calculated as the standard deviation divided by the mean. Gaps analysis was conducted on the EMG data. The gaps were defined as time periods with contraction levels consistently below 0.5% activation (MVE) for <0.2 s (Veiersted et al., 1990). Repeated measures analyses of variance (ANOVA) were conducted with time as the repeated measure and EMG levels (mean, peak, gaps and COV for each muscle), joint kinematics (mean, peak and COV for each joint angle), kinetics (peak, mean and COV for forces and moments) and effort time as the independent variables ($\alpha=0.05$). Dependent variables are listed in table 3.3. Significant effects were followed up with a least significance difference (LSD) post-hoc. Note that, as this study was exploratory in nature, attention was paid to trends using an α-level of 0.1 to denote relevant trends.

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Table 3.3

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3.4 Results

3.4.1 Time Parameters

The time required to complete the work cycle decreased over time where minute 0 was significantly different from all other trials ($F_{5, 70}$=14.023, $p<0.0005$). From minute 0 to minute 60, there was a 6.3 ± 2.1 second decrease in work cycle time for day 1. There was no significant change in time to complete the drill task, however significant decreases in time to complete the pipe push and finger pull occurred ($p<0.05$). Work time on day 2 was 5.3 ± 2.2 seconds faster than minute 0 on day 1, which was statistically significant ($F_{6,84}$=12.904, $p<0.0005$) (Figure 3.5).

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Figure 3.5

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3.4.2 Electromyography

Significant and relevant EMG trends for each muscle and task are summarized in table 3.4.

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Table 3.4

****

3.4.2.1 Biceps Brachii

A decrease of 2.6% MVE was seen in mean BB EMG from minute 0 to minute 48 during the hose connector task ($F_{5, 70}$=2.440, p<0.043) There were no significant changes in mean BB EMG for the work cycle or the two other sub-tasks (Figure 3.6a). A decrease of 6.8% MVE was seen in peak EMG from minute 0 and all time points during the hose connector task ($F_{5, 70}$=4.638, p<0.001). There were no significant changes in peak EMG for the work cycle or other sub-tasks (Figure 3.7a). There was a significant increase in BB COV for the work cycle ($F_{5, 70}$=2.706, p<0.027) and during the drill press task ($F_{5, 70}$=3.470, p<0.007)(Figure 3.8).

3.4.2.2 Triceps Brachii

No significant changes in mean EMG were shown during the work cycle or all sub-tasks. There was a decrease of 14.8 % MVE during the work cycle from minute 0 to minute 60 in peak TB EMG ($F_{5, 70}$=3.661, p<0.005) and during the finger pull task ($F_{5, 70}$=2.102, p<0.075) (Figure 3.7b). There was a significant decrease in TB EMG variability of 0.21 during the whole cycle ($F_{5, 70}$=2.355, p<0.049) and 0.23 during the finger pull ($F_{5, 70}$=3.590, p<0.06) (Figure 3.8b).

3.4.2.3 Anterior Deltoid

A significant decrease of 1.1% MVE in mean EMG was found during the finger pull task ($F_{5, 70}=2.709$, $p<0.027$) (Figure 3.6c). There was a decrease of 9.8% MVE in peak AD EMG during the work cycle ($F_{5, 70}=2.434$, $p<0.043$) and during the hose insertion task ($F_{5, 70}=2.784$, $p<0.024$). AD COV significantly increased over time during the finger pull task ($F_{5, 70}=3.409$, $p<0.008$) and a significant decrease over time during the work cycle ($F_{5, 70}=1.952$, $p<0.097$) and hose insertion task ($F_{5, 70}=3.531$, $p<0.007$) (Figure 3.8c).

3.4.2.4 Middle Deltoid

There was a significant increase in mean MD EMG during the drill task ($F_{5, 70}=2.392$, $p<0.046$) and during the work cycle ($F_{5, 70}=1.956$, $p<0.096$) (Figure 3.6d). A significant increase in peak MD EMG were found during the drill press ($F_{5, 70}=2.129$, $p<0.072$) and hose insertion push ($F_{5, 70}=1.931$, $p<0.1$). No significant changes were found for EMG COV in the work cycle or sub-tasks.

3.4.2.5 Posterior Deltoid

No significant changes were found in mean or peak PD EMG for the work cycle or sub-tasks. There was a significant decrease in PD EMG COV for the work cycle ($F_{5, 70}=2.864$, $p<0.021$) (see Figure 3.8e).

3.4.2.6 Upper Trapezius

There was a significant increase in mean UT EMG during the work cycle ($F_{5, 70}=2.017$, $p<0.087$). No significant changes were found in peak or variability of the upper trapezius muscle for work cycle or sub-tasks.

3.4.2.7 Lower Trapezius

There were no significant changes in mean or peak for LT EMG during the work cycle or sub-tasks. There was a significant increase in EMG COV during the drill press task ($F_{5, 70}$=2.495, $p<0.039$).

3.4.2.8 Infraspinatus

There was a significant increase in mean EMG during the drill press task ($F_{5, 70}$=2.259, $p<0.058$) and during the work cycle ($F_{5, 70}$=2.46, $p<0.041$). Peak EMG increased during the drill press task by 7.2% MVE ($F_{5, 70}$= 2.996, $p<0.017$) and decreased during the hose connector push ($F_{5, 70}$=3.599, $p<0.006$) and work cycle ($F_{5, 70}$=2.871, $p<0.02$). There was a significant decrease in EMG COV during the work cycle ($F_{5, 70}$=2.195, $p<0.064$).

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Figures 3.6, 3.7 and 3.8

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3.4.3 Kinetics

3.4.3.1 Work Cycle

Mean drill forces increased over time for F_z from 21 N to 28.1 N ($F_{5, 70}$=7.427, $p<0.0005$), F_x from 5.5 N to 9.0 N ($F_{5, 70}$=6.982, $p<0.0005$) and F_y from 0.3 N to 1.9 N ($F_{5, 70}$=3.245, $p<0.011$). Peak F_x increased from 21.3 to 26.1 N ($F_{5, 70}$=3.876, $p<0.004$), M_x increased from 3.9 Nm to 5.9 Nm ($F_{5, 70}$=2.294, $p<0.055$), F_y increased from 5.2 to

8.8 N ($F_{5, 70}$=3.717, p<0.005) and M_y increased from 2.2 Nm to 4.6 Nm ($F_{5, 70}$=1.993, p<0.09). Over time the COV for F_z and F_x decreased over time from 1.47 to 1.23 ($F_{5, 70}$=5.643, p<0.0005) and 1.48 to 1.22 ($F_{5, 70}$=6.863, p<0.0005), respectively.

3.4.3.2 Finger Pull

The peak pull force significantly decreased from 137.1 ± 42.0 N to 110.7 ± 28.7 N from minute 0 to minute 60 ($F_{5, 70}$=7.261, p<0.0005). Pull force COV showed a significant decrease over time from 0.79 ± 0.22 to 0.69 ± 0.31 ($F_{5, 70}$=5.591, p<0.0005).

3.4.3.3 Drill Task

Mean F_z, F_x and F_y showed significant increases over time (p<0.05). F_z (horizontal push, drilling direction) increased by 5.8 N (from 57.3 N to 63.1 N) ($F_{5, 70}$=2.996, p<0.039). Mean F_x and F_y (off-axis forces) increased from 14.8 N to 19.1 N and 2.4 N to 4.8 N, respectively. Increases were found for peak F_x from 21.3 ± 8.8 N to 26.1 ± 17.4 N ($F_{5, 70}$=3.797, p<0.004), peak F_y from 5.3 ± 5.0 N to 8.3 ± 7.2 N ($F_{5, 70}$=3.709, p<0.005) and peak M_x from 3.8 ± 2.0 Nm to 5.2 ± 4.2 Nm ($F_{5, 70}$=2.452, p<0.042).

3.4.3.4 Hose Connector Push

There was a significant effect of time on peak push force ($F_{5, 70}$=5.416, p<0.0005) (Figure 3.10). The peak push force decreased from 117 ± 31.0 N to 105 ± 34.5 N. There was no significant effect of time on mean force or push force variability.

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Figure 3.9

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3.4.4 Kinematics

Significant and relevant kinematic trends for each joint angle measure and task are summarized in table 3.5.

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Table 3.5

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3.4.4.1 *Shoulder Elevation*

There was a significant decrease in peak shoulder elevation during the work cycle ($F_{5, 70}$=2.909, p<0.019) (Figure 3.11a). No significant changes were found for mean and variability for shoulder elevation on day 1. There were no significant changes in mean, peak or COV between day 1 and day 2 (p<0.05). When examining the drill task, there was no significant change in shoulder elevation angles.

3.4.4.2 *Shoulder Abduction*

Significant decreases in shoulder abduction were seen in mean ($F_{5, 70}$=2.586, p<0.033), peak ($F_{5, 70}$=3.043, p<0.015) and COV ($F_{5, 70}$=2.076, p<0.079) (Figures 3.10b, 3.11b and 3.12b). Mean shoulder abduction on day 2 was significantly greater than minutes 36, 48 and 60 ($F_{6, 84}$=3.919, p<0.002) and peak shoulder abduction on day 2 was significantly different from minutes 24, 36, 48 and 60 during the work cycle on day 1 ($F_{6, 84}$=3.875, p<0.002). A significant increase in mean shoulder abduction was seen during the drill task ($F_{5, 70}$=2.004, p<0.089).

3.4.4.3 Shoulder Flexion

Peak shoulder flexion angle decreased by 7.0 ° over time during the work cycle from minute 0 to minute 60 ($F_{5, 70}$=4.890, p<0.0005) (Figure 3.11c). There was also a significant decrease in mean shoulder flexion ($F_{5, 70}$=2.449, p<0.042) (Figure 3.10c) and shoulder flexion COV ($F_{5, 70}$=2.035, p<0.084) (Figure 3.12c). Mean shoulder flexion on day 2 was significantly larger than minutes 36, 48 and 60 on day 1 but not minutes 0, 12 and 24 ($F_{5, 70}$=3.283, p<0.006). Peak shoulder flexion on day 2 was significantly larger than all other time points on day 1 except for minute 0 ($F_{6, 84}$=7.246, p<0.0005).

3.4.4.4 Elbow Flexion

Significant increases were found for mean ($F_{5, 70}$=2.099, p<0.076) (Figure 3.10d) and peak elbow flexion ($F_{5, 70}$=2.168, p<0.067) (Figure 3.11d). Elbow flexion variability (COV) decreased from minute 0 to minute 60 during the work cycle ($F_{5, 70}$=4.568, p<0.001) (Figure 3.12d). Elbow flexion variability on day 2 was also lower that minute 0 on day 1 ($F_{6, 84}$=3.393, p<0.005).

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Figures 3.10, 3.11, 3.12

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3.4.5 Ratings of Perceived Discomfort

No participants reached the threshold rating of perceived discomfort of an 8. The ratings of perceived discomfort increased by 1.2 units throughout the experimental protocol (Figure 3.6) ($F_{11,154}$ = 5.946, p=0.0005).

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Figure 3.13

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3.5 Discussion

This study represents one of the first attempts to evaluate the process of adaptation of the upper limb to highly repetitive cyclical work and evaluated whether any adaptations would persist to the next day. It is also one of the first studies to combine the analysis of all sub-tasks involved in one job. The examination of the combined effects of a complex job is important for assessing injury risk. Assessing jobs in isolation may seem “acceptable”; however it is the cumulative effects from all the tasks that may be important for injury risk. This study provides new insights on how the effects combine to contribute to risk of musculoskeletal injury.

We examined muscle activity throughout the work cycle, as well as the finger pull, drill press and hose connector push tasks. We found greater changes when analyzing the sub-tasks than when analyzing the work cycle as whole. For example, no significant effects were found during the work cycle for infraspinatus (IN), but a significant increase in peak IN EMG was found during the drill task and a significant decrease in peak EMG was found during the hose insertion task. The implications of these results are that important changes (e.g. increases) in muscle activity can be masked within the cycle but is evident in individual task. While no differences over time were noted when the whole cycle was analyzed, EMG variability (COV) decreased for triceps brachii during the finger pull task and anterior deltoid during the hose insertion task over time. This decreased variability in a sub-task suggests that analyzing the sub-tasks in a more complex task is beneficial in identifying risk of injury. Decreased muscle activity variability in occupational tasks is associated with increased injury risk (Madeleine et al., 2008). While this is not a novel concept, this suggests that when analyzing a job, each individual task needs to be considered to better understand which tasks place the worker more at risk than the others.

Recent research has shown an increase in muscle activity and decrease in EMG variability (COV) with grip force, especially anterior deltoid, latissimus dorsi and trapezius muscle (Hodder and Keir, 2012). Although there was a decrease in variability in upper trapezius and anterior deltoid, the current study found a decrease in muscle activity rather than an increase as shown by Hodder and Keir. When analyzing the work cycle or sub-tasks, EMG decreased for biceps brachii, triceps brachii, anterior deltoid and infraspinatus. Middle deltoid and infraspinatus were the only muscles to show increases in mean or peak EMG. We suspect that these results reflect the fact that, although a grip was involved in 3 of the 4 tasks, these grip forces were quite low relative to Hodder and

Keir (2012), especially since the drill was inactive and did not require the use of the trigger. We would expect that, with the higher grip forces used in the actual workplace, the muscle activity would increase over the work day.

Our results suggest that adaptations in performance are occurring well before any signs of fatigue. None of the subjects reported discomfort beyond a modest level (an RPD of 4 was the highest in the study. However, on day 2, most participants anecdotally reported symptoms of delayed onset muscle soreness (DOMS) in the deltoid area (this was not part of the study but participants freely offered this comment). DOMS is a muscular response to exercise or unaccustomed eccentric work of sufficient duration and/or intensity with causes a disruption in the tissue (Smith, 1991). This suggests that, although the participants did not perceive any fatigue, there was sufficient duration and intensity to cause muscle damage. Perhaps our perceptions of effort/discomfort are a misrepresentation of the actual work being conducted. This suggests that examining the process may be just as important as understanding the acute effects of fatigue.

Although we hypothesized that the work cycle time would increase over the hour, our results showed a significant decrease in length of time to complete the task. This may suggest a couple of things. First, it may suggest that participants capitalized on increasing rest between cycles (the time between the end of one cycle and beginning of the next). We conducted an EMG gaps analysis over the course of the hour to determine the number and amount of rest for each muscle within the work cycle. It is well known in the workplace that workers will work faster in order to receive longer rest periods. We found there to be no gaps for any subjects throughout the work cycle. Further gaps analysis should be conducted on the non-work time to determine whether this time is used as a rest period. Secondly, this decrease in time to complete the work cycle may reflect a learning effect. This learning effect may potentially be hazardous for the workers as they choose to work faster, thus creating higher muscular demands to complete the job,

As hypothesized, shoulder flexion decreased over the course of the hour. There was a maximum of a 5° decrease in peak shoulder flexion angle and an increase in elbow flexion (up to 5°) over the course of the hour. This suggests that the arm is moving closer towards the body (decrease in reach distance) and decreasing the moment created by the weight of the extended arm. Participants in this study were not allowed to move their feet throughout the experimental protocol and in order to decrease the reach distance, we hypothesize that participants would have had to lean in or rotate towards the apparatus. This change in body position relative to the apparatus may suggest why more significant increases in EMG did not occur in this study.

In some cases, we found a main effect for time where pairwise comparisons showed significant differences from minute 0 to 48 followed by a significant change from minute 48 to minute 60. For example, peak push force decreased over time during the hose connector task from the minute 0 to the 48th minute and increased approximately 6 N at minute 60 (Figure 3.9). This was also evident in some of the EMG results. For example, mean EMG for biceps brachii during the pipe connector task showed a decrease of 2.6% from minute 0 to minute 48 and a 1.3% increase from minute 48 to minute 60 (Figure 3.6a). Similar effects were evident in other force channels and muscles, however, they were insignificant. This trend suggests that knowing that it was the final trial altered the way in which participants performed the tasks.

A secondary purpose of this project was to determine whether a learning effect occurred after an hour of the experimental protocol by examining participant behaviour one day later. We found that the time to complete the task on day 2 was statistically different from the first minute on day 1. This suggests that for time to complete the work cycle, a learning effect occurred as day 2 was more similar to the final minute of day 1. (Figure 3.5). Additionally, we compared joint angles on day 1 to those on day 2. Contrary to what was found with time, mean and peak shoulder abduction angles and peak shoulder flexion angles on day 2 were significantly larger from the end of day 1. This suggests that the changes in shoulder angles did not persist from day 1 to day 2. This is contrary to what was hypothesized as greater flexion and abduction angles increase the load at the shoulder. For shoulder flexion angles, significant differences were seen in peak angle but not in mean angle. This suggests that further analysis could be conducted to determine whether there may be an altered kinematic strategy to complete the cycle. Moreover, the present study only lasted 61 minutes so a longer protocol may have induced more significant robust adaptations.

There are a few limitations to the current study. A relatively small number of young, healthy male adults participated and thus, generalizing to workers of all ages and training should be done with caution. The participants were from the university population and had no experience working on a manufacturing line, thus they may react differently than workers in the plants. An examination of work tasks on-site over time would provide a better insight to whether these changes occur with those actually performing the jobs. Additionally, research has shown that novices and experts exhibit different motor and EMG variability (Madeleine et al., 2008). On-site examinations with both experts and novices could further our knowledge on how individuals adapt to work-related stresses as well as evaluate learning effects. All task force values were set at 50% of the participants' maximum. This may not be as generalizable to the industrial workplace as forces required to perform jobs tend to be absolute. The organization of the tasks and the tasks themselves are different than those found in the workplace. For example, while you will find the use of the drill in the workplace, our task involved an inactive drill, thus we would expect the results to be different. Although significant changes occurred in BB, TB, AD, MD, PD and IN, we were limited to surface EMG and thus only IN of the rotator cuff muscles was accessed. Indwelling EMG may have provided better insight to other muscles of the rotator cuff as these muscles tend to be smaller and more susceptible to injury. Analysis on EMG to address fatigue was not conducted during this study. Some of the EMG results may reflect changes in muscle activity due to fatigue.

This study is one of the first to attempt to examine the process involved in with upper extremity adaptations due to repetitive movements. The effects of risk factors are well documented in the literature. It is well known that high repetition, extreme postures and heavy loads are large risk factors in the workplace; however it is not feasible to fully eliminate all risks from a job. Thus, employer must find a happy medium in order to keep workers at a low risk of injury. In order to do so, there must be a better understanding of how workers adapt to certain conditions and how these adaptations persist over time. This study is an examination of how adaptations occur and is a starting point for future research in examining the nature of these changes.

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3.7 Manuscript Tables and Figures

3.7.1 Tables

Table 3.1 Experimental set-up completion criteria for each task.

Task #	Task	Completion Criteria
Task 1	2 finger pull	Audible click
Task 2	Turning a knob	6 full rotations
Task 3	Anterior push with drill	Completion of 1 exertion held at 50% of maximum for 10 seconds (Visual feedback provided)
Task 4	Pipe connector push	Audible click

Table 3.2. Maximum Voluntary Exertion (MVE) protocol for each muscle.

Muscle	Testing Position	Movement
Biceps Brachii	Shoulder adducted, elbow in 90°, forearm supinated.	Subject pushes upward against resistance
Triceps Brachii	Shoulder adducted, elbow in 90°, forearm supinated.	Subject pushes downward against resistance
Upper Trapezius	Shoulder adducted	Subject attempts to shoulder shrug against resistance
Lower Trapezius	Shoulder in 90° of flexion	Subject attempts to flex shoulder against resistance
Anterior Deltoid	Shoulder flexed 90°, forearm neutral	Subject pushed upward against resistance
Middle Deltoid	Shoulder abducted 90°, forearm neutral	Subject abducts against resistance
Posterior Deltoid	Shoulder abducted 90°, forearm supinated (thumb up)	Subject pushes backwards against resistance
Infraspinatus	Shoulder adducted, elbow flexed 90°	Subject attempts external rotation against resistance
All*	Shoulder flexed 90°, abducted ~45°, forearm pronated	Subject attempts to push upwards against resistance

*****Empty Can Test was used as an additional MVE as it was shown to activate the majority of muscles of interest (Boettcher et al., 2008)

Table 3.3 List of dependent variables used in one-way repeated measures analysis of variance (ANOVA) with time as the repeated measure

	Dependent Variables	Units	Measures
EMG	• Biceps brachii • Triceps brachii • Anterior deltoid • Middle deltoid • Posterior deltoid • Upper trapezius • Lower trapezius • Infraspinatus	% MVE	• mean • peak • COV • gaps (rest)
Joint Angles	• Shoulder flexion • Shoulder elevation • Shoulder abduction • Elbow flexion	Degrees (°)	• mean • peak • COV
Forces	• F_z • F_x • M_x • F_y • M_y • Push force • Pull force	Newtons (N)	• mean • peak • COV

Time	• Work cycle time
	• Sub-task time
	    ○ Finger pull
	    ○ Drill press
	    ○ Hose insertion push
		Seconds (s)	• Length of time

Table 3.4 Summary table of significant and relevant EMG trends (p<0.1). Mean, peak and coefficient of variation are represented as M, P and COV, respectively. Results that were significant with a sphericity correction at p<0.05 are listed in bold. Results that are significant with no correction and at a significance of p<0.1 are in italics.

Task	BB	TB	AD	MD	PD	UT	LT	IN
Whole cycle	↑*COV*	↓**P** ↓*COV*	↓**P** ↓*COV*	↓*M*	↓**COV**	↑*M*		↑*M* ↓*P* ↓*COV*
Finger Pull		↓*P* ↓**COV**	↓**M** ↑**COV**					
Drill Press	↑*COV*			↑*M*↑*P*			↑*COV*	↑*M* ↑**P**
Hose Push	↓*M* ↓**P**	↓*P*	↓**P** ↓**COV**	↓*P*				↓**P**

Table 3.5 Summary table of significant and relevant kinematic trends ($p<0.1$). Mean, peak and coefficient of variation are represented as M, P and COV, respectively. Results that were significant with a sphericity correction at $p<0.05$ are listed in bold. Results that are significant with no correction and at a significance of $p<0.1$ are in italics.

	Shoulder Flexion	**Shoulder Elevation**	**Shoulder Abduction**	**Elbow Flexion**
Whole Cycle	↓*M* ↓**P** ↓*COV*	↓*P*	↓*M* ↓*P* ↓*M*	↑*M*↑*P* ↓**COV**
Drill Press	↑*M*			

3.7.2 Figure Captions

Figure 3.1. Experimental set up. (a) Tasks were performed in order as listed in upper left corner. Task 1 (finger pull) and task 3 (hose push) were set at umbilicus level while task 2 (knob turn) and task 4 (drill push) were set at shoulder level. (b) The distance of the tasks were 30 cm on either side of the midline.

Figure 3.2 Three-dimensional force transducer with axes denoting a positive force output. The corresponding positive moments are counter clockwise about the axes shown.

Figure 3.3 EMG electrode placement with reflective tracking markers for motion capture. a) anterior view and b) posterior view.

Figure 3.4 Screen capture of the modelled segments with their respective axes system. The Y-axis is not shown as it runs anterior-posterior with anterior being positive.

Figure 3.5 Active cycle times for Day 1 and Day 2. All time points are statistically different from time 1 ($F_{6,84}$=12.904, $p<0.0005$).

Figure 3.6 Mean EMG values for (a) biceps brachii, (b) triceps brachii, (c) anterior deltoid, (d) middle deltoid, (e) posterior deltoid, (f) upper trapezius, (g) lower trapezius and (h) infraspinatus. *, +, • and ▫ denote significant difference between time points during work cycle, finger pull, drill press and connector push, respectively.

Figure 3.7 Peak EMG for (a) biceps brachii, (b) triceps brachii, (c) anterior deltoid, (d) middle deltoid, (e) posterior deltoid, (f) upper trapezius, (g) lower trapezius

3.7.3 Figures

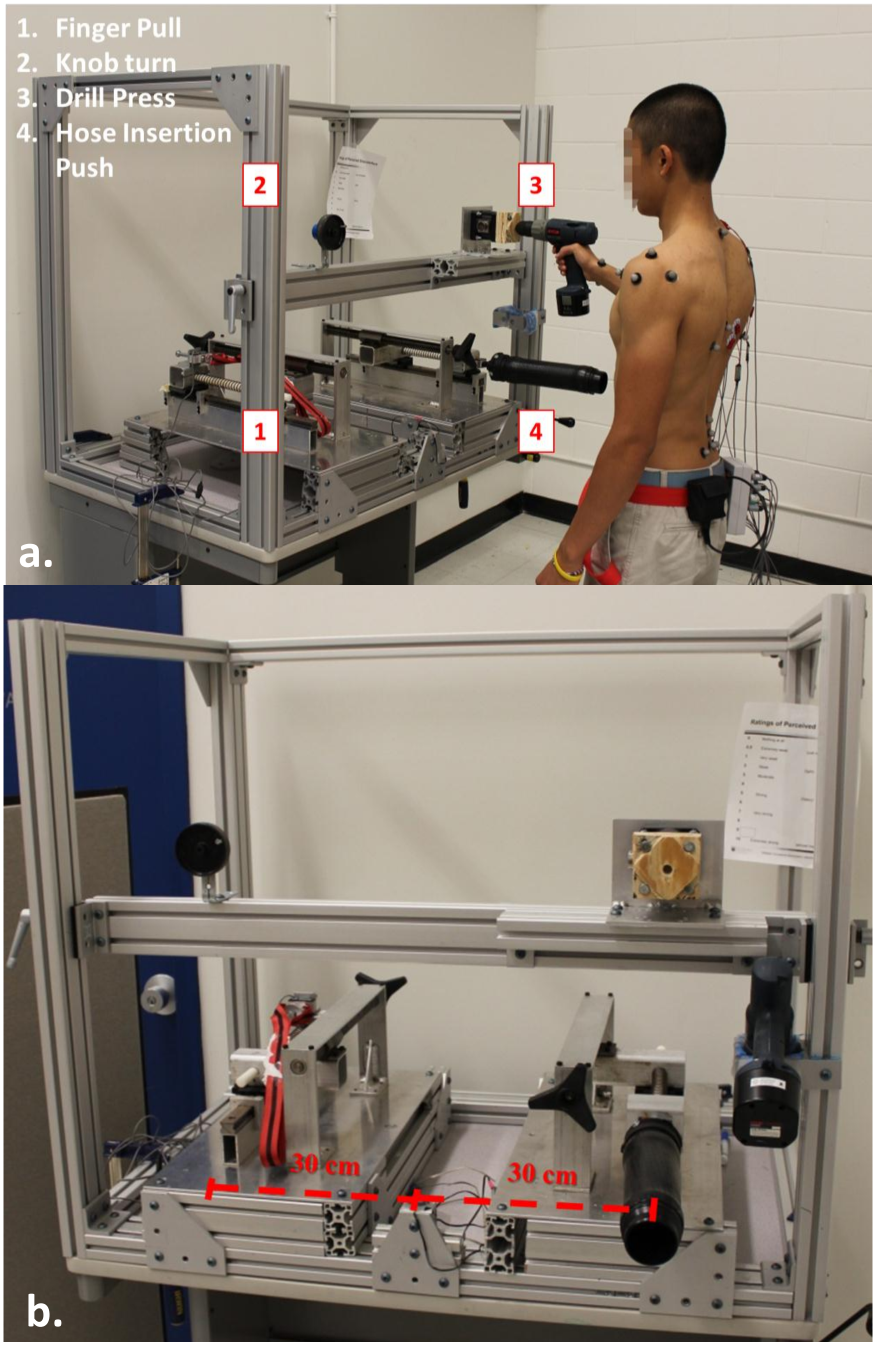

Figure 3.1 Experimental set up. (a) Tasks were performed in order as listed in upper left corner. Task 1 (finger pull) and task 3 (hose push) were set at umbilicus level while task 2 (knob turn) and task 4 (drill push) were set at shoulder level. (b) The distance of the tasks were 30 cm on either side of the midline.

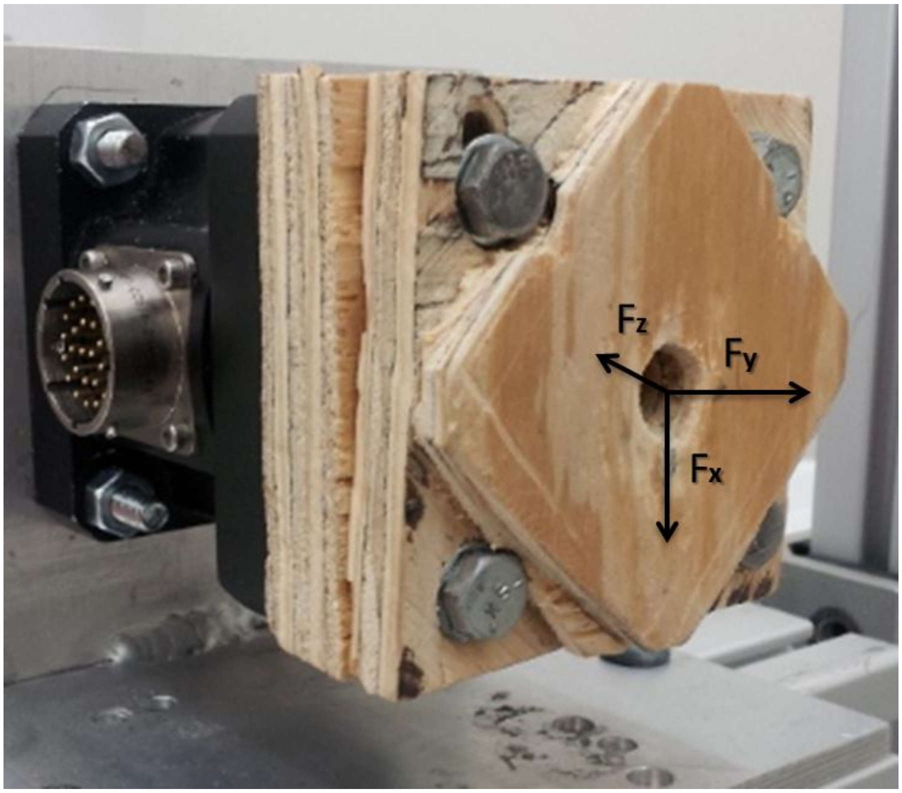

Figure 3.2 Three-dimensional force transducer with axes denoting a positive force output. The corresponding positive moments are counter clockwise about the axes shown.

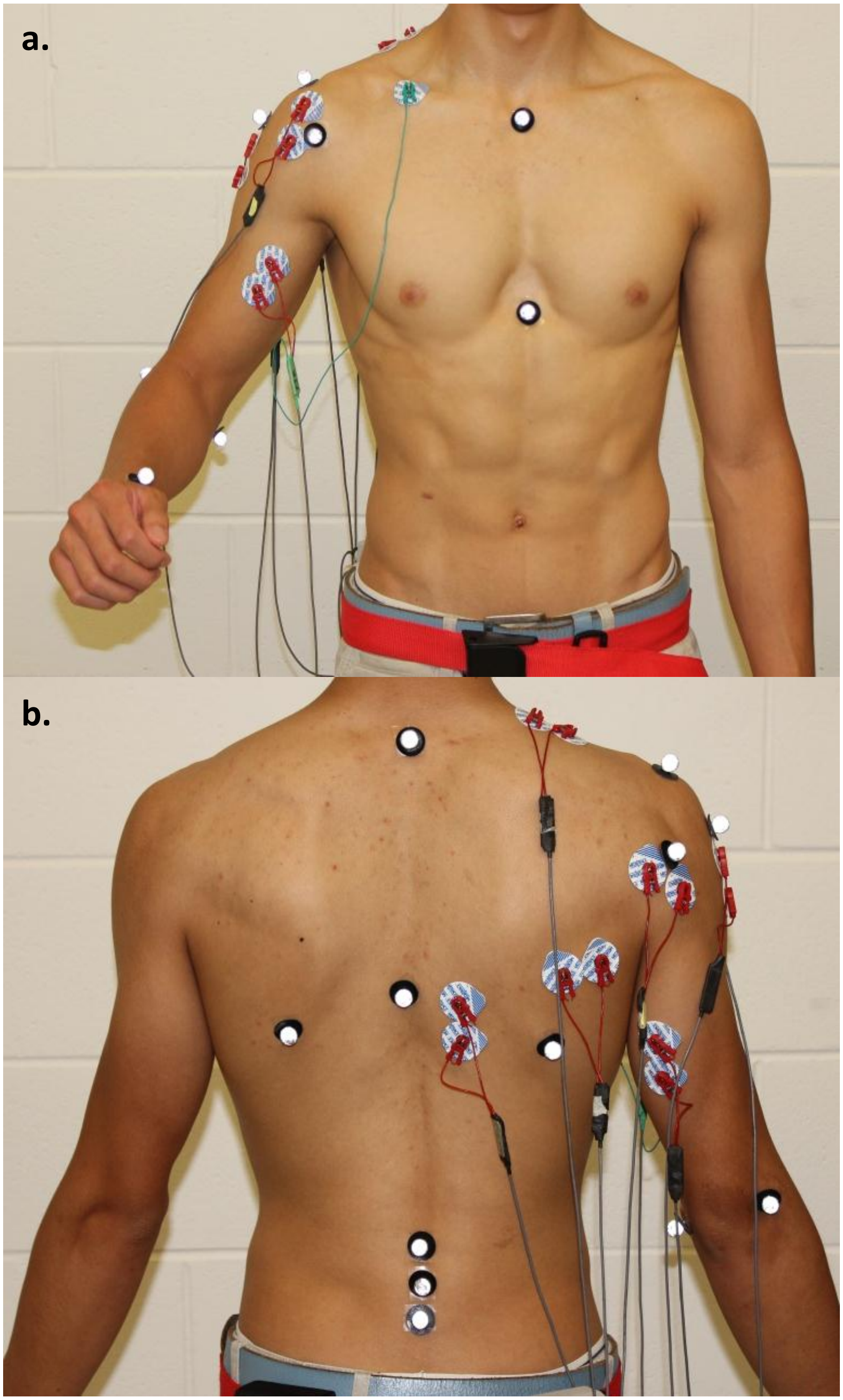

Figure 3.3 EMG electrode placement with reflective tracking markers for motion capture. a) anterior view and b) posterior view.

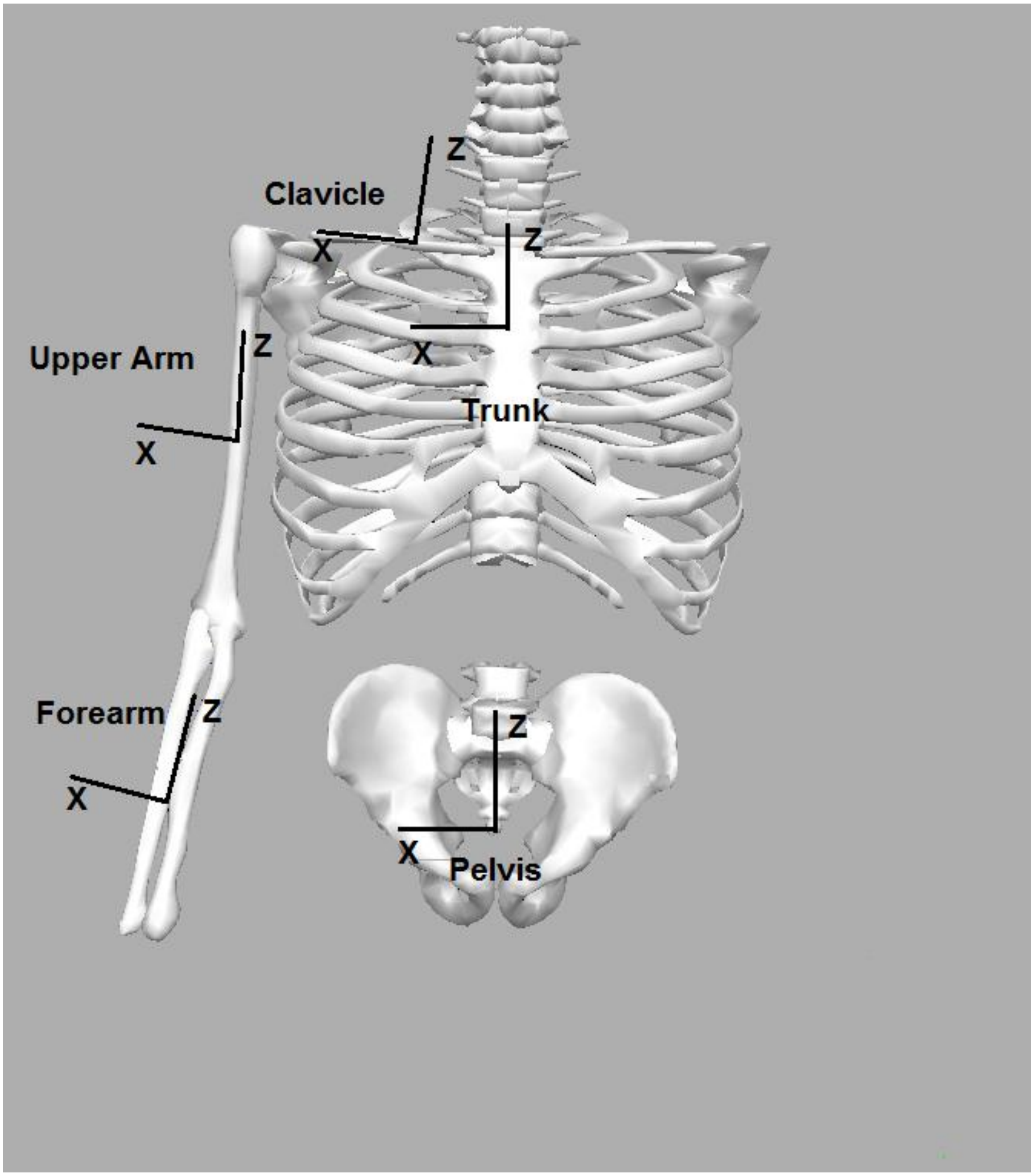

Figure 3.4 Screen capture of the modelled segments with their respective axes system. The Y-axis is not shown as it runs anterior-posterior with anterior being positive.

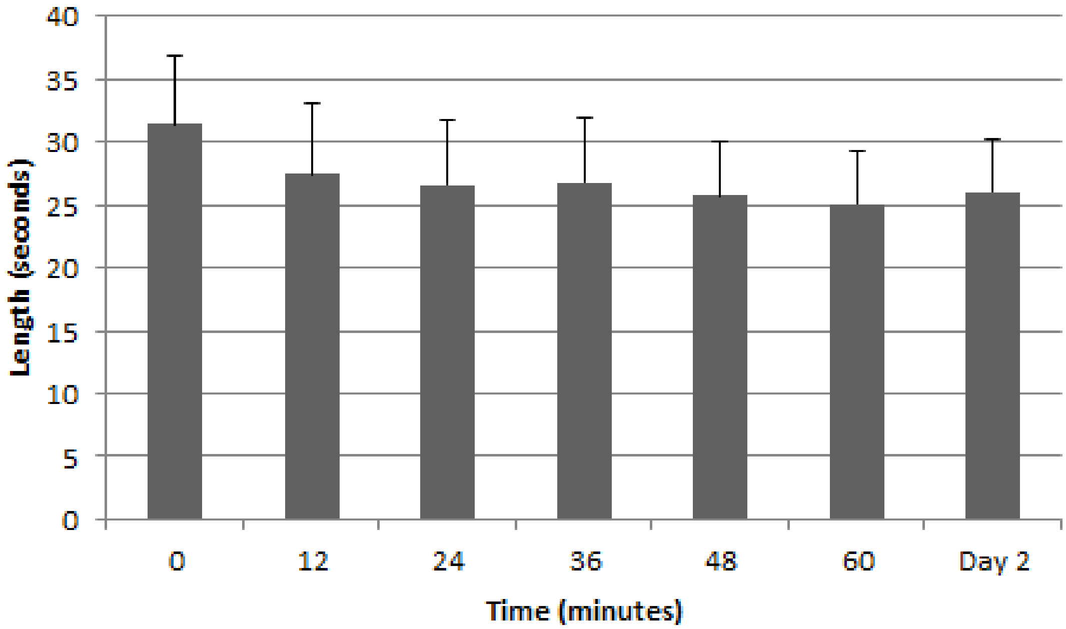

Figure 3.5 Active cycle times for Day 1 and Day 2. All time points are statistically different from time 0 ($F_{6,84}$=12.904, p<0.0005).

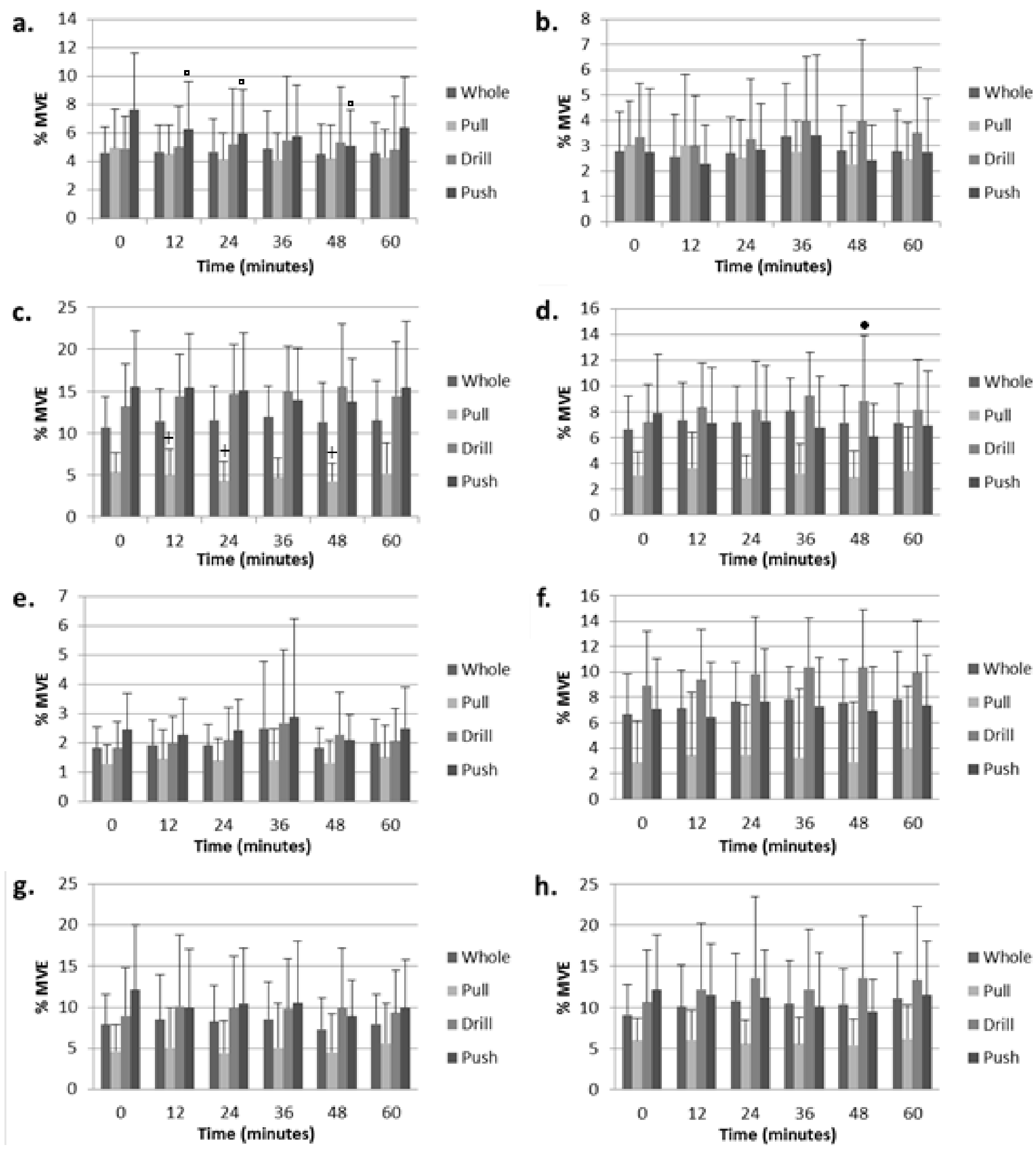

Figure 3.6 Mean EMG values for (a) biceps brachii, (b) triceps brachii, (c) anterior deltoid, (d) middle deltoid, (e) posterior deltoid, (f) upper trapezius, (g) lower trapezius and h. infraspinatus. *, +, • and ▫ denote significant differences from minute 0 during active cycle, finger pull, drill press and connector push, respectively.

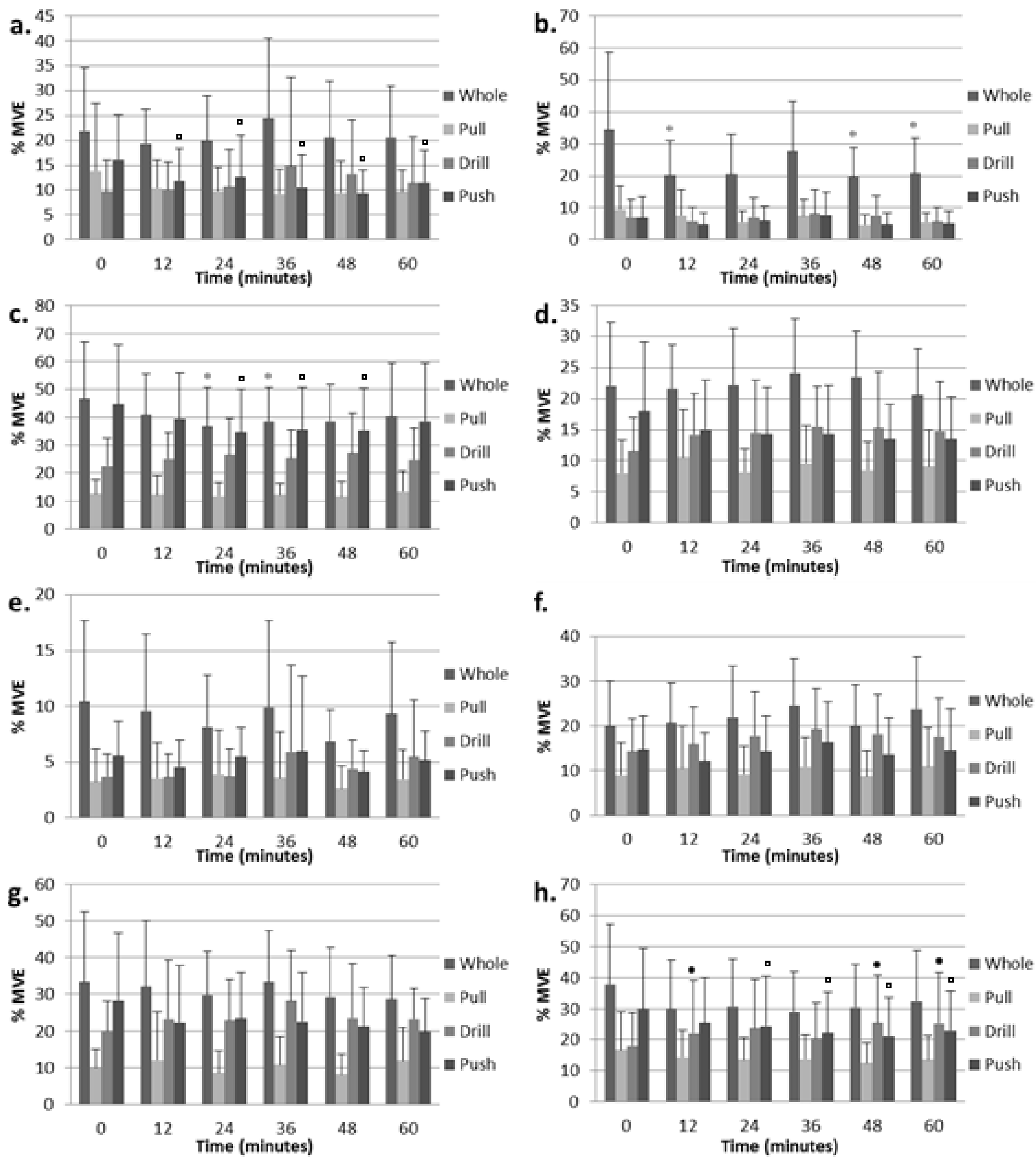

Figure 3.7 Peak EMG values for (a) biceps brachii, (b) triceps brachii, (c) anterior deltoid, (d) middle deltoid, (e) posterior deltoid, (f) upper trapezius, (g) lower trapezius and h. infraspinatus. *, +, • and ▫ denote significant differences from minute 0 during active cycle, finger pull, drill press and connector push, respectively.

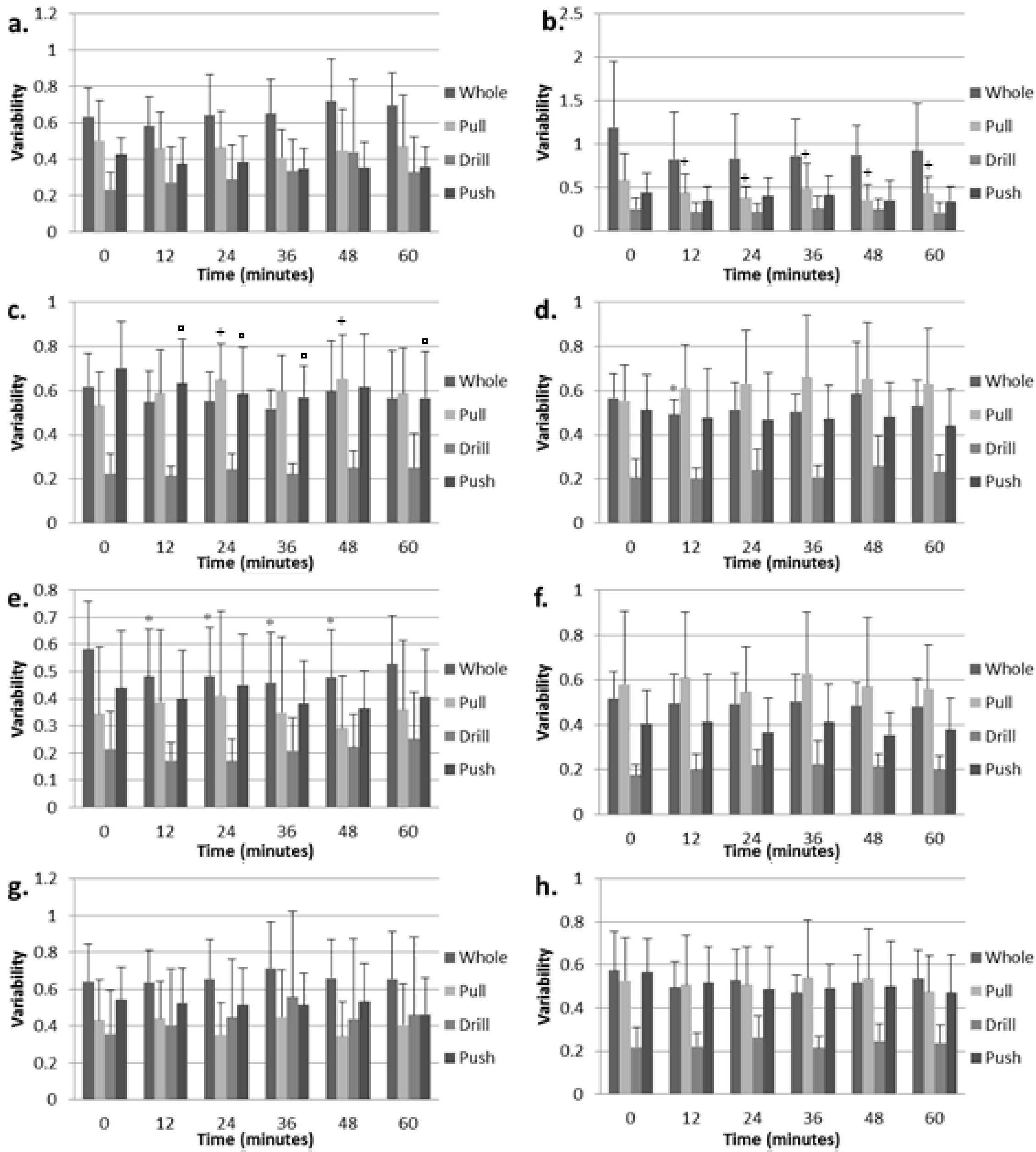

Figure 3.8 EMG variability (COV) for (a) biceps brachii, (b) triceps brachii, (c) anterior deltoid, (d) middle deltoid, (e) posterior deltoid, (f) upper trapezius, (g) lower trapezius and h. infraspinatus. *, +, • and ▫ denote significant differences from minute 0 during active cycle, finger pull, drill press and connector push, respectively.

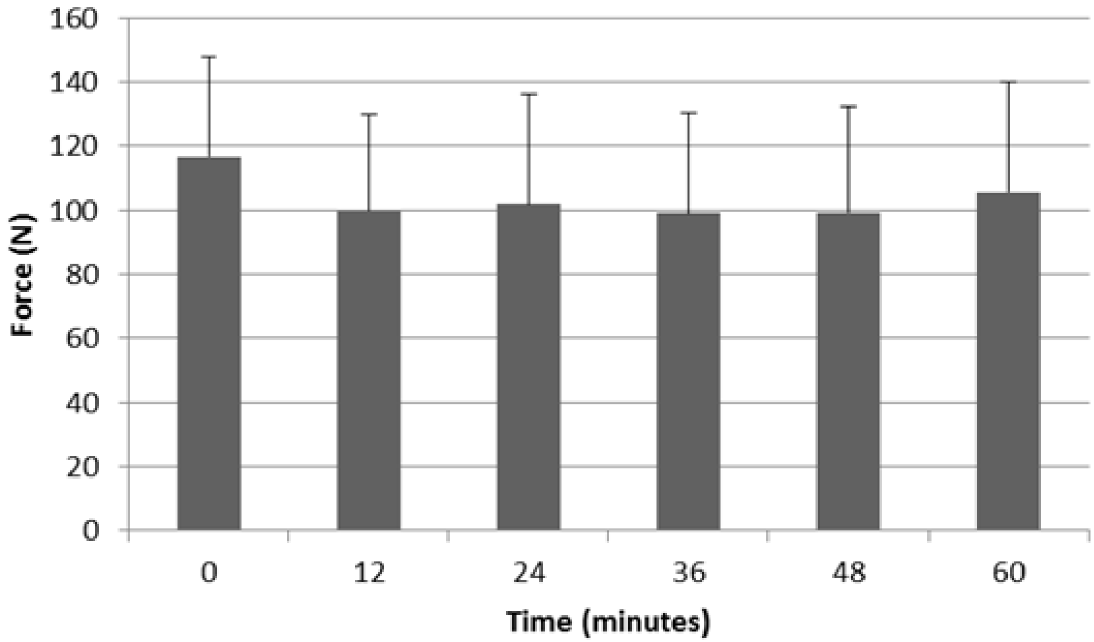

Figure 3.9 Peak push force during the hose insertion task. All time points, except minute 61, are statistically different from minute 1 ($F_{5, 70}$=5.416, p<0.0005).

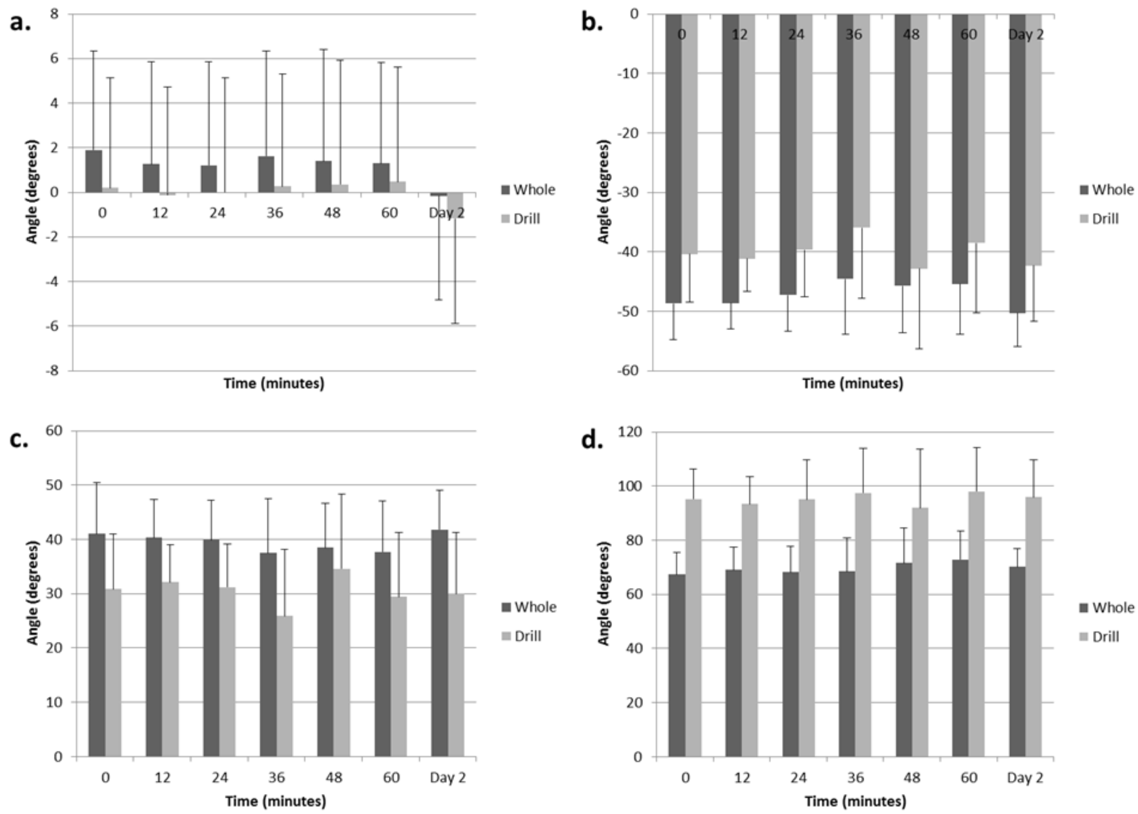

Figure 3.10 Mean joint angles (with standard deviation) for the work cycle and the drill task. (a) shoulder elevation, (b) shoulder abduction, (c) shoulder flexion and (d) elbow flexion**.**

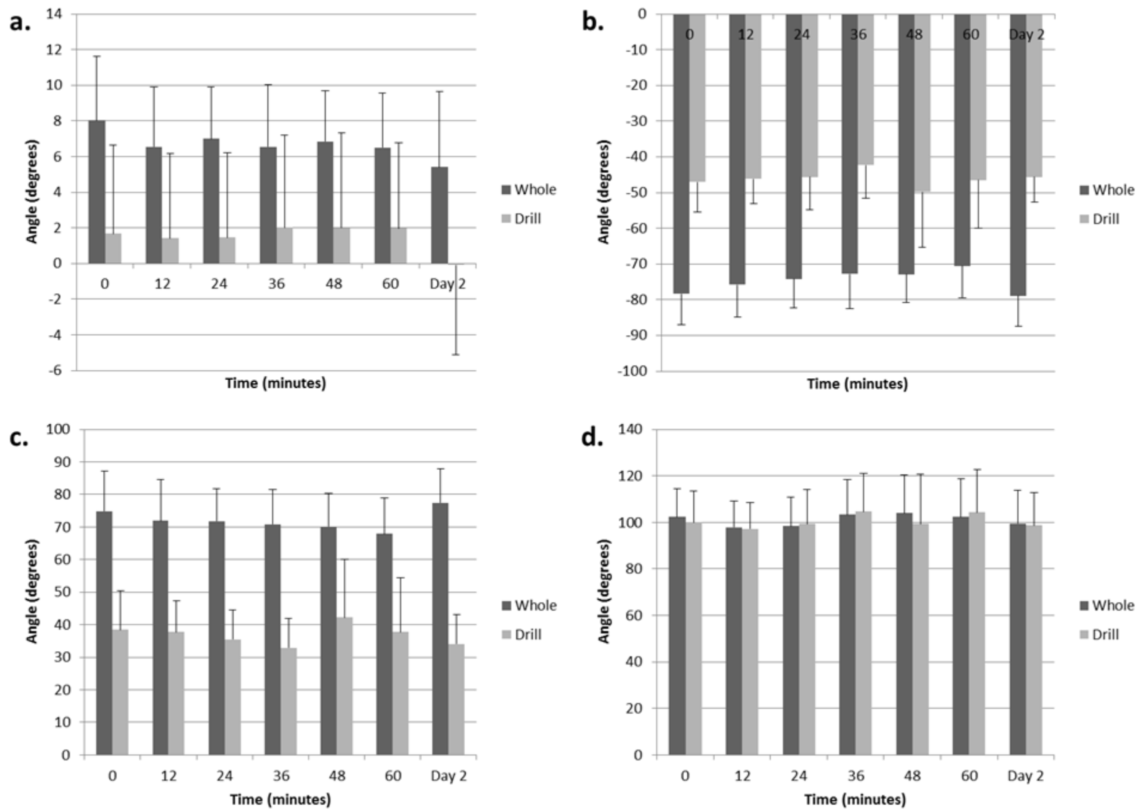

Figure 3.11 Peak joint angles (with standard deviation) for the work cycle and the drill task. (a) shoulder elevation, (b) shoulder abduction, (c) shoulder flexion and (d) elbow flexion.

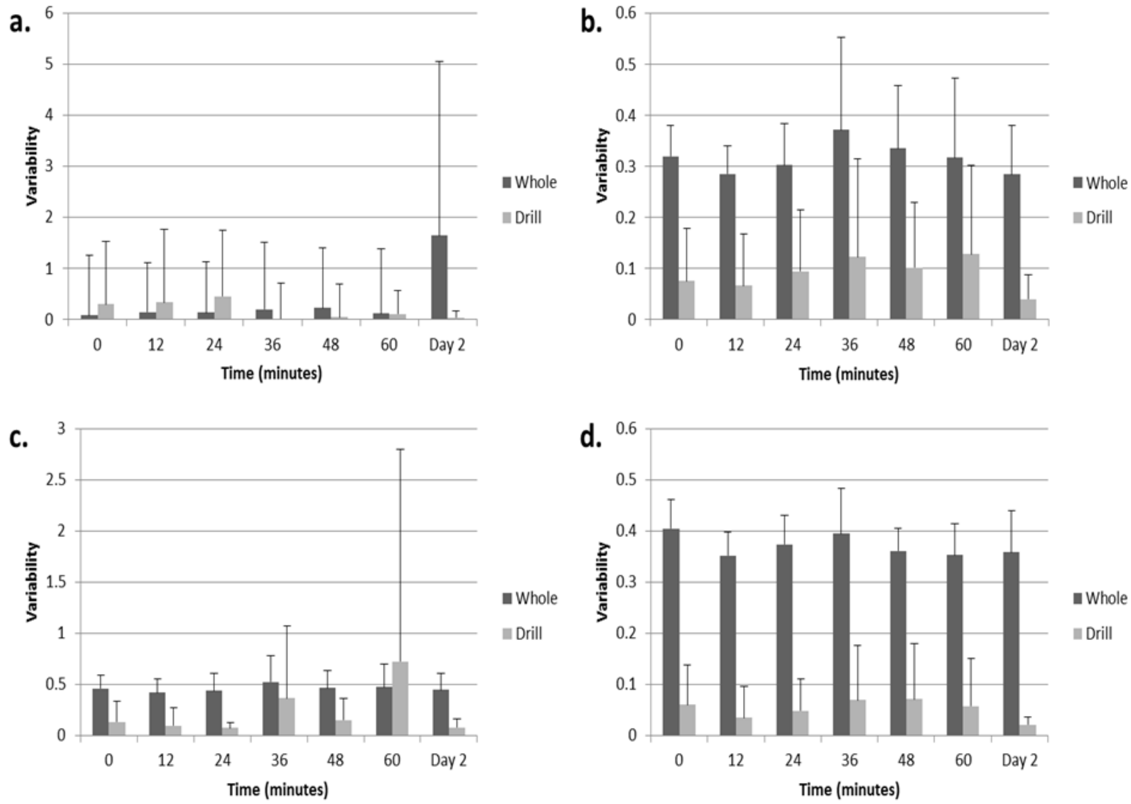

Figure 3.12 Joint angle variability (COV) (with standard deviation) for the work cycle and the drill task. (a) shoulder elevation, (b) shoulder abduction, (c) shoulder flexion and (d) elbow flexion**.**

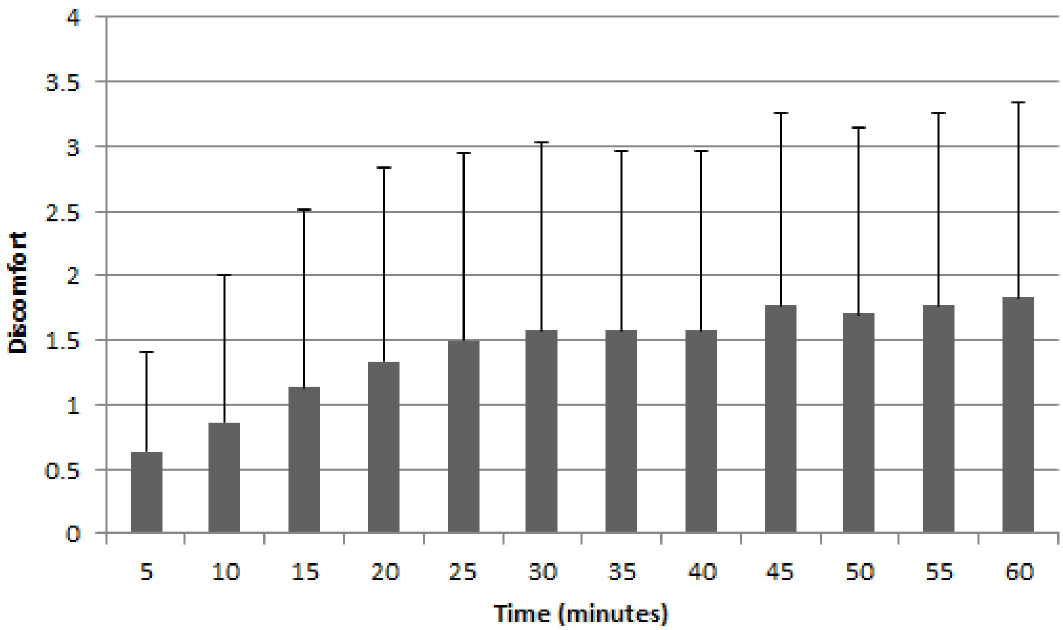

Figure 3.13 Mean ratings of perceived discomfort. All time points are statistically greater than minute 5 ($F_{11,154}$ = 5.946, p=0.0005).

CHAPTER 4 – THESIS SUMMARY AND FUTURE DIRECTIONS

4.1 Thesis Summary and Conclusions

This thesis represents one of the first attempts to evaluate the process of adaptation to a simulated cyclic work task. My thesis was an attempt to understand how the upper extremity, and shoulder in particular, adapted to repetitive work by analyzing a number of muscles at the shoulder along with the kinematics of the upper extremity. To do this, muscle activity was analyzed for the work cycle, and three of the four sub-tasks which were monitored using force transducers (finger pull, drill and hose connector push). We found significant main effects when analyzing a sub-task where no main effects occurred when analyzing the whole task. For example, the peak activity was increased in four muscles during the drill task. In comparison, the peak muscle activity increased for two muscles and actually decreased for one muscle when analyzing the whole active cycle. This suggests that, when analyzing a job as a whole using EMG and kinematics, we may be missing important information and some of the real issues may be hidden within a sub-task. In other words, by analyzing the sub-tasks, we can evaluate where and when the loads are greatest, thus being better able to organize the order of sub-tasks within a complex job.

In addition to examining the muscle activity within the sub-tasks, we conducted Rapid Upper Limb Assessment (RULA) and Strain Index (SI) assessments on the each of the four tasks individually and all four combined. Table B.2 indicates the scores for each task with both assessments and the colours indicate the level of injury risk for each job (e.g. high vs. low). Both assessment tools indicated that the whole active cycle was high risk of injury; however none of the sub-tasks were identified as high risk. When assessing the individual tasks, ergonomic tools do not identify where the problem issues lie, whereas the EMG results may provide into where within these sub-tasks the risk occurs. This suggests that although these tools are useful, they do not provide an in-depth look at where, within the job, the issues truly lie. Thus, understanding changes in EMG over time and incorporating that with ergonomic assessment tools is key for proper workplace assessments. This is also one of the first studies to examine the combined effects of a complex task. When examining the tasks individually, they seem "acceptable" or low risk of injury; however it is the cumulative effects that raise concerns.

Our results suggest that there are adaptations occurring well before any signs of high discomfort. None of our subjects reported levels of discomfort greater than a 4 on the Borg Scale. However, contrary to what we would have expected, most participants reported on day 2 symptoms of delayed onset muscle soreness (DOMS) around the deltoid area. DOMS is a muscular response to exercise or unaccustomed eccentric work of sufficient duration and/or intensity with causes a disruption in the tissue (Smith, 1991). This suggests that, although the participants perceived the work and/or discomfort to be easy/weak to moderate, there was sufficient duration and intensity to cause muscle damage. Perhaps our perceptions of effort/discomfort are a misrepresentation of the actual work being conducted. Frequency analysis will be conducted on the EMG data to confirm whether or not there were any signs of fatigue.

4.2 Contributions of Thesis

The goal of the current study was to improve the understanding of the effects of highly repetitive tasks on movement and muscle activation of the upper extremity. This study was one of the first to attempt to examine the process involved with adaptations due to repetitive movements. The effects of risk factors are well documented in the literature. It is well known that high repetition, extreme postures and heavy loads are large risk factors in the workplace; however it is not feasible to fully eliminate all risks from a job. Thus, employer must find a happy medium in order to keep workers at low risk of injury. In order to do so, there must be a better understanding of how workers adapt to certain conditions and how these adaptations persist over time. This study is an examination of how adaptations occur and is a starting point for future research in examining the nature of these changes.

4.3 Future Directions

The present study only analyzed the joint angles of the shoulder and elbow. Further analysis should be done to examine changes in velocities and accelerations at these joints as these factors have been shown to be associated with higher injury risk and, therefore, should be taken into consideration when examining potential injury risk (Marras and Schoenmarklin, 1993). Participants were also set up with markers along the pelvis and shoulders. As the mean elbow flexion angle (especially at the drill press) increased throughout the protocol, we might expect that the participants were leaning into the apparatus as they were instructed to keep their feet planted. Further kinematic analysis of trunk lean and rotation may provide insight to whether or not participants began to depend on using their bodyweight to complete the tasks.

This study is one of the first to show temporal changes in muscle activity and joint angles during a simulated automotive task. Our results showed significant decreases in EMG variability, which previous research has shown to be linked with an increased in jury risk (Madeleine & Farina, 2008). This study was only conducted over a 61 minute period, whereas workers work up to 8-10 hours a day. Future studies should examine the changes with highly repetitive work over a longer period of time. Furthermore, one of the main limitations of this study was that participants were young, healthy males from the university population. Some of the results may be less generalizable due to the different age and population that appears in the industry. An examination of work tasks on-site over time would provide a better insight to whether these changes occur with those actually performing the jobs. Additionally, research has shown that novices and experts exhibit different motor and EMG variability (Madeleine et al., 2008). On-site examinations, with both experts and novices, could further our knowledge on how individuals adapt to work-related stresses, as well as evaluate learning effects. Future research on these adaptations is necessary to understand whether these are strategies used for workers to prolong fatigue and therefore, work longer.

The knowledge of how workers adapt to stressors and how these stressors increase injury risk is still not completely understood. Additionally, there is a great deal of variability on how different individuals adapt to these stressors. Although not yet examined, there appeared to be a wide range of individual variability within the current study. Ideally, one might investigate changes in EMG for workers over an extended period of time and document incidences of injury to create a better understanding of what adaptations are harmful and when they occur. This type of study is difficult to conduct and studies that combine both examining changes to repetitive tasks over a prolonged period of time with groups of healthy and injured individuals. This could provide insight as to whether muscle activity or kinematics of healthy individuals resembles that of injured individuals after a certain period of time.

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APPENDICES

APPENDIX A: ANTHROPOMETRICS

Table A.1. Descriptive statistics of anthropometrics (n=15)

	Age (yrs)	Height (cm)	Mass (kg)	Arm Length (cm)	Shoulder Height (cm)	Umbilicus Height (cm)
Mean	21.87	176.17	73.30	76.89	146.43	107.33
Std. Dev.	2.67	6.91	10.66	5.20	5.92	3.90
Max.	28	189.7	99	90	157	113
Min.	19	164	61.2	70	139.5	101

APPENDIX B: ACCESSORY DATA

Table B.1. Ratings of perceived discomfort (RPD) as reported by the participants. Participant numbers are down the left and time is across the top.

	Time (minutes)											
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
1	0.5	0.5	1	1	2	2	2	2	3	3	3	3
2	2	3	4	4	4	4	4	4	4	4	4	4
3	0.5	0.5	1	1	1.5	2	2.5	2.5	3	3	3	3.5
4	0.5	0.5	1	1.5	1.5	2	2.5	2.5	3	3	3.5	3.5
5	1	1	1	2	2	2	2	2	2	2	3	3
6	0	0.5	0.5	1	1	1	1	1	2	2	2	2
7	2	3	3	4	4	4	4	4	4	4	4	4
8	0	0	0	0	0	0	0	0	0	0	0	0.5
9	0	0	0.5	0.5	1	1	1	1	1	1	1	1
10	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1
11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1
12	0	0	0	0	0	0	0	0	0	0	0.5	0.5
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
15	2	3	4	4	4	4	3	3	3	2	0.5	0
Mean	0.63	0.87	1.13	1.33	1.5	1.57	1.57	1.57	1.77	1.7	1.77	**1.83**
Std. Dev.	0.77	1.14	1.38	1.50	1.45	1.46	1.40	1.40	1.49	1.45	1.5	**1.51**

Table B.2 - Indicates the scores for each task. RULA scores in green indicate acceptable or changes may be required, yellow indicates changes soon and red indicates changes required now. SI scores in green indicate safe, yellow indicates caution and red indicates hazardous.

	RULA	**Strain Index**
Whole Active Cycle	7	20.25
Finger Pull	6	3.375
Knob Turn	5	2.25
Drill Press	6	2.25
Hose Connector Push	6	6.75

APPENDIX C: RATINGS OF PERCEIVED DISCOMFORT

Ratings of Perceived Discomfort

0	Nothing at all	
0.5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4		
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost maximum)

Figure C.1. Ratings of perceived discomfort

APPENDIX D: ETHICS AND CONSENT FORM

McMaster University Health Sciences

RESEARCH ETHICS BOARD

Hamilton Health Sciences
EXEMPLARY CARE • ACADEMIC EXCELLENCE

AMENDMENT REQUEST

REB Project #: 09-548

Locally Responsible Investigator: Dr. Peter Keir

Title of Study: The effect of hand and arm actions on muscle activity and load distribution in the shoulder complex

Document(s) Amended with version # and date:

- Administrative Change - Added Investigator: Samantha Ebata, MSc Candidate; Deleted Investigator: Joanne Hodder, MSc, PhD Candidate
- Protocol Amendment - Detailed Protocol Dated: 14 December, 2011
- Consent Form - Participant Information Sheet/Consent Form Dated: 13 December, 2011
- Recruitment Poster - Study Recruitment Poster

Research Ethics Board Review
(this box to be completed by REB Chair only)

[X] **Amendment approved as submitted**

[ ] **Amendment approved conditional on changes noted in "Conditions" section below**

[ ] **New enrolment suspended**

[ ] **Study suspended pending further review**

Level of Review:

[ ] Full Research Ethics Board

[X] Research Ethics Board Executive

Conditions:

The Hamilton Health Sciences/McMaster Health Sciences Research Ethics Board operates in compliance with the ICH Good Clinical Practice Guidelines and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans and Division 5 Health Canada Food and Drug Regulations.

S. Salama — 12/19/2011

Suzette Salama PhD., Chair — Date

Hamilton Health Sciences/Faculty of Health Sciences Research Ethics Board

All Correspondence should be addressed to the REB Chair and forwarded to:
REB Coordinator, Hamilton Health Sciences
293 Wellington St. N., Suite 102, Hamilton ON L8L 8E7
Telephone: 905-521-2100, ext. 42013
Fax: 905-577-8378

McMaster University

Inspiring Innovation and Discovery

PARTICIPANT INFORMATION SHEET

Title of Study: The effect of hand and arm actions on muscle activity and load distribution in the shoulder complex

Samantha Ebata, MSc Candidate, Department of Kinesiology, Faculty of Science, McMaster University

Peter J Keir, PhD, Associate Professor, Department of Kinesiology, Faculty of Science, McMaster University

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You are being invited to participate in a study conducted by Joanne Hodder because you are either a healthy male or are currently awaiting rotator cuff repair surgery. The study will help us to learn more about the coordination of shoulder muscles.

In order to decide whether or not you want to be a part of this research study, you should understand what is involved and the potential risks and benefits. This form gives detailed information about the research study, which will be discussed with you. Once you understand the study, you will be asked to sign this form if you wish to participate. Please take your time to make your decision. Feel free to discuss it with your friends and family.

WHY IS THIS RESEARCH BEING DONE?

Shoulder injuries are a common workplace injury. We need to better understand these injuries in order to prevent and rehabilitate them. Combining shoulder and hand efforts are used frequently in the workplace, for example using a hand tool. However, this combination of tasks have been shown to change how muscles of the shoulder work, such that the larger muscles were not working as hard and the smaller muscles having to work even harder. The small muscles of the shoulder are the most often injured and increased effort may result in greater risk of injury for these muscles, especially during repetitious work or when fatigued

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to measure the effort of the muscles surrounding the shoulder during a cyclic repetitive task simulating work on an automotive assembly line to better understand how muscle activity changes with time.

WHAT WILL MY RESPONSIBILITIES BE IF I TAKE PART IN THE STUDY?

If you volunteer to participate in this study, we will ask you to do the following things:

STUDY PROTOCOL

In these studies, we are interested in measuring muscle activity during various tasks using the arm and hand. To measure muscle activity we use surface electrodes to measure the superficial muscles of the shoulder and upper arm. These electrodes will only monitor the electrical activity of the muscle of interest and will not transmit an electrical signal to the body. Surface electrodes are small circular self adhesive pads with a conductive gel in the middle. The skin over each muscle of interest will be cleaned with alcohol and two surface electrodes will be placed. For this study, the following muscles of the right side of the participant will be investigated: three heads of deltoid, upper and lower trapezius, and biceps.

Once the electrodes are placed, you will be asked to complete a series of reference contractions and maximal efforts for each muscle being investigated. These will be static efforts against resistance. You will be asked to perform 4 work-related tasks with the right arm in a clockwise direction at your own pace within a 1-minute cycle continuously for a maximum of 2 hours, The 4 tasks will consist of a two-finger pull, pipe connector push, turning a knob and an anterior push while holding a drill. thus the duty cycle will be self-determined. You must fully complete each task before moving on to the subsequent task or you will be required to repeat the task. A beep will indicate the start of each cycle. You will also be asked to rate your level of exertion for the task every 5-minutes. At the end of the test, you will be asked to perform another set of maximal contractions. On day 2, participants will be instructed to complete the same protocol as on day 1 without the EMG.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

It is not possible to predict all possible risks or discomforts that participants may experience in any research study. The present investigator anticipates no major risks or discomforts will occur in the current study. It is important however to recognize the following potential risks and discomforts that may be incurred.

1. You may experience mild discomfort or skin irritation from being shaved and cleansed in preparation for electrode placement. This is usually very mild and clear within 24 hours.
2. There may be discomfort related to the delayed onset of muscle soreness associated with maximal and isometric contractions of the arm muscles. If muscle soreness does occur, it is usually very mild and should dissipate within 72 hours.
3. Maximal effort isometric contractions are associated with an increase in blood pressure. If you have received medical clearance and/or are already physically active, the risks are minimal. The researchers' first priority as an investigator is to maintain the emotional, psychological, and physical health of those participating in the study.

HOW MANY PEOPLE WILL BE IN THIS STUDY?

Thirty males from the University population will be recruited for this study.

WHAT ARE THE POSSIBLE BENEFITS FOR ME AND/OR FOR SOCIETY?

Participants will receive no direct benefits from participating in this study. However, participants should know that their willingness to serve as a subject for this experiment will help develop an understanding of shoulder mechanics during rotator cuff injury, which may benefit individuals in the future.

IF I DO NOT WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

Participation in this study is voluntary. Refusal to participate will not result in loss of access to any services or programs at McMaster University to which you are entitled. You will inform the investigator, Samantha Ebata, of your intention to withdrawal at any point during this study.

WHAT INFORMATION WILL BE KEPT PRIVATE?

Your data will not be shared with anyone except with your consent or as required by law. All personal information such as your name, address, phone number or email will be removed from the data and will be replaced with a number. A list linking the number with your name will be kept in a secure place, separate from your file. The data, with identifying information removed will be securely stored in a locked office in the research office and on an encrypted hard drive. The data for this research study will be retained for ten years.

For the purposes of ensuring the proper monitoring of the research study, it is possible that a member of the Hamilton Health Sciences/FHS McMaster University Research Ethics Board, a Health Canada representative may consult your research data. However, no records which identify you by name or initials will be allowed to leave the institution/university/hospital. By signing this consent form, you authorize such access.

If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published without your specific consent to the disclosure.

CAN PARTICIPATION IN THE STUDY END EARLY?

If you volunteer to be in this study, you may withdraw at any time. You have the option of removing your data from the study. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

If you agree to take part, we will reimburse you $ 30 for your time.

WILL THERE BE ANY COSTS?

Your participation in this research project may involve additional costs of parking for the duration of the study collection (approximately 2 hours).

WHAT HAPPENS IF I HAVE A RESEARCH-RELATED INJURY?

If you are injured as a direct result of taking part in this study, all necessary medical treatment will be made available to you at no cost. Financial compensation for such things as lost wages, disability or discomfort due to this type of injury is not routinely available.

However, if you sign this consent form it does not mean that you waive any legal rights you may have under the law, nor does it mean that you are releasing the investigator(s), institution(s) and/or sponsor(s) from their legal and professional responsibilities.

IF I HAVE ANY QUESTIONS OR PROBLEMS, WHOM CAN I CALL?

If you have any questions about the research now or later, please contact Joanne Hodder at 905-525-9140, ext. 21334 or Dr. Peter Keir at 905-525-9140, ext.23543.

If you have any questions regarding your rights as a research participant, you may contact the Office of the Chair of the Hamilton Health Sciences/Faculty of Health Sciences Research Ethics Board at 905-521-2100, ext. 42013.

CONSENT STATEMENT

SIGNATURE OF RESEARCH PARTICIPANT/LEGALLY-AUTHORIZED REPRESENTATIVE*

I have read the preceding information thoroughly. I have had the opportunity to ask questions, and all of my questions have been answered to my satisfaction. I agree to participate in this study. I understand that I will receive a signed copy of this form.

____
Name of Participant

____
Name of Legally Authorized Representative

______________________________ ____________
Signature of Participant (**or Legally Authorized Representative**) Date

Consent form administered and explained in person by:

____
Name and title

______________________________ ____________
Signature Date

SIGNATURE OF INVESTIGATOR:

In my judgement, the participant is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

______________________________ ____________
Signature of Investigator Date

McMaster
University

Shoulder study needs participants

The McMaster Occupational Biomechanics Laboratory in the Department of Kinesiology is currently conducting a study of the shoulder. We are looking for healthy men (no wrist, hand, arm, shoulder problems/pain) between the ages of 19 and 55 to volunteer for these studies. Participants will be remunerated for their time.

Participants will be required to complete a continuous cycle of tasks with their hand and arm. Two sessions will be required. The total time commitment should be less than 4 hours.

For more information, please email Samantha at ebatas@mcmaster.ca

Hamilton Health Sciences/McMaster
DEC 19 2011
Research Ethics Board